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A New Soft Set Operation: Complementary Soft Binary Piecewise Lambda (λ) Operation

Ashhan SEZGİN¹ and Eda YAVUZ²

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Research Article

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Abstract

In 1999, Molodtsov introduced Soft Set Theory as a mathematical tool to deal with uncertainty. It has been applied to many fields both as theoretical and application aspects. Since 1999, different kinds of soft set operations have been defined and used in various types. In this paper, we define a new kind of soft set operation called, “complementary soft binary piecewise lambda operation” and we handle its basic algebraic properties. Also, it is intended to contribute to the literature of soft set by gaining the relationships between this new soft set operation and some other types of soft set operations via examining the distribution of complementary soft binary piecewise lambda operation over extended soft set operations, complementary extended soft set operations, soft binary piecewise operations, complementary soft binary piecewise operations and restricted soft set operations in order to inspire to obtain the algebraic structures of soft sets and some new decision making methods.

Keywords: Soft sets, soft set operations, conditional complements

Yeni Bir Esnek Küme İşlemi: Tümleyenli Esnek İkili Parçalı Lambda (λ) İşlemi

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Öz

Molodtsov, 1999 yılında Esnek Küme Teoriyi belirsizlikle başa çıkmak için bir matematiksel araç olarak ortaya koymuştur. Teori, hem teorik hem de uygulama yönüyle birçok alana uygulanmıştır. 1999 yılından bu yana, farklı çeşitlerde esnek küme işlemleri tanımlanmış ve çeşitli türlerde kullanılmıştır. Bu çalışmada, “tümleyenli esnek ikili parçalı lambda işlemi” adı verilen yeni bir esnek küme işlemi tanımlanmış ve temel cebirsel özellikleri araştırılmıştır. Ayrıca tümleyenli esnek ikili parçalı lambda işleminin genişletilmiş esnek küme işlemleri, tümleyenli genişletilmiş esnek küme işlemleri, esnek ikili parçalı işlemler, tümleyenli esnek ikili parçalı işlemler ve kısıtlanmış esnek küme işlemleri üzerine dağılması incelenerek bu yeni esnek küme işlemi ile diğer esnek küme işlemleri arasındaki ilişkiler elde edilerek esnek kümelerin cebirsel yapılarını ve bazı yeni karar verme yöntemlerini elde etmek için okuyuculara ilham vermek adına esnek küme literatürüne katkı sağlanması amaçlanmaktadır.

Anahtar Kelimeler: Esnek kümeler, esnek küme işlemleri, koşullu tümleyenler

Introduction

Molodtsov [1] introduced Soft Set Theory as a mathematical tool to overcome some types of uncertainty in many fields. There are three well-known basic theories that we can count as a mathematical tool to deal with uncertainties, which are Probability Theory, Fuzzy Set Theory and Interval Mathematics. But since all these theories have their own shortcomings, Soft Set Theory has seen many interest and it has been applied to many fields both as theoretically and application. Maji et. al. [2] and Pei and Miao [3] made first contributions as regards soft set operations. After then, several soft set operations (restricted and extended soft set operations) were introduced and examined in Ali et. al. [4]. Basic properties of soft set operations were discussed and the interconnections of soft set operations with each other were illustrated in Sezgin and Atagün [5]. They also defined the notion of restricted symmetric difference of soft sets and investigated its properties. A new soft set operation called extended difference of soft sets was defined in Sezgin et al. [6] and extended symmetric difference of soft sets was defined and its properties were investigated in Stojanovic [7]. When the studies are investigated, we see that the operations in soft set theory can be categorized in two main headings, as restricted soft set operations and extended soft set operations. Two conditional complements of sets as new concepts of set theory were proposed and the relationships between them were examined by Çağman [8]. Via the inspiration of this study, some new complements of sets were defined by Sezgin et al. [9]. They also transferred these complements to soft set theory, and some new restricted soft set operations and extended soft set operations were defined by Aybek [10]. Demirci [11], Sarıalioğlu [12], Akbulut [13] defined a new type of extended operation by changing the form of extended soft set operations and studied the basic properties of them in detail. Also, a new type of soft difference operation was defined in Eren [14] and by being inspired this study, Yavuz [15] defined some new soft set operations, which is called soft binary piecewise operations and they studied their basic properties in detail, too. Also, Sezgin and Sarıalioğlu [16], Sezgin and Demirci [17], Sezgin and Atagün [18], Sezgin and Çağman [19], Sezgin and Aybek [20] and Sezgin et al. [21, 22] continued their work on soft set operations by defining a new type of soft binary piecewise operation. They changed the form of soft binary piecewise operation by using the complement at the first row of the soft binary piecewise operations. The purpose of this study is to contribute to the soft set theory literature by describing a new soft set operation which is called “complementary soft binary piecewise lambda operation”. For this intend, the definition of the operation and its example are given, the algebraic properties, such as closure, associative, unit and inverse element and abelian property of this new operation are examined in detail. Especially it is intended to contribute to the soft set literature by obtaining the distributions of the complementary soft binary piecewise lambda operation over extended soft set operations, complementary extended soft set operations, soft binary piecewise operations, complementary soft binary piecewise operations and restricted soft set operations.

Preliminaries

In this section, some basic concepts related to soft set theory are compiled.

Definition 1. Let U be the universal set, E be the parameter set, $P(U)$ be the power set of U and $A \subseteq E$. A pair (F, A) is called a soft set over U where F is a set-valued function such that $F: A \rightarrow P(U)$ [1].

Throughout this paper, the set of all the soft sets over U (no matter what the parameter set is) is designated by $S_E(U)$. Let A be a fixed subset of E and $S_A(U)$ be the collection of all soft sets over U with the fixed parameters set A . Clearly, $S_A(U)$ is a subset of $S_E(U)$ and, in fact, all the soft sets are the elements of $S_E(U)$.

Definition 2. (Z, D) is called a relative null soft set (with respect to the parameter set D), denoted by \emptyset_D , if $Z(t) = \emptyset$ for all $t \in D$ and (Z, D) is called a relative whole soft set (with respect to the parameter set D), denoted by U_D if $Z(t) = U$ for all $t \in D$. The relative whole soft set U_E with respect to the universe set of parameters E is called the absolute soft set over U [4]. We shall denote by \emptyset_\emptyset the unique soft set over U with an empty parameter set, which is called the empty soft set over U . Note that by \emptyset_\emptyset and by \emptyset_A are different soft sets over U [23].

Definition 3. For two soft sets (Z, D) and (R, J) , we say that (Z, D) is a soft subset of (R, J) and it is denoted by $(Z, D) \subseteq (R, J)$, if $D \subseteq J$ and $Z(t) \subseteq R(t)$, $\forall t \in D$. Two soft sets (Z, D) and (R, J) are said to be soft equal if (Z, D) is a soft subset of (R, J) and (R, J) is a soft subset of (Z, D) [3].

Definition 4. The relative complement of a soft set (Z, D) , denoted by $(Z, D)^r$, is defined by $(Z, D)^r = (Z, D)$, where $Z^r: D \rightarrow P(U)$ is a mapping given by $(Z, D)^r = U \setminus Z(t)$ for all $t \in D$ [4]. From now on, $U \setminus Z(t) = [Z(t)]'$ will be designated by $Z'(t)$ for the sake of designation.

Two conditional complements of sets as a new concept of set theory were defined in [8]. For the sake of illustration, we show these complements as $+$ and θ , respectively. These complements are binary operations and are defined as follows: Let D and J be two subsets of U . J -inclusive complement of D is defined by, $D+J = D' \cup J$ and J -Exclusive complement of D is defined by $D\theta J = D' \cap J'$. Here, U refers to a universe, D' is the complement of D over U . For more information, we refer to [8]. The relations between these two complements were examined in detail by Sezgin et. al [9] and they also introduced such new three complements as binary operations of sets as follows: Let D and J be two subsets of U . Then, $D*J = D' \cup J'$, $D\gamma J = D' \cap J$, $D\lambda J = D \cup J'$ [9]. These set operations were also conveyed to soft sets in [10] and they defined restricted and extended soft set operations and examined their properties. As a summary for soft set operations, we can categorize all types of soft set operations: Let " ∇ " be used to represent the set operations (i.e., here ∇ can be $\cap, \cup, \setminus, +, \theta, *, \lambda, \gamma$), then restricted operations, extended operations, complementary extended operations, soft binary piecewise operations, complementary soft binary piecewise operations are defined in soft set theory as follows:

Definition 5. [4, 5, 10] Let (Z, D) and (R, J) be soft sets over U . The restricted ∇ operation of (Z, D) and (R, J) is the soft set (S, T) , denoted by, $(Z, D)\nabla_R(R, J) = (S, T)$, where $T = D \cap J \neq \emptyset$ and $\forall t \in T$, $S(t) = Z(t) \nabla R(t)$. Here note that if $D \cap J = \emptyset$, then $(Z, D)\nabla_R(R, J) = \emptyset_\emptyset$ [23].

Definition 6. [2, 4, 6, 7, 10] Let (Z, D) and (R, J) be soft sets over U . The extended ∇ operation of (Z, D) and (R, J) is the soft set (S, T) , denoted by, $(Z, D)\nabla_\varepsilon(R, J) = (S, T)$, where $T = D \cup J$ and $\forall t \in T$,

$$S(t) = \begin{cases} Z(t), & t \in D \setminus J, \\ R(t), & t \in J \setminus D, \\ Z(t)\nabla R(t), & t \in D \cap J. \end{cases}$$

Definition 7. [11-13] Let (Z, D) and (R, J) be soft sets over U . The complementary extended ∇ operation of (Z, D) and (R, J) is the soft set (S, T) , denoted by, $(Z, D) \overset{*}{\nabla}_\varepsilon(R, J) = (S, T)$, where $T = D \cup J$ and $\forall t \in T$

$$S(t) = \begin{cases} Z'(t), & t \in D \setminus J, \\ R'(t), & t \in J \setminus D, \\ Z(t)\nabla R(t), & t \in D \cap J. \end{cases}$$

Definition 8. [14, 15] Let (Z, D) and (R, J) be soft sets over U . The soft binary piecewise ∇ operation of (Z, D) and (R, J) is the soft set (S, D) , denoted by $(Z, D) \overset{\sim}{\nabla}(R, J) = (S, D)$, where $\forall t \in D$,

$$S(t) = \begin{cases} Z(t), & t \in D \setminus J \\ Z(t) \nabla R(t), & t \in D \cap J \end{cases}$$

Definition 9. [16-22] Let (Z, D) and (R, J) be soft sets over U . The complementary soft binary piecewise ∇ operation of (Z, D) and (R, J) is the soft set (S, D) , denoted by $(Z, D) \overset{*}{\sim}_{\nabla}(R, J) = (S, D)$, where $\forall t \in D$;

$$S(t) = \begin{cases} Z'(t), & t \in D \setminus J \\ Z(t) \nabla R(t), & t \in D \cap J \end{cases}$$

Let (S, \bullet) be a groupoid. An element $e \in S$ is called a left identity element if $e \bullet s = s$ for all $s \in S$. Similarly, e is a right identity element if $s \bullet e = s$ for all $s \in S$. An element which is both a left and a right identity is an identity element. A groupoid may have more than one left identity element: in fact the operation defined by $x \bullet y = y$ for all $x, y \in S$ defines a groupoid (in fact, a semigroup) on any set S , and every element is a left identity. But as soon as a groupoid has both a left and a right identity, they are necessarily unique and equal. For if e is a left identity and f is a right identity, then $f = e \bullet f = e$ [24].

Let (S, \bullet) be a groupoid. An absorbing (annihilating/zero) element is an element z such that for all s in S , $z \bullet s = s \bullet z = z$. This notion can be refined to the notions of left absorbing, where one requires only that $z \bullet s = z$, and right absorbing, where $s \bullet z = z$. As a similar case for identity element, if a groupoid has both a

left absorbing element z and a right absorbing element z' , then it has an absorbing element, since $z=z \cdot z' = z'$ [25].

Complementary soft binary piecewise lambda (λ) operation and its properties

Definition 10. Let (F, Y) and (Z, L) be soft sets over U . The complementary soft binary lambda (λ)

operation of (F, Y) and (Z, L) is the soft set (H, Y) , denoted by, $(F, Y) \underset{\lambda}{\sim}^* (Z, L) = (H, Y)$, where $\forall l \in Y$,

$$H(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F(l) \cup Z'(l), & l \in Y \cap L \end{cases}$$

Example 1. Let $E = \{e_1, e_2, e_3, e_4\}$ be the parameter set $Y = \{e_1, e_3\}$ and $L = \{e_2, e_3, e_4\}$ be the subsets of E and $U = \{h_1, h_2, h_3, h_4, h_5\}$ be the initial universe set. Assume that (F, Y) and (Z, L) are the soft sets over U defined as follows:

$$(F, Y) = \{(e_1, \{h_2, h_5\}), (e_3, \{h_1, h_2, h_5\})\}$$

$$(Z, L) = \{(e_2, \{h_1, h_4, h_5\}), (e_3, \{h_2, h_3, h_4\}), (e_4, \{h_3, h_5\})\}.$$

Let $(F, Y) \underset{\lambda}{\sim}^* (Z, L) = (H, Y)$. Then,

$$H(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F(l) \cup Z'(l), & l \in Y \cap L \end{cases}$$

Since $Y = \{e_1, e_3\}$ and $Y \setminus L = \{e_1\}$, so $H(e_1) = F'(e_1) = \{h_1, h_3, h_4\}$. And since $Y \cap L = \{e_3\}$ so $H(e_3) = F(e_3) \cup Z'(e_3) = \{h_1, h_2, h_5\} \cup \{h_1, h_5\} = \{h_1, h_2, h_5\}$.

Thus, $(F, Y) \underset{\lambda}{\sim}^* (Z, L) = \{(e_1, \{h_1, h_3, h_4\}), (e_3, \{h_1, h_2, h_5\})\}$

Theorem 1. (Algebraic properties of the operation)

1) The set $S_E(U)$ is closed under the operation $\underset{\lambda}{\sim}^*$. That is, when (F, Y) and (Z, L) are two soft sets over

U , then so is $(F, Y) \underset{\lambda}{\sim}^* (Z, L)$.

Proof. It is clear that \sim_{λ}^* is a binary operation in $S_E(U)$. Hence, the set $S_E(U)$ is closed under the

operation \sim_{λ}^* .

$$2) [(F, Y) \sim_{\lambda}^* (Z, Y)] \sim_{\lambda}^* (H, Y) \neq (F, Y) \sim_{\lambda}^* [(Z, Y) \sim_{\lambda}^* (H, Y)]$$

Proof. Let $(F, Y) \sim_{\lambda}^* (Z, Y) = (T, Y)$, where $\forall l \in Y$;

$$T(l) = \begin{cases} F'(l), & l \in Y \setminus Y = \emptyset \\ F(l) \cup Z'(l), & l \in Y \cap Y = Y \end{cases}$$

Let $(T, Y) \sim_{\lambda}^* (H, Y) = (M, Y)$, where $\forall l \in Y$;

$$M(l) = \begin{cases} T'(l), & l \in Y \setminus Y = \emptyset \\ T(l) \cup H'(l), & l \in Y \cap Y = Y \end{cases}$$

Thus,

$$M(l) = \begin{cases} T'(l), & l \in Y \setminus Y = \emptyset \\ [F(l) \cup Z'(l)] \cup H'(l), & l \in Y \cap Y = Y \end{cases}$$

Let $(Z, Y) \sim_{\lambda}^* (H, Y) = (L, Y)$, where $\forall l \in Y$;

$$L(l) = \begin{cases} Z'(l), & l \in Y \setminus Y = \emptyset \\ Z(l) \cup H'(l), & l \in Y \cap Y = Y \end{cases}$$

Let $(F, Y) \sim_{\lambda}^* (L, Y) = (N, Y)$, where $\forall l \in Y$;

$$N(l) = \begin{cases} F'(l), & l \in Y \setminus Y = \emptyset \\ F(l) \cup L'(l), & l \in Y \cap Y = Y \end{cases}$$

Thus,

$$N(I) = \begin{cases} F'(I), & I \in Y \setminus Y = \emptyset \\ F(I) \cup [Z'(I) \cap H(I)], & I \in Y \cap Y = Y \end{cases}$$

It is seen that $(M, Y) \neq (N, Y)$.

That is, for the soft sets whose parameter sets are the same, the operation \sim_{λ} does not have associativity property. Moreover, we have the following:

$$3) [(F, Y) \sim_{\lambda} (Z, L)] \sim_{\lambda} (H, R) \neq (F, Y) \sim_{\lambda} [(Z, L) \sim_{\lambda} (H, R)]$$

Proof. Let $(F, Y) \sim_{\lambda} (Z, L) = (T, Y)$, where $\forall I \in Y$;

$$T(I) = \begin{cases} F'(I), & I \in Y \setminus L \\ F(I) \cup Z'(I), & I \in Y \cap L \end{cases}$$

Let $(T, Y) \sim_{\lambda} (H, R) = (M, Y)$, where $\forall I \in Y$;

$$M(I) = \begin{cases} T'(I), & I \in Y \setminus R \\ T(I) \cup H'(I), & I \in Y \cap R \\ F(I), & I \in (Y \setminus L) \setminus R = Y \cap L' \cap R' \\ F'(I) \cap Z(I), & I \in (Y \cap L) \setminus R = Y \cap L \cap R' \\ F'(I) \cup H'(I), & I \in (Y \setminus L) \cap R = Y \cap L' \cap R \\ [F(I) \cup Z'(I)] \cup H'(I), & I \in (Y \cap L) \cap R = Y \cap L \cap R \end{cases}$$

Let $(Z, L) \sim_{\lambda} (H, R) = (K, L)$, where $\forall I \in L$;

$$K(I) = \begin{cases} Z'(I), & I \in L \setminus R \\ Z(I) \cup H'(I), & I \in L \cap R \end{cases}$$

Let $(F, Y) \sim_{\lambda} (K, L) = (S, Y)$, where $\forall I \in Y$;

$$S(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F(l) \cup K'(l), & l \in Y \cap L \end{cases}$$

Thus,

$$S(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F(l) \cup Z(l), & l \in Y \cap (L \setminus R) = Y \cap L \cap R' \\ F(l) \cup [Z'(l) \cap H(l)], & l \in Y \cap (L \cap R) = Y \cap L \cap R \end{cases}$$

Here let's handle $l \in Y \setminus L$ in the second equation of the first line. Since $Y \setminus L = Y \cap L'$, if $l \in L'$, then $l \in R \setminus L$ or $l \in (L \cup R)'$. Hence, if $l \in Y \setminus L$, then $l \in Y \cap L' \cap R'$ or $l \in Y \cap L' \cap R$. Thus, it is seen that $(M, Y) \neq (S, Y)$. That

is, for the soft sets whose parameter sets are not the same, the operation $\underset{\lambda}{\sim}^*$ has not associativity property in the set $S_E(U)$.

$$4) (F, Y) \underset{\lambda}{\sim}^* (Z, L) \neq (Z, L) \underset{\lambda}{\sim}^* (F, Y)$$

Proof. Here, while the parameter set of the soft set of the left hand side is Y ; the parameter set of the soft set of the right hand side is L . Thus, by the definition of soft equality

$$(F, Y) \underset{\lambda}{\sim}^* (Z, L) \neq (Z, L) \underset{\lambda}{\sim}^* (F, Y).$$

Hence, the operation $\underset{\lambda}{\sim}^*$ has not commutative property in the set $S_E(U)$,

$$5) (F, Y) \underset{\lambda}{\sim}^* (F, Y) = U_Y$$

Proof. Let $(F, Y) \underset{\lambda}{\sim}^* (F, Y) = (H, Y)$, where $\forall l \in Y$;

$$H(l) = \begin{cases} F'(l), & l \in Y \setminus Y = \emptyset \\ F(l) \cup F'(l), & l \in Y \cap Y = Y \end{cases}$$

Here $\forall l \in Y$; $H(l) = F(l) \cup F'(l) = U$, thus $(H, Y) = U_Y$.

That is, the operation $\underset{\lambda}{\sim}^*$ does not have idempotency property in the set $S_E(U)$.

$$6) \underset{\lambda}{(F, Y)} \underset{\lambda}{\sim} \underset{\lambda}{\emptyset_Y} = U_Y$$

Proof. Let $\emptyset_Y = (S, Y)$. Then, $\forall l \in Y; S(l) = \emptyset$. Let $\underset{\lambda}{(F, Y)} \underset{\lambda}{\sim} \underset{\lambda}{(S, Y)} = \underset{\lambda}{(H, Y)}$, where $\forall l \in Y$,

$$H(l) = \begin{cases} F'(l), & l \in Y \setminus Y = \emptyset \\ F(l) \cup S'(l), & l \in Y \cap Y = Y \end{cases}$$

Hence, $\forall l \in Y; H(l) = F(l) \cup S'(l) = F(l) \cup U = U$. Thus, $(H, Y) = U_Y$

$$7) \underset{\lambda}{\emptyset_Y} \underset{\lambda}{\sim} \underset{\lambda}{(F, Y)} = \underset{\lambda}{(F, Y)^r}$$

Let $\emptyset_Y = (S, Y)$. Then, $\forall l \in Y; S(l) = \emptyset$. Let $\underset{\lambda}{(S, Y)} \underset{\lambda}{\sim} \underset{\lambda}{(F, Y)} = \underset{\lambda}{(H, Y)}$, where $\forall l \in Y$;

$$H(l) = \begin{cases} S'(l), & l \in Y \setminus Y = \emptyset \\ S(l) \cup F'(l), & l \in Y \cap Y = Y \end{cases}$$

Thus, $\forall l \in Y; H(l) = S(l) \cup F'(l) = \emptyset \cup F'(l) = F'(l)$, hence $(H, Y) = (F, Y)^r$.

$$8) \underset{\lambda}{(F, Y)} \underset{\lambda}{\sim} \underset{\lambda}{\emptyset_E} = U_Y$$

Proof. Let $\emptyset_E = (S, E)$. Hence $\forall l \in E; S(l) = \emptyset$. Let $\underset{\lambda}{(F, Y)} \underset{\lambda}{\sim} \underset{\lambda}{(S, E)} = \underset{\lambda}{(H, Y)}$. Thus, $\forall l \in Y$,

$$H(l) = \begin{cases} F'(l), & l \in Y \setminus E = \emptyset \\ F(l) \cup S'(l), & l \in Y \cap E = Y \end{cases}$$

Hence, $\forall l \in Y, H(l) = F(l) \cup S'(l) = F(l) \cup U = U$, so $(H, Y) = U_Y$.

$$9) \underset{\lambda}{(F, Y)} \underset{\lambda}{\sim} \underset{\lambda}{U_Y} = \underset{\lambda}{(F, Y)}$$

Proof. Let $U_Y = (T, Y)$. Then, $\forall l \in Y; T(l) = U$. Let $\underset{\lambda}{(F, Y)} \underset{\lambda}{\sim} \underset{\lambda}{(T, Y)} = \underset{\lambda}{(H, Y)}$, where $\forall l \in Y$;

$$H(l) = \begin{cases} F'(l), & l \in Y \setminus Y = \emptyset \\ F(l) \cup T'(l), & l \in Y \cap Y = Y \end{cases}$$

Thus, $\forall l \in Y; H(l) = F(l) \cup T'(l) = F(l) \cup \emptyset = F(l)$, hence $(H, Y) = (F, Y)$.

Note that, for the soft sets whose parameter set is Y , U_Y is the right-identity element for the operation

$\begin{matrix} * \\ \sim \\ \lambda \end{matrix}$

$$10) U_Y \underset{\lambda}{\sim}^* (F, Y) = U_Y.$$

Proof. Let $U_Y = (T, Y)$. Then, $\forall l \in Y; T(l) = U$. Assume that $(T, Y) \underset{\lambda}{\sim}^* (F, Y) = (H, Y)$, where $\forall l \in Y;$

$$H(l) = \begin{cases} T'(l) & l \in Y \setminus Y = \emptyset \\ T(l) \cup F'(l) & l \in Y \cap Y = Y \end{cases}$$

Hence, $\forall l \in Y; H(l) = T(l) \cup F'(l) = U \cup F'(l) = U$. Thus, $(T, Y) = U_Y$

Note that for the soft sets whose parameter set is Y , U_Y is the left-absorbing element for the operation

$\begin{matrix} * \\ \sim \\ \lambda \end{matrix}$

$$11) (F, Y) \underset{\lambda}{\sim}^* U_E = (F, Y).$$

Proof. Let $U_E = (T, E)$. Hence, $\forall l \in E, T(l) = U$. Let $(F, Y) \underset{\lambda}{\sim}^* (T, E) = (H, Y)$, then $\forall l \in Y,$

$$H(l) = \begin{cases} F'(l), & l \in Y \setminus E = \emptyset \\ F(l) \cup T'(l), & l \in Y \cap E = Y \end{cases}$$

Hence, $\forall l \in Y, H(l) = F(l) \cup T'(l) = F(l) \cup \emptyset = F(l)$, so $(H, Y) = (F, Y)$.

Note that, for the soft sets (no matter what the parameter set is), U_E is the right-identity element for the

operation $\begin{matrix} * \\ \sim \\ \lambda \end{matrix}$ in the set $S_E(U)$.

$$12) (F, Y) \underset{\lambda}{\sim} (F, Y)^r = (F, Y).$$

Proof. Let $(F, Y)^r = (H, Y)$. Hence, $\forall l \in Y; H(l) = F'(l)$. Let $(F, Y) \underset{\lambda}{\sim} (H, Y) = (T, Y)$, where $\forall l \in Y$,

$$T(l) = \begin{cases} F'(l), & l \in Y \setminus Y = \emptyset \\ F(l) \cup H'(l), & l \in Y \cap Y = Y \end{cases}$$

Hence, $\forall l \in Y; T(l) = F(l) \cup H'(l) = F(l) \cup F(l) = F(l)$, thus $(T, Y) = (F, Y)$.

Note that, relative complement of every soft set is its own right-identity element for the operation $\underset{\lambda}{\sim}$ in the set $S_E(U)$.

$$13) (F, Y)^r \underset{\lambda}{\sim} (F, Y) = (F, Y)^r.$$

Proof. Let $(F, Y)^r = (H, Y)$. Hence, $\forall l \in Y; H(l) = F'(l)$. Let $(H, Y) \underset{\lambda}{\sim} (F, Y) = (T, Y)$, where $\forall l \in Y$;

$$T(l) = \begin{cases} H'(l), & l \in Y \setminus Y = \emptyset \\ H(l) \cup F'(l), & l \in Y \cap Y = Y \end{cases}$$

Hence, $\forall l \in Y; T(l) = H(l) \cup F'(l) = F'(l) \cup F'(l) = F'(l)$, thus $(T, Y) = (F, Y)^r$.

Note that, relative complement of a soft set is the left-absorbing element of its own soft set for the operation $\underset{\lambda}{\sim}$ in the set $S_E(U)$.

$$14) [(F, Y) \underset{\lambda}{\sim} (Z, L)]^r = (F, Y) \underset{\lambda}{\check{\sim}} (Z, L).$$

Proof. Let $(F, Y) \underset{\lambda}{\sim} (Z, L) = (H, Y)$. Then, $\forall l \in Y$,

$$H(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F(l) \cup Z'(l), & l \in Y \cap L \end{cases}$$

Let $(H, Y)^r = (T, Y)$, so $\forall l \in Y$,

$$T(l) = \begin{cases} F(l), & l \in Y \setminus L \\ F'(l) \cap Z(l), & l \in Y \cap L \end{cases}$$

Thus, $(T, Y) = (F, Y) \tilde{\gamma} (Z, L)$.

In classical theory, $A \cup B = \emptyset \Leftrightarrow A = \emptyset$ and $B = \emptyset$. Now, we have the following:

$$15) \underset{\lambda}{(F, Y)} \underset{\lambda}{\sim} \underset{\lambda}{(Z, Y)} = \underset{\lambda}{\emptyset_Y} \Leftrightarrow \underset{\lambda}{(F, Y)} = \underset{\lambda}{\emptyset_Y} \text{ and } \underset{\lambda}{(Z, Y)} = \underset{\lambda}{U_Y}.$$

Proof. Let $\underset{\lambda}{(F, Y)} \underset{\lambda}{\sim} \underset{\lambda}{(Z, Y)} = \underset{\lambda}{(T, Y)}$. Hence, $\forall l \in Y$,

$$T(l) = \begin{cases} F'(l), & l \in Y \setminus Y = \emptyset \\ F(l) \cup Z'(l), & l \in Y \cap Y = Y \end{cases}$$

Since $(T, Y) = \emptyset_Y$, $\forall l \in Y$, $T(l) = \emptyset$. Hence, $\forall l \in Y$, $T(l) = F(l) \cup Z'(l) = \emptyset \Leftrightarrow \forall l \in Y$, $F(l) = \emptyset$ and $Z'(l) = \emptyset \Leftrightarrow \forall l \in Y$, $F(l) = \emptyset$ and $Z(l) = U \Leftrightarrow (F, Y) = \emptyset_Y$ and $(Z, Y) = U_Y$.

In classical theory, for all A , $\emptyset \subseteq A$. Now, we have the following:

$$16) \underset{\lambda}{\emptyset_Y} \underset{\lambda}{\cong} \underset{\lambda}{(F, Y)} \underset{\lambda}{\sim} \underset{\lambda}{(Z, L)} \text{ and } \underset{\lambda}{\emptyset_L} \underset{\lambda}{\cong} \underset{\lambda}{(Z, L)} \underset{\lambda}{\sim} \underset{\lambda}{(F, Y)}.$$

In classical theory, for all A , $A \subseteq U$. Now, we have the following:

$$17) \underset{\lambda}{(F, Y)} \underset{\lambda}{\sim} \underset{\lambda}{(Z, L)} \underset{\lambda}{\cong} \underset{\lambda}{U_Y} \text{ and } \underset{\lambda}{(Z, L)} \underset{\lambda}{\sim} \underset{\lambda}{(F, Y)} \underset{\lambda}{\cong} \underset{\lambda}{U_L}.$$

In classical theory, $A \subseteq A \cup B$ and $A \subseteq A \cup B$. Now, we have the following analogy:

$$18) \underset{\lambda}{(F, Y)} \underset{\lambda}{\cong} \underset{\lambda}{(F, Y)} \underset{\lambda}{\sim} \underset{\lambda}{(Z, Y)} \text{ and } \underset{\lambda}{(Z, Y)^f} \underset{\lambda}{\cong} \underset{\lambda}{(F, Y)} \underset{\lambda}{\sim} \underset{\lambda}{(Z, Y)}.$$

Proof. Let $\underset{\lambda}{(F, Y)} \underset{\lambda}{\sim} \underset{\lambda}{(Z, Y)} = \underset{\lambda}{(H, Y)}$. First of all, $Y \subseteq Y$. Moreover, $\forall l \in Y$,

$$H(I) = \begin{cases} F'(I), & I \in Y \setminus Y = \emptyset \\ F(I) \cup Z'(I), & I \in Y \cap Y = Y \end{cases}$$

Since $\forall I \in Y, H(I) = F(I) \subseteq F(I) \cup Z'(I)$ and $Z'(I) \subseteq F(I) \cup Z'(I)$, the rest of the proof is obvious.

Distribution Rules

In this section, distribution of complementary soft binary piecewise lambda (λ) operation over other soft set operations such as extended soft set operations, complementary extended soft set operations, soft binary piecewise operations, complementary soft binary piecewise operations and restricted soft set operations are examined in detail and many interesting results are obtained.

Distribution of complementary soft binary piecewise lambda (λ) operation over extended soft set operations:

i) Left-distribution of complementary soft binary piecewise lambda (λ) operation over extended soft set operations

$$1) (F, Y) \underset{\lambda}{\overset{*}{\sim}} [(Z, L) \cap_{\varepsilon} (H, R)] \underset{\lambda}{\overset{*}{\sim}} (F, Y) \underset{\lambda}{\overset{*}{\sim}} [(H, R) \underset{\lambda}{\overset{*}{\sim}} (F, Y)], \text{ where } Y \cap L' \cap R = \emptyset$$

Proof. Let's first handle the left hand side of the equality and let $(Z, L) \cap_{\varepsilon} (H, R) = (M, L \cup R)$ where $\forall I \in L \cup R$;

$$M(I) = \begin{cases} Z(I), & I \in L \setminus R \\ H(I), & I \in R \setminus L \\ Z(I) \cap H(I), & I \in L \cap R \end{cases}$$

Assume that $(F, Y) \underset{\lambda}{\overset{*}{\sim}} (M, L \cup R) = (N, Y)$, where $\forall I \in Y$;

$$N(I) = \begin{cases} F'(I), & I \in Y \setminus (L \cup R) \\ F(I) \cup M'(I), & I \in Y \cap (L \cup R) \end{cases}$$

Hence

$$N(I) = \begin{cases} F'(I), & I \in Y \setminus (L \cup R) = Y \cap L' \cap R' \\ F(I) \cup Z'(I), & I \in Y \cap (L \setminus R) = Y \cap L \cap R' \\ F(I) \cup H'(I), & I \in Y \cap (R \setminus L) = Y \cap L' \cap R \\ F(I) \cup [(Z'(I) \cup H'(I))], & I \in Y \cap L \cap R = Y \cap L \cap R \end{cases}$$

Now let's handle the right hand side of the equality $[(F, Y) \underset{\lambda}{\sim} (Z, L)] \underset{+}{\tilde{\cup}} [(H, R) \underset{\lambda}{\sim} (F, Y)]$. Assume that

$$(F, Y) \underset{\lambda}{\sim} (Z, L) = (V, Y), \text{ where } \forall I \in Y;$$

$$V(I) = \begin{cases} F'(I), & I \in Y \setminus L \\ F(I) \cup Z'(I), & I \in Y \cap L \end{cases}$$

$$\text{Let } (H, R) \underset{+}{\sim} (F, Y) = (W, Y), \text{ where } \forall I \in R;$$

$$W(I) = \begin{cases} H'(I), & I \in R \setminus Y \\ H'(I) \cup F(I), & I \in R \cap Y \end{cases}$$

$$\text{Let } (V, Y) \underset{+}{\tilde{\cup}} (W, R) = (T, Y), \text{ where } \forall I \in Y;$$

$$T(I) = \begin{cases} V(I), & I \in Y \setminus R \\ V(I) \cup W(I), & I \in Y \cap R \end{cases}$$

Thus,

$$T(I) = \begin{cases} F'(I), & I \in (Y \setminus L) \setminus R = Y \cap L' \cap R' \\ F(I) \cup Z'(I), & I \in (Y \cap L) \setminus R = Y \cap L \cap R' \\ F'(I) \cup H'(I), & I \in (Y \setminus L) \cap (R \setminus Y) = \emptyset \\ F'(I) \cup [H'(I) \cup F(I)], & I \in (Y \setminus L) \cap (R \cap Y) = Y \cap L' \cap R \\ [F(I) \cup Z'(I)] \cup H'(I), & I \in (Y \cap L) \cap (R \setminus Y) = \emptyset \\ [F(I) \cup Z'(I)] \cup [H'(I) \cup F(I)], & I \in (Y \cap L) \cap (R \cap Y) = Y \cap L \cap R \end{cases}$$

It is seen that $(N, Y) = (T, Y)$.

$$2) (F, Y) \underset{\lambda}{\overset{*}{\sim}} [(Z, L) \cup_{\varepsilon} (H, R)] = [(F, Y) \underset{\lambda}{\overset{*}{\sim}} (Z, L)] \underset{+}{\overset{*}{\tilde{\sim}}} [(H, R) \underset{\lambda}{\overset{*}{\sim}} (F, Y)], \text{ where } Y \cap L' \cap R = \emptyset$$

$$3) (F, Y) \underset{\lambda}{\overset{*}{\sim}} [(Z, L) \lambda_{\varepsilon} (H, R)] = [(F, Y) \underset{\lambda}{\overset{*}{\sim}} (Z, L)] \underset{\cup}{\overset{*}{\tilde{\sim}}} [(H, R) \underset{\lambda}{\overset{*}{\sim}} (F, Y)], \text{ where } Y \cap L' \cap R = \emptyset.$$

$$4) (F, Y) \underset{\lambda}{\overset{*}{\sim}} [(Z, L) \setminus_{\varepsilon} (H, R)] = [(F, Y) \underset{\lambda}{\overset{*}{\sim}} (Z, L)] \underset{\cup}{\overset{*}{\tilde{\sim}}} [(H, R) \underset{\lambda}{\overset{*}{\sim}} (F, Y)] \text{ where } Y \cap L' \cap R = \emptyset.$$

ii) Right-distribution of complementary soft binary piecewise lambda (λ) operation over extended soft set operations

$$1) [(F, Y) \cup_{\varepsilon} (Z, L)] \underset{\lambda}{\overset{*}{\sim}} (H, R) = [(F, Y) \underset{\lambda}{\overset{*}{\sim}} (H, R)] \cup_{\varepsilon} [(Z, L) \underset{\lambda}{\overset{*}{\sim}} (H, R)], \text{ where } Y \cap L \cap R' = \emptyset.$$

Moreover, $[(F, Y) \cup_{\varepsilon} (Z, L)] \underset{\lambda}{\overset{*}{\sim}} (H, R) = [(F, Y) \underset{\lambda}{\overset{*}{\sim}} (H, R)] \cap_{\varepsilon} [(Z, L) \underset{\lambda}{\overset{*}{\sim}} (H, R)], \text{ where } Y \cap L \cap R = \emptyset.$

Proof. Let's first handle the left hand side of the equality and let $(F, Y) \cup_{\varepsilon} (Z, L) = (M, Y \cup L)$, where $\forall l \in Y \cup L$;

$$M(l) = \begin{cases} F(l), & l \in Y \setminus L \\ Z(l), & l \in L \setminus Y \\ F(l) \cup Z(l), & l \in Y \cap L \end{cases}$$

Suppose that $(M, Y \cup L) \underset{\lambda}{\overset{*}{\sim}} (H, R) = (N, Y \cup L)$, where $\forall l \in Y \cup L$;

$$N(l) = \begin{cases} M'(l), & l \in (Y \cup L) \setminus R \\ M(l) \cup H'(l), & l \in (Y \cup L) \cap R \end{cases}$$

Thus,

$$N(l) = \begin{cases} F'(l), & l \in (Y \setminus L) \setminus R = Y \cap L' \cap R' \\ Z'(l), & l \in (L \setminus Y) \setminus R = Y' \cap L \cap R' \\ F'(l) \cap Z'(l), & l \in (Y \cap L) \setminus R = Y \cap L \cap R' \\ F(l) \cup H'(l), & l \in (Y \setminus L) \cap R = Y \cap L' \cap R \\ Z(l) \cup H'(l), & l \in (L \setminus Y) \cap R = Y' \cap L \cap R \\ [F(l) \cup Z(l)] \cup H'(l), & l \in (Y \cap L) \cap R = Y \cap L \cap R \end{cases}$$

Now let's handle the right hand side of the equality: $[(F, Y) \sim_{\lambda}^* (H, R)] \cup_{\varepsilon} [(Z, L) \sim_{\lambda}^* (H, R)]$. Let

$$(F, Y) \sim_{\lambda}^* (H, R) = (V, Y), \text{ where } \forall l \in Y;$$

$$V(l) = \begin{cases} F'(l), & l \in Y \setminus R \\ F(l) \cup H'(l), & l \in Y \cap R \end{cases}$$

Let $(Z, L) \sim_{\lambda}^* (H, R) = (W, L)$, where $\forall l \in L$;

$$W(l) = \begin{cases} Z'(l), & l \in L \setminus R \\ Z(l) \cup H'(l), & l \in L \cap R \end{cases}$$

Assume that $(V, Y) \cup_{\varepsilon} (W, L) = (T, Y \cup L)$, where $\forall l \in Y \cup L$;

$$T(l) = \begin{cases} V(l), & l \in Y \setminus L \\ W(l), & l \in L \setminus Y \\ V(l) \cup W(l), & l \in Y \cap L \end{cases}$$

Hence,

T(I)=	F'(I),	$I \in (Y \setminus R) \setminus L = Y \cap L' \cap R'$
	F(I) \cup H'(I),	$I \in (Y \cap R) \setminus L = Y \cap L' \cap R$
	Z'(I),	$I \in (L \setminus R) \setminus Y = Y' \cap L \cap R'$
	Z(I) \cup H'(I),	$I \in (L \cap R) \setminus Y = Y' \cap L \cap R$
	F'(I) \cup Z'(I),	$I \in (Y \setminus R) \cap (L \setminus R) = Y \cap L \cap R'$
	F'(I) \cup [Z(I) \cup H'(I)]	$I \in (Y \setminus R) \cap (L \cap R) = \emptyset$
	[F(I) \cup H'(I)] \cup Z'(I),	$I \in (Y \cap R) \cap (L \setminus R) = \emptyset$
	[F(I) \cup H'(I)] \cup [Z(I) \cup H'(I)],	$I \in (Y \cap R) \cap (L \cap R) = Y \cap L \cap R$

It is seen that $(N, Y \cup L) = (T, Y \cup L)$.

$$[(F, Y) \cup_{\varepsilon} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{\lambda}{\sim} (H, R)] \cap_{\varepsilon} [(Z, L) \underset{\lambda}{\sim} (H, R)], \text{ where } Y \cap L \cap R = \emptyset \text{ can be shown}$$

similarly.

$$2) [(F, Y) \cap_{\varepsilon} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{\lambda}{\sim} (H, R)] \cap_{\varepsilon} [(Z, L) \underset{\lambda}{\sim} (H, R)], \text{ where } Y \cap L \cap R' = \emptyset.$$

$$\text{Moreover, } [(F, Y) \cap_{\varepsilon} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{\lambda}{\sim} (H, R)] \cup_{\varepsilon} [(Z, L) \underset{\lambda}{\sim} (H, R)], \text{ where } Y \cap L \cap R = \emptyset.$$

$$3) [(F, Y) \setminus_{\varepsilon} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{\lambda}{\sim} (H, R)] \cap_{\varepsilon} [(Z, L) \underset{\lambda}{\sim} (H, R)], \text{ where } Y \cap L \cap R' = Y' \cap L \cap R = \emptyset.$$

$$4) [(F, Y) \lambda_{\varepsilon} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{\lambda}{\sim} (H, R)] \cup_{\varepsilon} [(Z, L) \underset{\lambda}{\sim} (H, R)], \text{ where } Y \cap L \cap R' = Y' \cap L \cap R = \emptyset.$$

Distribution of complementary soft binary piecewise lambda (λ) operation over complementary extended soft set operations:

i) Left-distribution of complementary soft binary piecewise lambda (λ) operation over complementary extended soft set operations

$$1) (F, Y) \underset{\lambda}{\sim} [(Z, L) \underset{\theta_{\varepsilon}}{*} (H, R)] = [(F, Y) \underset{\cup}{\sim} (Z, L)] \underset{\cup}{\sim} [(H, R) \underset{\cup}{\sim} (F, Y)], \text{ where } Y \cap L' \cap R = \emptyset$$

Proof. Let's first handle the left hand side of the equality. Assume $(Z,L) \overset{*}{\theta_\varepsilon} (H,R)=(M,L\cup R)$, so

$\forall l \in L \cup R$,

$$M(l) = \begin{cases} Z'(l), & l \in L \setminus R \\ H'(l), & l \in R \setminus L \\ Z'(l) \cap H'(l), & l \in L \cap R \end{cases}$$

Let $(F,Y) \underset{\lambda}{\sim} (M,L \cup R) = (N,Y)$, then $\forall l \in Y$,

$$N(l) = \begin{cases} F'(l), & l \in Y \setminus (L \cup R) \\ F(l) \cup M'(l), & l \in Y \cap (L \cup R) \end{cases}$$

Hence,

$$N(l) = \begin{cases} F'(l), & l \in Y \setminus (L \cup R) = Y \cap L' \cap R' \\ F(l) \cup Z(l), & l \in Y \cap (L \setminus R) = Y \cap L \cap R' \\ F(l) \cup H(l), & l \in Y \cap (R \setminus L) = Y \cap L' \cap R \\ F(l) \cup [(Z(l) \cup H(l))], & l \in Y \cap L \cap R = Y \cap L \cap R \end{cases}$$

Now let's handle the right hand side of the equality $[(F,Y) \underset{U}{\sim} (Z,L)] \overset{*}{\sim} [(H,R) \underset{U}{\sim} (F,Y)]$. Let $(F,Y) \underset{U}{\sim}$

$(Z,L)=(V,Y)$, so $\forall l \in Y$,

$$V(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F(l) \cup Z(l), & l \in Y \cap L \end{cases}$$

Let $(H,R) \underset{U}{\sim} (F,Y)=(W,R)$, hence $\forall l \in R$,

$$W(l) = \begin{cases} H'(l), & l \in Y \setminus R \\ H(l) \cup F(l), & l \in R \cap Y \end{cases}$$

Assume that $(V,Y) \overset{*}{\sim} (W,R)=(T,Y)$, hence $\forall l \in Y$,

$$T(l) = \begin{cases} V(l), & l \in Y \setminus R \\ V(l) \cup W(l), & l \in Y \cap R \end{cases}$$

Hence,

$$T(I) = \begin{cases} F'(I), & I \in (Y \setminus L) \setminus R = Y \cap L' \cap R' \\ F(I) \cup Z(I), & I \in (Y \cap L) \setminus R = Y \cap L \cap R' \\ F'(I) \cup H'(I), & I \in (Y \setminus L) \cap (R \setminus Y) = \emptyset \\ F'(I) \cup [H(I) \cup F(I)], & I \in (Y \setminus L) \cap (R \cap Y) = Y \cap L' \cap R \\ [F(I) \cup Z(I)] \cup H'(I), & I \in (Y \cap L) \cap (R \setminus Y) = \emptyset \\ [F(I) \cup Z(I)] \cup [H(I) \cup F(I)], & I \in (Y \cap L) \cap (R \cap Y) = Y \cap L \cap R \end{cases}$$

It is seen that $(N, Y) = (T, Y)$.

$$2) (F, Y) \underset{\lambda}{\sim} [(Z, L) \underset{*}{\underset{\varepsilon}{*}} (H, R)] = [(F, Y) \underset{\cup}{\sim} (Z, L)] \underset{\cup}{\tilde{\sim}} [(H, R) \underset{\cup}{\sim} (F, Y)], \text{ where } Y \cap L' \cap R = \emptyset$$

$$3) (F, Y) \underset{\lambda}{\sim} [(Z, L) \underset{+}{\underset{*}{+}} (H, R)] = [(F, Y) \underset{\cup}{\sim} (Z, L)] \underset{\cup}{\tilde{\sim}} [(H, R) \underset{+}{\sim} (F, Y)], \text{ where } Y \cap L' \cap R = \emptyset.$$

$$4) (F, Y) \underset{\lambda}{\sim} [(Z, L) \underset{+}{\underset{*}{\gamma_{\varepsilon}}} (H, R)] = [(F, Y) \underset{\cup}{\sim} (Z, L)] \underset{\cup}{\tilde{\sim}} [(H, R) \underset{+}{\sim} (F, Y)], \text{ where } Y \cap L' \cap R = \emptyset.$$

ii) Right-distribution of complementary soft binary piecewise lambda (λ) operation over complementary extended soft set operations

$$1) [(F, Y) \underset{*}{\underset{\varepsilon}{*}} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{*}{\sim} (H, R)] \underset{\cup_{\varepsilon}}{[(Z, L) \underset{*}{\sim} (H, R)]}, \text{ where } Y \cap L \cap R' = \emptyset$$

Proof. Let's first handle the left hand side of the equality, let $(F, Y) \underset{*}{\underset{\varepsilon}{*}} (Z, L) = (M, Y \cup L)$, where $\forall I \in Y \cup L$;

$$M(I) = \begin{cases} F'(I), & I \in Y \setminus L \\ Z'(I), & I \in L \setminus Y \\ F'(I) \cup Z'(I), & I \in Y \cap L \end{cases}$$

Let $(M, Y \cup L) \underset{\lambda}{\sim} (H, R) = (N, Y \cup L)$, where $\forall I \in Y \cup L$;

$$N(I) = \begin{cases} M'(I), & I \in (Y \cup L) \setminus R \\ M(I) \cup H'(I), & I \in (Y \cup L) \cap R \end{cases}$$

Thus,

$$N(I) = \begin{cases} F(I), & I \in (Y \setminus L) \setminus R = Y \cap L' \cap R' \\ Z(I), & I \in (L \setminus Y) \setminus R = Y' \cap L \cap R' \\ F(I) \cap Z(I), & I \in (Y \cap L) \setminus R = Y \cap L \cap R' \\ F'(I) \cup H'(I), & I \in (Y \setminus L) \cap R = Y \cap L' \cap R \\ Z'(I) \cup H'(I), & I \in (L \setminus Y) \cap R = Y' \cap L \cap R \\ [F'(I) \cup Z'(I)] \cup H'(I), & I \in (Y \cap L) \cap R = Y \cap L \cap R \end{cases}$$

Now let's handle the right hand side of the equality: $[(F, Y) \underset{*}{\sim} (H, R)] \cup_{\varepsilon} [(Z, L) \underset{*}{\sim} (H, R)]$. Assume

that $(F, Y) \underset{*}{\sim} (H, R) = (V, Y)$, where $\forall I \in Y$;

$$V(I) = \begin{cases} F(I), & I \in Y \setminus R \\ F'(I) \cup H'(I), & I \in Y \cap R \end{cases}$$

Let $(Z, L) \underset{*}{\sim} (H, R) = (W, L)$, where $\forall I \in L$;

$$W(I) = \begin{cases} Z(I), & I \in L \setminus R \\ Z'(I) \cup H'(I), & I \in L \cap R \end{cases}$$

Assume that $(V, Y) \cup_{\varepsilon} (W, L) = (T, Y \cup L)$, where $\forall I \in Y \cup L$;

$$T(I) = \begin{cases} V(I), & I \in Y \setminus L \\ W(I), & I \in L \setminus Y \\ V(I) \cup W(I), & I \in Y \cap L \end{cases}$$

Thus,

$$T(I) = \begin{cases} F(I), & I \in (Y \setminus R) \setminus L = Y \cap L' \cap R' \\ F'(I) \cup H'(I), & I \in (Y \cap R) \setminus L = Y \cap L' \cap R \\ Z(I), & I \in (L \setminus R) \setminus Y = Y' \cap L \cap R' \\ Z'(I) \cup H'(I), & I \in (L \cap R) \setminus Y = Y' \cap L \cap R \\ F(I) \cup Z(I), & I \in (Y \setminus R) \cap (L \setminus R) = Y \cap L \cap R' \\ F(I) \cup [Z'(I) \cup H'(I)], & I \in (Y \setminus R) \cap (L \cap R) = \emptyset \\ [F'(I) \cup H'(I)] \cup Z(I), & I \in (Y \cap R) \cap (L \setminus R) = \emptyset \\ [F'(I) \cup H'(I)] \cup [Z'(I) \cup H'(I)], & I \in (Y \cap R) \cap (L \cap R) = Y \cap L \cap R \end{cases}$$

It is seen that $(N, Y \cup L) = (T, Y \cup L)$.

$$2) [(F, Y) \underset{\theta_\varepsilon}{*} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{*}{\sim} (H, R)] \cap_\varepsilon [(Z, L) \underset{*}{\sim} (H, R)], \text{ where } Y \cap L \cap R' = \emptyset$$

$$3) [(F, Y) \underset{\forall_\varepsilon}{*} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{*}{\sim} (H, R)] \cap_\varepsilon [(Z, L) \underset{\lambda}{\sim} (H, R)], \text{ where } Y \cap L \cap R' = Y' \cap L \cap R = \emptyset$$

$$4) [(F, Y) \underset{+_\varepsilon}{*} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{*}{\sim} (H, R)] \cup_\varepsilon [(Z, L) \underset{\lambda}{\sim} (H, R)], \text{ where } Y \cap L \cap R' = Y' \cap L \cap R = \emptyset.$$

Distribution of complementary soft binary piecewise lambda (λ) operation over soft binary piecewise operations:

i) Left-distribution of complementary soft binary piecewise lambda (λ) operation over soft binary piecewise operations

The followings are held when $Y \cap L' \cap R = \emptyset$.

$$1) (F, Y) \underset{\lambda}{\sim} [(Z, L) \underset{\sim}{\cup} (H, R)] = [(F, Y) \underset{\lambda}{\sim} (Z, L)] \underset{+}{\tilde{\cap}} [(H, R) \underset{\sim}{\cup} (F, Y)].$$

Proof. Let's first handle the left hand side of the equality, let $(Z, L) \underset{\sim}{\cup} (H, R) = (M, L)$, where $\forall I \in L$;

$$M(I) = \begin{cases} Z(I), & I \in L \setminus R \\ Z(I) \cup H(I), & I \in L \cap R \end{cases}$$

*
Let $(F, Y) \sim_{\lambda} (M, L) = (N, Y)$, where $\forall l \in Y$;

$$N(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F(l) \cup M'(l), & l \in Y \cap L \end{cases}$$

Thus,

$$N(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F(l) \cup Z'(l), & l \in Y \cap (L \setminus R) = Y \cap L \cap R^c \\ F(l) \cup [Z'(l) \cap H'(l)] & l \in Y \cap L \cap R = Y \cap L \cap R \end{cases}$$

Now let's handle the right hand side of the equality: $[(F, Y) \sim_{\lambda} (Z, L)] \tilde{\cap} [(H, R) \sim_{\lambda} (F, Y)]$. Let $(F, Y) \sim_{\lambda} (Z, L) = (V, Y)$, where $\forall l \in Y$;

$$V(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F(l) \cup Z'(l), & l \in Y \cap L \end{cases}$$

*
Let $(H, R) \sim_{\lambda} (F, Y) = (W, R)$, where $\forall l \in R$;

$$W(l) = \begin{cases} H'(l), & l \in R \setminus Y \\ H'(l) \cup F(l), & l \in R \cap Y \end{cases}$$

Suppose $(V, Y) \tilde{\cap} (W, R) = (T, Y)$, where $\forall l \in Y$;

$$T(l) = \begin{cases} V(l), & l \in Y \setminus R \\ V(l) \cap W(l), & l \in Y \cap R \end{cases}$$

Therefore,

$$T(I) = \begin{cases} F'(I), & I \in (Y \setminus L) \setminus R = Y \cap L' \cap R' \\ F(I) \cup Z'(I), & I \in (Y \cap L) \setminus R = Y \cap L \cap R' \\ F'(I) \cap H'(I), & I \in (Y \setminus L) \cap (R \setminus Y) = \emptyset \\ F'(I) \cap [H'(I) \cup F(I)], & I \in (Y \setminus L) \cap (R \cap Y) = Y \cap L' \cap R \\ [F(I) \cup Z'(I)] \cap H'(I), & I \in (Y \cap L) \cap (R \setminus Y) = \emptyset \\ [F(I) \cup Z'(I)] \cap [H'(I) \cup F(I)], & I \in (Y \cap L) \cap (R \cap Y) = Y \cap L \cap R \end{cases}$$

Here let's handle $I \in Y \setminus L$ in the first equation of the first line. Since $Y \setminus L = Y \cap L'$, if $I \in L'$, then $I \in R \setminus L$ or $I \in (L \cup R)'$. Hence, if $I \in Y \setminus L$, then $I \in Y \cap L' \cap R'$ or $I \in Y \cap L' \cap R$. Thus, it is seen that $(N, Y) = (T, Y)$.

$$2) (F, Y) \underset{\lambda}{\sim} [(Z, L) \tilde{\cap} (H, R)] = [(F, Y) \underset{\lambda}{\sim} (Z, L)] \tilde{\cup} [(H, R) \underset{\lambda}{\sim} (F, Y)].$$

$$3) (F, Y) \underset{\lambda}{\sim} [(Z, L) \tilde{\setminus} (H, R)] = [(F, Y) \underset{\lambda}{\sim} (Z, L)] \tilde{\cup} [(H, R) \underset{\lambda}{\sim} (F, Y)].$$

$$4) (F, Y) \underset{\lambda}{\sim} [(Z, L) \tilde{\cap} (H, R)] = [(F, Y) \underset{\lambda}{\sim} (Z, L)] \tilde{\cap} [(H, R) \underset{\lambda}{\sim} (F, Y)].$$

ii) Right-distribution of complementary soft binary piecewise lambda (λ) operation over soft binary piecewise operations

$$1) [(F, A) \tilde{\cap} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{\lambda}{\sim} (H, R)] \tilde{\cap} [(Z, L) \underset{\lambda}{\sim} (H, R)]$$

Proof. Let's first handle the left hand side of the equality. Suppose $(F, Y) \tilde{\cap} (Z, L) = (M, Y)$, where $\forall I \in Y$,

$$M(I) = \begin{cases} F(I), & I \in Y \setminus L \\ F(I) \cap Z(I), & I \in Y \cap L \end{cases}$$

Let $(M, Y) \underset{\lambda}{\sim} (H, R) = (N, Y)$, where $\forall I \in Y$,

$$N(I) = \begin{cases} M'(I), & I \in Y \setminus R \\ M(I) \cup H'(I), & I \in Y \cap R \end{cases}$$

Thus,

$$N(I) = \begin{cases} F'(I), & I \in (Y \setminus L) \setminus R = Y \cap L' \cap R' \\ F'(I) \cup Z'(I), & I \in (Y \cap L) \setminus R = Y \cap L \cap R' \\ F(I) \cup H'(I), & I \in (Y \setminus L) \cap R = Y \cap L' \cap R \\ [F(I) \cap Z(I)] \cup H'(I), & I \in (Y \cap L) \cap R = Y \cap L \cap R \end{cases}$$

Now let's handle the right hand side of the equality: $[(F, Y) \underset{\lambda}{\sim} (H, R)] \underset{\lambda}{\tilde{\cap}} [(Z, L) \underset{\lambda}{\sim} (H, R)]$. Let

$$(F, Y) \underset{\lambda}{\sim} (H, R) = (V, Y), \text{ where } \forall I \in Y;$$

$$V(I) = \begin{cases} F'(I), & I \in Y \setminus R \\ F(I) \cup H'(I), & I \in Y \cap R \end{cases}$$

Let $(Z, L) \underset{\lambda}{\sim} (H, R) = (W, L)$, where $\forall I \in L$;

$$W(I) = \begin{cases} Z'(I), & I \in L \setminus R \\ Z(I) \cup H'(I), & I \in L \cap R \end{cases}$$

Suppose that $(V, Y) \underset{\lambda}{\tilde{\cap}} (W, L) = (T, Y)$, where $\forall I \in Y$;

$$T(I) = \begin{cases} V(I), & I \in Y \setminus L \\ V(I) \cap W(I), & I \in Y \cap L \end{cases}$$

Hence,

$$T(I) = \begin{cases} F'(I), & I \in (Y \setminus R) \setminus L = Y \cap L' \cap R' \\ F(I) \cup H'(I), & I \in (Y \cap R) \setminus L = Y \cap L' \cap R \\ F'(I) \cap Z'(I), & I \in (Y \setminus R) \cap (L \setminus R) = Y \cap L \cap R' \\ F'(I) \cap [Z(I) \cup H'(I)], & I \in (Y \setminus R) \cap (L \cap R) = \emptyset \\ [F(I) \cup H'(I)] \cap Z'(I), & I \in (Y \cap R) \cap (L \setminus R) = \emptyset \\ [F(I) \cup H'(I)] \cap [Z(I) \cup H'(I)], & I \in (Y \cap R) \cap (L \cap R) = Y \cap L \cap R \end{cases}$$

It is seen that $(N, Y) = (T, Y)$.

$$2) [(F, A) \tilde{\cup} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{\lambda}{\sim} (H, R)] \tilde{\cup} [(Z, L) \underset{\lambda}{\sim} (H, R)]$$

$$3) [(F, A) \tilde{\lambda} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{\lambda}{\sim} (H, R)] \tilde{\cup} [(Z, L) \underset{\lambda}{\sim} (H, R)]$$

$$4) [(F, A) \tilde{\setminus} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{\lambda}{\sim} (H, R)] \tilde{\cap} [(Z, L) \underset{\lambda}{\sim} (H, R)]$$

Distribution of complementary soft binary piecewise lambda (λ) operation over complementary soft binary piecewise operations:

i) Left-distribution of complementary soft binary piecewise lambda (λ) operation over complementary soft binary piecewise operations

The followings are held where $Y \cap L' \cap R = \emptyset$.

$$1) (F, Y) \underset{\lambda}{\sim} [(Z, L) \underset{\lambda}{\sim} (H, R)] = [(F, Y) \underset{\cup}{\sim} (Z, L)] \tilde{\cap} [(H, R) \underset{\cup}{\sim} (F, Y)].$$

Proof. Let's first handle the left hand side of the equality, let $(Z, L) \underset{\lambda}{\sim} (H, R) = (M, L)$, where $\forall l \in L$;

$$M(l) = \begin{cases} Z'(l), & l \in L \setminus R \\ Z'(l) \cup H'(l), & l \in L \cap R \end{cases}$$

Let $(F, Y) \underset{\lambda}{\sim} (M, L) = (N, Y)$, where $\forall l \in Y$;

$$N(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F(l) \cup M'(l), & l \in Y \cap L \end{cases}$$

Therefore,

$$N(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F(l) \cup Z(l), & l \in Y \cap (L \setminus R) = Y \cap L \cap R' \\ F(l) \cup [(Z(l) \cap H(l))], & l \in Y \cap L \cap R = Y \cap L \cap R \end{cases}$$

Now let's handle the right hand side of the equality: $[(F, Y) \underset{U}{\sim} (Z, L)] \underset{U}{\tilde{\cap}} [(H, R) \underset{U}{\sim} (F, Y)]$ Let

$$(F, Y) \underset{U}{\sim} (Z, L) = (V, Y), \text{ where } \forall l \in Y;$$

$$V(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F(l) \cup Z(l), & l \in Y \cap L \end{cases}$$

Suppose that $(H, R) \underset{U}{\sim} (F, Y) = (W, R)$, where $\forall l \in R$;

$$W(l) = \begin{cases} H'(l), & l \in R \setminus Y \\ H(l) \cup F(l), & l \in R \cap Y \end{cases}$$

Let $(V, Y) \underset{U}{\tilde{\cap}} (W, R) = (T, Y)$, where $\forall l \in Y$;

$$T(l) = \begin{cases} V(l), & l \in Y \setminus R \\ V(l) \cap W(l), & l \in Y \cap R \end{cases}$$

Hence,

$$T(l) = \begin{cases} F'(l), & l \in (Y \setminus L) \setminus R = Y \cap L' \cap R' \\ F(l) \cup Z(l), & l \in (Y \cap L) \setminus R = Y \cap L \cap R' \\ F'(l) \cap H'(l), & l \in (Y \setminus L) \cap (R \setminus Y) = \emptyset \\ F'(l) \cap [H(l) \cup F(l)], & l \in (Y \setminus L) \cap (R \cap Y) = Y \cap L' \cap R \\ [F(l) \cup Z(l)] \cap H'(l), & l \in (Y \cap L) \cap (R \setminus Y) = \emptyset \\ [F(l) \cup Z(l)] \cap [H(l) \cup F(l)], & l \in (Y \cap L) \cap (R \cap Y) = Y \cap L \cap R \end{cases}$$

Take care that since $Y \setminus L = Y \cap L'$, if $l \in L'$, then $l \in R \setminus L$ or $l \in (L \cup R)'$. Hence, if $l \in Y \setminus L$, $l \in Y \cap L' \cap R'$ or $l \in Y \cap L' \cap R$. Thus, it is seen that $(N, Y) = (T, Y)$.

$$2) (F, Y) \underset{\lambda}{\sim} [(Z, L) \underset{\theta}{\sim} (H, R)] = [(F, Y) \underset{U}{\sim} (Z, L)] \underset{U}{\tilde{\cup}} [(H, R) \underset{U}{\sim} (F, Y)]$$

$$3) (F, Y) \underset{\lambda}{\sim} [(Z, L) \underset{\gamma}{\sim} (H, R)] = [(F, Y) \underset{\cup}{\sim} (Z, L)] \underset{+}{\tilde{\cup}} [(H, R) \underset{+}{\sim} (F, Y)]$$

$$4) (F, Y) \underset{\lambda}{\sim} [(Z, L) \underset{+}{\sim} (H, R)] = [(F, Y) \underset{\cup}{\sim} (Z, L)] \underset{+}{\tilde{\cap}} [(H, R) \underset{+}{\sim} (F, Y)]$$

ii) Right-distribution of complementary soft binary piecewise lambda (λ) operation over complementary soft binary piecewise operations

The followings are held when $Y \cap L \cap R' = \emptyset$.

$$1) [(F, A) \underset{\theta}{\sim} (Z, L)] \underset{\lambda}{\sim} (H, R) = [(F, Y) \underset{*}{\tilde{\sim}} (H, R)] \underset{\tilde{\cap}}{=} [(Z, L) \underset{*}{\tilde{\sim}} (H, R)].$$

Proof. Let's first handle the left hand side of the equality, let $(F, Y) \underset{\theta}{\sim} (Z, L) = (M, Y)$, where $\forall l \in Y$,

$$M(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F'(l) \cap Z'(l), & l \in Y \cap L \end{cases}$$

Let $(M, Y) \underset{\lambda}{\sim} (H, R) = (N, Y)$, where $l \in Y$,

$$N(l) = \begin{cases} M'(l), & l \in Y \setminus R \\ M(l) \cup H'(l), & l \in Y \cap R \end{cases}$$

Hence,

$$N(l) = \begin{cases} F(l), & l \in (Y \setminus L) \setminus R = Y \cap L' \cap R' \\ F(l) \cup Z(l) & l \in (Y \cap L) \setminus R = Y \cap L \cap R' \\ F'(l) \cup H'(l) & l \in (Y \setminus L) \cap R = Y \cap L' \cap R \\ [F'(l) \cap Z'(l)] \cup H'(l) & l \in (Y \cap L) \cap R = Y \cap L \cap R \end{cases}$$

Now let's handle the right hand side of the equality: $[(F, Y) \underset{*}{\tilde{\sim}} (H, R)] \underset{\tilde{\cap}}{=} [(Z, L) \underset{*}{\tilde{\sim}} (H, R)]$. Let

$(F, Y) \underset{*}{\tilde{\sim}} (H, R) = (V, Y)$, where $\forall l \in Y$;

$$V(l) = \begin{cases} F(l), & l \in Y \setminus R \\ F'(l) \cup H'(l), & l \in Y \cap R \end{cases}$$

Assume that $(Z,L) \overset{\sim}{*} (H,R)=(W,L)$, where $\forall l \in L$;

$$W(l) = \begin{cases} Z(l), & l \in L \setminus R \\ Z'(l) \cup H'(l), & l \in L \cap R \end{cases}$$

Let $(V,Y) \overset{\sim}{\cap} (W,L)=(T,Y)$, where $\forall l \in Y$;

$$T(l) = \begin{cases} V(l) & l \in Y \setminus L \\ V(l) \cap W(l) & l \in Y \cap L \end{cases}$$

Therefore,

$$T(l) = \begin{cases} F(l), & l \in (Y \setminus R) \setminus L = Y \cap L' \cap R' \\ F'(l) \cup H'(l), & l \in (Y \cap R) \setminus L = Y \cap L' \cap R \\ F(l) \cap Z(l), & l \in (Y \setminus R) \cap (L \setminus R) = Y \cap L \cap R' \\ F(l) \cap [Z'(l) \cup H'(l)], & l \in (Y \setminus R) \cap (L \cap R) = \emptyset \\ [F'(l) \cup H'(l)] \cap Z(l), & l \in (Y \cap R) \cap (L \setminus R) = \emptyset \\ [F'(l) \cup H'(l)] \cap [Z'(l) \cup H'(l)], & l \in (Y \cap R) \cap (L \cap R) = Y \cap L \cap R \end{cases}$$

It is seen that $(N)=(T,Y)$.

$$2) [(F, A) \overset{*}{\sim} (Z,L)] \overset{*}{\sim} (H,R) = [(F,Y) \overset{\sim}{*} (H,R)] \overset{\sim}{\cup} [(Z,L) \overset{\sim}{*} (H,R)]$$

$$3) [(F, A) \overset{*}{\sim} (Z,L)] \overset{*}{\sim} (H,R) = [(F,Y) \overset{\sim}{*} (H,R)] \overset{\sim}{\cup} [(Z,L) \overset{\sim}{\lambda} (H,R)]$$

$$4) [(F, A) \overset{*}{\sim} (Z,L)] \overset{*}{\sim} (H,R) = [(F,Y) \overset{\sim}{*} (H,R)] \overset{\sim}{\cap} [(Z,L) \overset{\sim}{\lambda} (H,R)]$$

Distribution of complementary soft binary piecewise lambda (λ) operation over restricted soft set operations:

The followings are held when $Y \cap L \cap R = \emptyset$.

$$1) (F, Y) \underset{\lambda}{\sim} [(Z, L) \cap_R (H, R)] = \underset{\lambda}{[(F, Y) \sim (Z, L)]} \cap_R \underset{\lambda}{[(F, Y) \sim (H, R)]}.$$

Proof. Let's first handle the left hand side of the equality, suppose $(Z, L) \cap_R (H, R) = (M, L \cap R)$ and so

$$\forall l \in L \cap R, M(l) = Z(l) \cap H(l). \text{ Let } (F, Y) \underset{\lambda}{\sim} (M, L \cap R) = (N, Y), \text{ so } \forall l \in Y,$$

$$N(l) = \begin{cases} F'(l), & l \in Y \setminus (L \cap R) \\ F(l) \cup M'(l), & l \in Y \cap (L \cap R) \end{cases}$$

Thus,

$$N(l) = \begin{cases} F'(l), & l \in Y \setminus (L \cap R) \\ F(l) \cup [Z'(l) \cup H'(l)], & l \in Y \cap (L \cap R) \end{cases}$$

Now let's handle the right hand side of the equality: $\underset{\lambda}{[(F, Y) \sim (Z, L)]} \cap_R \underset{\lambda}{[(F, Y) \sim (H, R)]}$, Let

$$(F, Y) \underset{\lambda}{\sim} (Z, L) = (V, Y), \text{ and } \forall l \in Y,$$

$$V(l) = \begin{cases} F'(l), & l \in Y \setminus L \\ F'(l) \cup Z'(l), & l \in Y \cap L \end{cases}$$

Let $(F, Y) \underset{\lambda}{\sim} (H, R) = (W, Y)$ and $\forall l \in Y,$

$$W(l) = \begin{cases} F'(l), & l \in Y \setminus R \\ F'(l) \cup H'(l), & l \in Y \cap R \end{cases}$$

Assume that $(V, Y) \cap_R (W, Y) = (T, Y)$, so $\forall l \in T(l) = V(l) \cup W(l)$,

$$T(I) = \begin{cases} F'(I) \cap F'(I), & I \in (Y \setminus L) \cap (Y \setminus R) \\ F'(I) \cap [F'(I) \cup H'(I)], & I \in (Y \setminus L) \cap (Y \cap R) \\ [F'(I) \cup Z'(I)] \cap F'(I), & I \in (Y \cap L) \cap (Y \setminus R) \\ [F'(I) \cup Z'(I)] \cap [F'(I) \cup H'(I)], & I \in (Y \cap L) \cap (Y \cap R) \end{cases}$$

Thus,

$$T(I) = \begin{cases} F'(I), & I \in Y \cap L' \cap R' \\ F'(I), & I \in Y \cap L' \cap R \\ F'(I), & I \in Y \cap L \cap R' \\ [F'(I) \cup Z'(I)] \cap [F'(I) \cup H'(I)], & I \in Y \cap L \cap R \end{cases}$$

Considering the parameter set of the first equation of the first row, that is, $Y \setminus (L \cap R)$; since $Y \setminus (L \cap R) = Y \cap (L \cap R)'$, an element in $(L \cap R)'$ may be in $L \setminus R$, in $R \setminus L$ or $(L \cup R)$. Then, $Y \setminus (L \cap R)$ is equivalent to the following 3 states: $Y \cap (L \cap R)'$, $Y \cap (L' \cap R)$ and $Y \cap (L' \cap R)'$. Hence, $(N, Y) = (T, Y)$.

$$2) (F, Y) \underset{\lambda}{\sim} [(Z, L) \cup_R (H, R)] = \underset{\lambda}{[(F, Y) \sim (Z, L)]} \cap_R \underset{\lambda}{[(F, Y) \sim (H, R)]}.$$

$$3) (F, Y) \underset{\lambda}{\sim} [(Z, L) \theta_R (H, R)] = \underset{\lambda}{[(F, Y) \sim (Z, L)]} \cup_R \underset{\lambda}{[(F, Y) \sim (H, R)]}.$$

$$4) (F, Y) \underset{\lambda}{\sim} [(Z, L) * _R (H, R)] = \underset{\lambda}{[(F, Y) \sim (Z, L)]} \cap_R \underset{\lambda}{[(F, Y) \sim (H, R)]}.$$

$$5) (F, Y) \underset{\lambda}{\sim} [(Z, L) \gamma_R (H, R)] = \underset{\lambda}{[(F, Y) \sim (Z, L)]} \cap_R \underset{\lambda}{[(F, Y) \sim (H, R)]}.$$

$$6) (F, Y) \underset{\lambda}{\sim} [(Z, L) \lambda_R (H, R)] = \underset{\lambda}{[(F, Y) \sim (Z, L)]} \cup \underset{\lambda}{[(F, Y) \sim (H, R)]}.$$

$$7) [(F, Y) \sim \underset{\lambda}{[(Z, L) \setminus_R (H, R)]}] = \underset{\lambda}{[(F, Y) \sim (Z, L)]} \cap_R \underset{\lambda}{[(F, Y) \sim (H, R)]}.$$

$$\begin{array}{ccc} * & * & * \\ \text{8) } (F, Y) \sim_{\lambda} [(Z, L) +_R (H, R)] & = & [(F, Y) \sim (Z, L)] \cap_R [(F, Y) \sim (H, R)]. \\ \lambda & + & * \end{array}$$

Conclusion

In this paper, we have contributed to the soft set literature by defining a new kind of soft set operation which we call complementary soft binary piecewise lambda operation. The basic algebraic properties of the operations have been investigated. Moreover by examining the distribution rules, we have obtained the relationships between this new soft set operation and other types of soft set operations such extended soft set operations, complementary extended soft set operations, soft binary piecewise operations, complementary soft binary piecewise operations and restricted soft set operations. This paper can be regarded as a theoretical study for soft sets and some future studies may continue by defining some new decision making methods by using this new operation and algebraic structures of soft sets can be handled again with the help of this new operation.

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**Manyetik Kantilever ile IgG Antikorlarının Tespiti****Orhan Orçun İNAN¹**, **Gamze DİK²**, **Ahmet ULU²**, **Burhan ATEŞ²** ve **Selçuk ATALAY¹**

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S.A: 0000-0002-8840-7766**Received:** 06.07.2023**Accepted:** 31.10.2023**Öz**

Bu çalışmada, IgG antikorlarını algılamak için kantilever olarak $Fe_{40}Ni_{38}Mo_4B_{18}$ amorf ferromanyetik şerit kullanılmıştır. Sensör yüzeyi IgG algılaması için fonksiyonel hale getirilmiş ve daha sonra yapılan ölçümlerde ppm ya da ng mertebesinde IgG algılaması yapılmıştır.

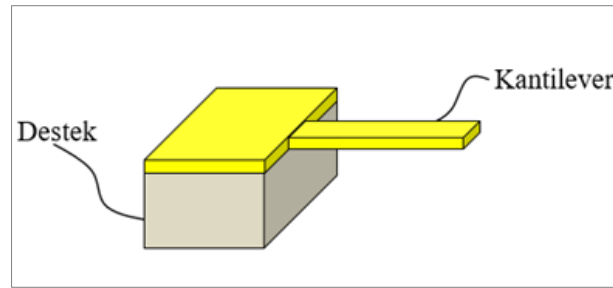
Anahtar Kelimeler: Kantilever, amorf ferromanyetik şerit, IgG**Detection of IgG Antibodies with Magnetic Cantilever**¹İnönü Üniversitesi,
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License ile lisanslanmıştır**Abstract**

In this study, $Fe_{40}Ni_{38}Mo_4B_{18}$ amorphous ferromagnetic ribbon was used as cantilever to detect IgG antibodies. The sensor surface was functionalized for IgG detection, and IgG detection was performed at the level of ppm or ng.

Keywords: Cantilever, amorphous ferromagnetic ribbon, IgG**Giriş**

İmmünoglobülin G (IgG) antikor, bağışıklık yanıtı uyandırabilen belirli molekülleri veya maddeleri ifade eder. IgG, antikorların varlığına bağışıklık sistemi tarafından üretilen bir antikor veya immünoglobülinidir. Antikorlar, bakteri, virüs veya diğer patojenler gibi yabancı maddelerdir ve bağışıklık yanıtını tetikler. IgG antikorları, enfeksiyonlara karşı bağışıklık sisteminin savunmasında

kritik bir rol oynar: Antijenleri tanıır ve bağlanırlar, diđer bađıřıklık hücreleri tarafından imha edilmeleri veya zararlı etkilerinin nötralize edilmesi için iřaretlerler. IgG antikorları uzun vadeli bađıřıklık sađlar, çünkü aynı antijenlere karřı tekrarlayan enfeksiyonlara karřı koruma sađlamak için kan dolařımında uzun süre kalabilirler. Belirli antijenlere karřı IgG antikorlarının tespiti, hastalık teřhisi, tedavi etkinliđinin izlenmesi ve ařılama yanıtlarının deđerlendirilmesi gibi çeřitli uygulamalarda önemlidir. IgG antikorlarının varlıđını ve konsantrasyonunu ölçerek, sađlık profesyonelleri ve arařtırmacılar bireyin bađıřıklık yanıtını anlayabilir ve belirli hastalıklara karřı koruma düzeyini belirleyebilirler [1, 2]. Son yıllarda, immünolojik teřhis alanında IgG antikorların tespiti ve miktarının ölçümü konusunda önemli ilerlemeler kaydedilmiřtir. Enzim bađlı immünosorbent testler (ELISA) gibi geleneksel yöntemler, IgG antikor tespitinde uzun süredir kabul gören altın standart olmuřtur. Ancak, bu teknikler genellikle karmařık laboratuvar süreçlerini, zaman alıcı protokolleri ve özel donanımları gerektirir, bu durum kaynak sınırlı ortamlarda eriřilebilirliklerini kısıtlar. Bu zorlukların üstesinden gelmek için, yenilikçi teknolojiler ve yaklařımlar ortaya çıkmıř ve IgG antikorunun tespiti alanında devrim yaratmıřtır. Bu ileri teknikler, geliřtirilmiř duyarlılık, özgüllük ve hızlı sonuç alma süreleri sunarak enfeksiyon hastalıđı teřhisi, otoimmün bozukluk izlemi ve terapötik antikor geliřtirme gibi geniř bir uygulama yelpazesinde ideal hale gelmiřtir [3, 4]. Bu yöntemlerden birisi de kantilever kullanılarak geliřtirilen ölçüm sistemidir. Kantileverlar veya mikrokantileverlar bir ucundan sabitlenmiř diđer ucu ise serbestçe titreřebilir durumda olan milimetre boyutunda veya mikrometre boyutlarındaki katı malzemelerden yapılmıř (silikon, nikel ve benzer malzemeler gibi) řeritler olarak tanımlanmaktadır (řekil 1). Kantileverların hava, vakum ve sıvı gibi belirli ortamlar içindeki titreřimleri incelenerek belirli deđerkenleri ölçülerek sensör uygulamalarında kullanılmaktadır. Bir bařka bakıř ađısından kantileverlar, moleküler boyuttaki etkileřmeleri sinyale dönüřtüren sensörlerdir ve bu özellikleriyle pikogram algılama platformu olarak büyük potansiyele sahip cihazlardır [5-17].



řekil 1. Kantilever řekilsel gösterimi

Üretim tekniklerindeki geliřmeler kantilever sensörlerin yeteneklerini genişleterek sıcaklık [8-10], kütle [11-14], manyetik [15-17] ve biyokimyasal [18-27] gibi fiziksel ve kimyasal özellikleri ölçebilen pek çok sensör uygulamasında kullanımına olanak sađlamıřtır. Kantilever yüzeyini belirli bir hedef moleküle seçici olarak yüzeySEL emici bir malzeme ile kaplayarak bir řerit oldukça hassas ve seçici bir kimyasal veya biyokimyasal sensöre dönüřtürülebilir. Kantilever hedef madde ile temasa geçtiğinde mekanik bir tepki verir: konsol bükülür ve rezonans frekansı deđerir. Böylelikle rezonans sinyalindeki

değişim ölçülerek hedef maddenin tanımlanmasına ve kantitatif tespitine olanak tanır [5]. Kantileverların çalışma prensibi, tespit edilmek istenen maddenin moleküler kütle yüzeysel emiciliğine dayanmaktadır. Küçük boyutları, hızlı tepki vermeleri, hassasiyetleri, etiket gerektirmemeleri kantileverları sensör uygulamalarında cazip hale getirmektedir. Kantilever sensör sistemlerinde analiz edilecek molekül kantilever yüzeyindeki reseptörlere bağlandığında sistemin kütlede bir artışa sebep olmakta sensör de iki tür değişim oluşturmaktadır. Bunlara bağlı olarak, kantileverların iki çalışma modu vardır: statik ve dinamik mod [22-25]. Statik mod olarak adlandırılan yöntemde kantileverın eğilme açısı ölçülmekte ve buradan yüzeyde toplanan kütle miktarı belirlenmekte veya yüzeye bağlanması amaçlanan moleküller, virüsler, bakteriler vs. gibi farklı yapılar algılanmaktadır. Dinamik mod olarak adlandırılan yöntemde ise kütle değişimine bağlı olarak kantileverın rezonans frekansında oluşan değişim veya kayma ölçülmektedir [22-25]. Genel olarak titreşen kantileverın titreşim frekansı optik algılamaya dayanan yöntemle verilmektedir. U metotta kantileverın sabitlenmemiş ucu, farklı titreşim modlarında bir titreşimci tarafından uyarılır ve doğal frekansları (1) denklemi ile verilir.

$$f_n = \frac{c_n \cdot t}{l^2} \left(\frac{E}{\rho} \right)^{\frac{1}{2}} \quad (1)$$

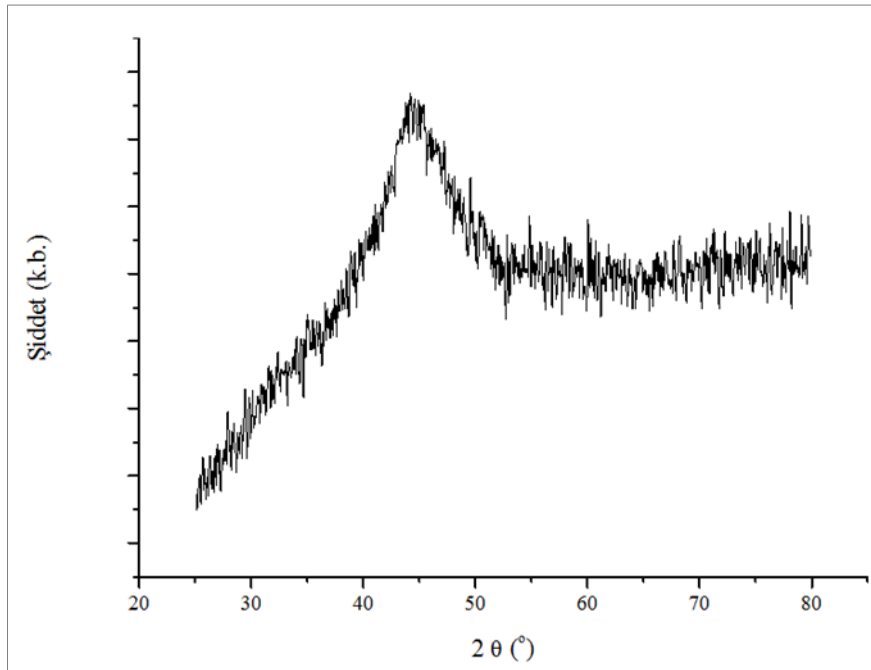
Burada E, Young modülü, t kalınlık, ρ yoğunluğu göstermektedir ve sabitler c_n değerleri birinci üç mod için sırasıyla 0.28, 1.75 ve 4.91 olarak verilmektedir (l verilmemiştir). Önceki çalışmamızda [28], Fe_3O_4 manyetik nanoparçacıkların algılanması için manyetoelastik sensör kullanılmıştır. Bu çalışmada, IgG antijeni algılanması için kantilever sistemi kullanılmıştır.

Deneysel

Ölçüm Metotları

Örneğin rezonans frekansı, titreşimli kavis yöntemiyle uygulanan alanın bir fonksiyonu olarak ölçülmüştür. Sistemdeki titreşim frekansı ise optik olarak ölçülmüştür. Burada amorf ferromanyetik $Fe_{40}Ni_{38}Mo_4B_{18}$ (Metglas 2826MB) şeritler kullanılmış ve şeritler 3 cm uzunluğunda ve 2 mm genişliğinde bilgisayar denetimli mikro kesici testere ile kesilmiştir. Örnek kalınlığı yaklaşık 25 μm 'dir. Kesilen örnek bir kısıp içine yerleştirilmiş ve bir uçtan 1.5 cm serbest bırakılmıştır. Kelepçe, sinüzoidal çıkışlı değişken frekanslı bir sinyal üretici tarafından çalıştırılan mekanik bir vibratöre bağlanmıştır. Kelepçenin titreşimi 2826MB şeritin titreşimine neden olur. Bu salınımın genliği, şerit titreşim modlarından birinin rezonans frekansında çalıştırıldığında en büyük değerine ulaşmaktadır. Titreşen şerit ölçüm sistemi Şekil 1'de gösterilmiştir. Şerit, lazer kaynağı ile fotodiyotlar arasına yerleştirilmiştir. Şeklin ekinde gösterildiği gibi iki fotodiyot vardır ve her bir fotodiyotun çıkışı, lock-in yükseltecin iki girişine bağlanmıştır ve lock-in yükseltecin iki girişi arasındaki farkları almak için A-B modunda kullanılmıştır. Şerit titreşmediği zaman, lock-in yükseltecinin çıkışı sıfırdır çünkü her iki fotodiyot da aynı miktarda ışık yoğunluğu almaktadır. Örnek titreşmeye başladığında, önce fotodiyotlardan birine (örneğin diyot a) doğru hareket eder. Bu durumda, fotodiyot b daha fazla miktarda ışık almaktadır,

dolayısıyla $V_b > V_a$ olur. Daha sonra örnek fotodiyot b'ye doğru hareket ederek $V_a > V_b$ 'ye yol açar. Bu titreşim, rezonans frekansında lock-in yükselteç çıkışında maksimum sinüzoidal çıkışa neden olur. Rezonansta titreşim genliği ve frekans değeri de manyetik alanın bir fonksiyonu olarak ölçülmüştür. Ayrıca hangi manyetik alanda daha iyi sonuç alınabileceği de incelenmiştir. Ölçümlerde öncelikle temel modun frekansı ölçülmüş, ardından diğer modların rezonans frekansları ölçülmüştür. Birinci mod çok parazite işarete sahip olduğu için, ikinci rezonans frekans değerinde ölçümler yapılmıştır. IgG antijeni algılama sürecinde farklı oranlardaki IgG yüzeyi fonksiyonelleştirilmiş olan kantilever üzerine bir mikropipet yardımı ile damlatılmış ve rezonans frekansındaki değişim ölçülmüştür. Örneğin yapısı, Rigaku Rad B model X-ışını toz difraksiyon difraktometresi ile incelenmiştir.



Şekil 2. Üretilen 2826MB kantilever sensörün X-ışınları kırınım tayfı

Kullanılan Kimyasallar

Kullanılan kimyasal maddeler Sigma-Aldrich firmasından ticari olarak satın alınmış ve ileri bir saflaştırma yapılmaksızın kullanılmışlardır. Tüm sulu çözeltiler, Millipore Direct-Q® 3 su arıtma cihazıyla saflaştırılan saf su ile hazırlandı.

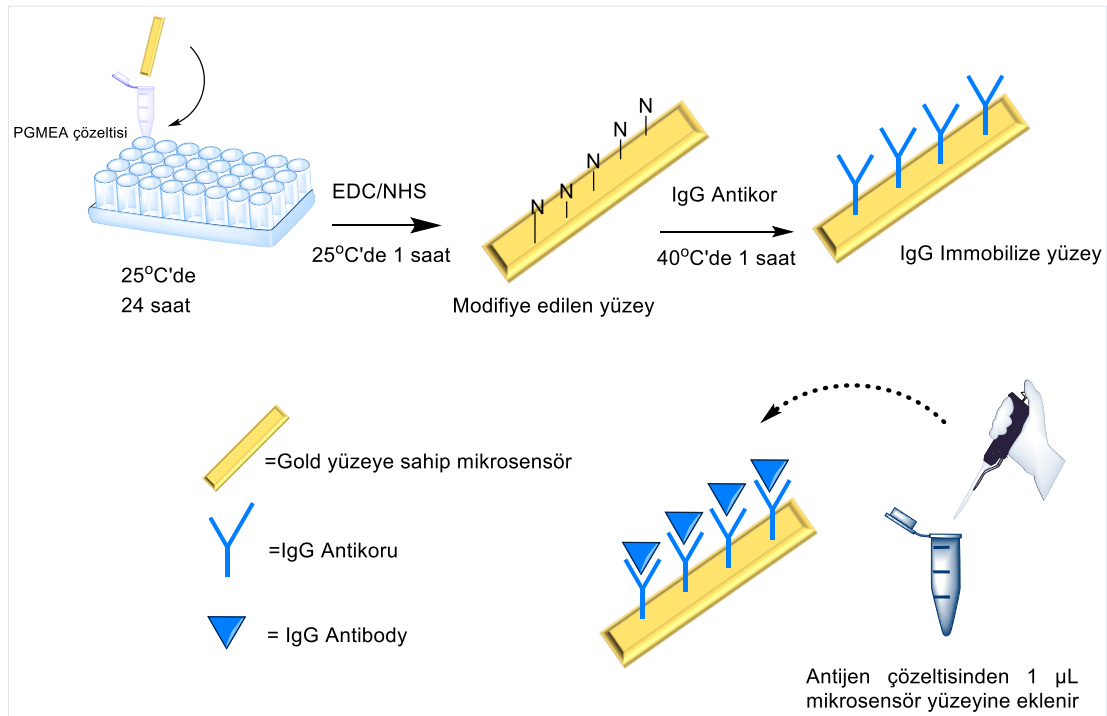
Sensör Yüzeyinin Değişimi

Kesilen 2826 MB örneğinin X-ışını kırınım tayfı Şekil 2’de verilmiştir. Şekilden de görüldüğü gibi yapı amorf bir yapıya sahiptir. Daha sonra 2826 MB örneği öncelikle 100 nm kalınlığında sensör yüzeyinin aşınma özelliklerini iyileştirmek için krom (Cr) ile kaplanmış ve Cr kaplamanın üzerine 100 nm Au kaplanmıştır. Au kaplama yapmamızın nedeni yüzeye olan tutunmanın artmasını sağlamak içindir. Hazırlanan altın yüzeye sahip kantileverlerin yüzeyleri 6 mg/mL olacak şekilde poli etilen glikol 2-merkaptto etil eter asetik asit ile muamele edilmiştir. Bu işlem 25°C’de 1 gece süreyle

gerçekleştirilmiştir. İşlemin tamamlanmasının ardından kantilever yüzeyler saf su ile yıkanarak bağlanmayan gruplar uzaklaştırılmıştır. Ardından bu yüzeyler oda koşullarında 1-etil-3-(3-dimetilamino-propil) karbodiimid/N-hidroksisüksinimid (EDC/NHS) ile fonksiyonel hale getirilmiştir. EDC/NHS modifikasyonu için 2.87 mg EDC 3.45 mg NHS ayrı ayrı 1 ml pH 7.4 fosfat tampon çözeltisi (50 mM, PBS) içerisinde çözülmüştür. Sonrasında kantilever yüzeyine 500 μ L EDC çözeltisi ve 500 μ L NHS eklenerek oda koşullarında 1 saat süreyle karıştırılmaya bırakılmıştır. Reaksiyon süresi tamamlandıktan sonra kantilever yüzeyleri saf su ile bir kez yıkanmıştır.

IgG Antikorumun İmmobilizasyonu

Fonksiyonel hale getirilen kantilever yüzeylerine 12.5 μ L IgG antikor çözeltisi eklenmiş ve üzeri PBS (50 mM, pH 7.4) ile 1 mL'ye tamamlanmıştır. Bu reaksiyon 40°C'de 1 saat süreyle gerçekleştirilmiştir. İşlem tamamlandıktan sonra kantilevera eklenen süpernatant protein testleri için ayrıştırılmış, kantilever ise 1 kez saf su ile yıkanarak ölçüm işlemleri için bekletilmiştir. Yapılan işlemler Şekil 3'de şematize edilmektedir.



Şekil 3. Altın yüzeye sahip mikrosensörlere IgG antikor immobilizasyonunun gerçekleştirilmesi

Antijen Çözeltisinin Hazırlanması

Ölçüm işlemlerinin en önemli aşamalarından bir antijen çözeltisinin mikrosensör yüzeyine damlatılması ve seçici olarak algılanmasıdır. Yaptığımız çalışmada ilk olarak antijen çözeltisi 1000 ppm olacak şekilde stok halinde hazırlanmıştır. Karar verilen diğer konsantrasyonlar (500, 250, 100, 75, 50, 25 ve 10 ppm) stok çözeltinin seri dilüsyonu ile elde edilmiştir. Ölçüm sırasında her bir farklı konsantrasyondaki örnekten 1 μ L alınarak mikrosensör yüzeyine damlatılmış ve frekanstaki

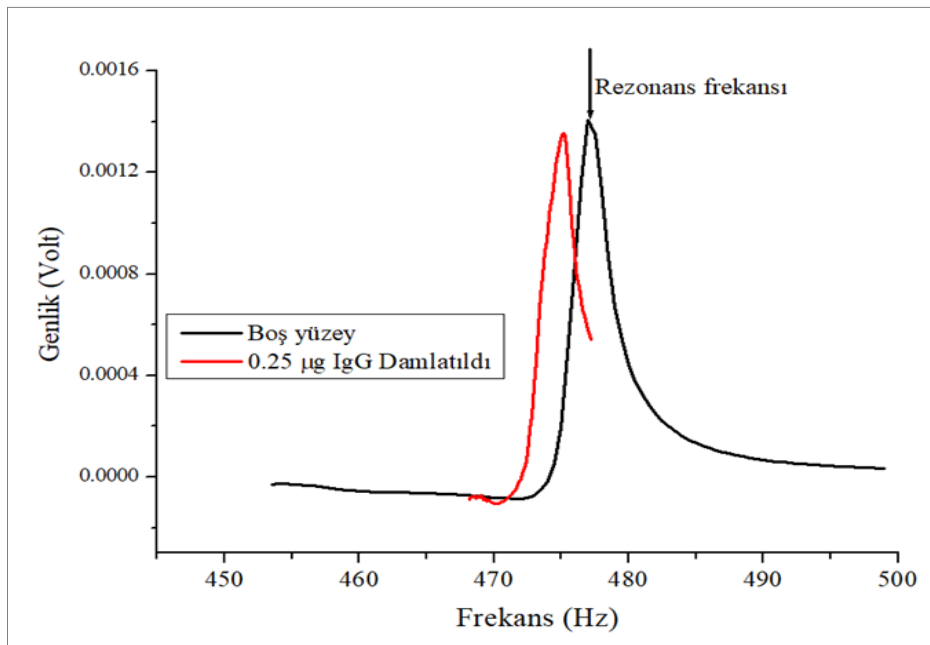
değişiklikler not edilmiştir. Aşağıda verilmiş olan Tablo 1’de farklı konsantrasyondaki her örnekten 1 μ l alındıktan sonra mikrosensör yüzeyindeki antikorlarla etkileşen madde miktarı belirtilmiştir.

Tablo 1. Mikrosensör yüzeyine eklenen madde miktarları

Konsantrasyon (ppm)	Madde miktarı (ng)
1000	1000
500	500
250	250
100	100
75	75
50	50
25	25
10	10

IgG Antikorumun Algılanması

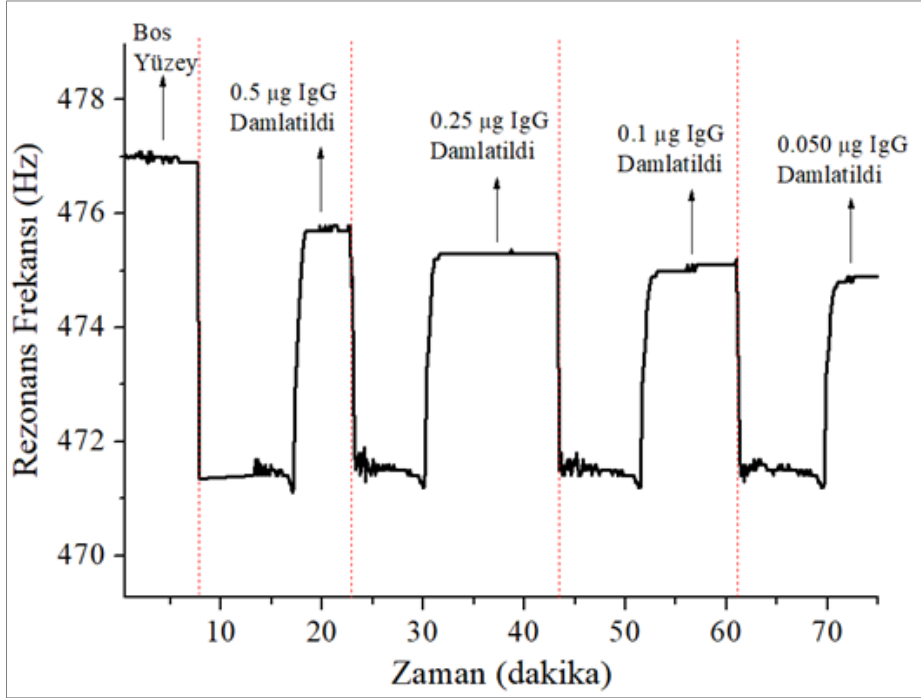
Kantilever sensör yüzeyinde IgG Antijeninin tespiti için kullanılan sensörün frekans aralığı 440 Hz ile 450 Hz olarak belirlenmiştir. Ölçüm sırasında öncelikli olarak Şekil 4’de görüldüğü gibi hava ortamında boş yüzey ölçümü alınmış ve daha sonra kantilever üzerine sırasıyla farklı konsantrasyonlarda hazırlanmış antijen çözeltisi her ölçümde 1 μ l olarak eklenmiştir.



Şekil 4. Havada serbestçe titreşen kantilever ve 0.25 μ g antijenin kantilever yüzeyine eklendikten sonraki rezonans eğrileri

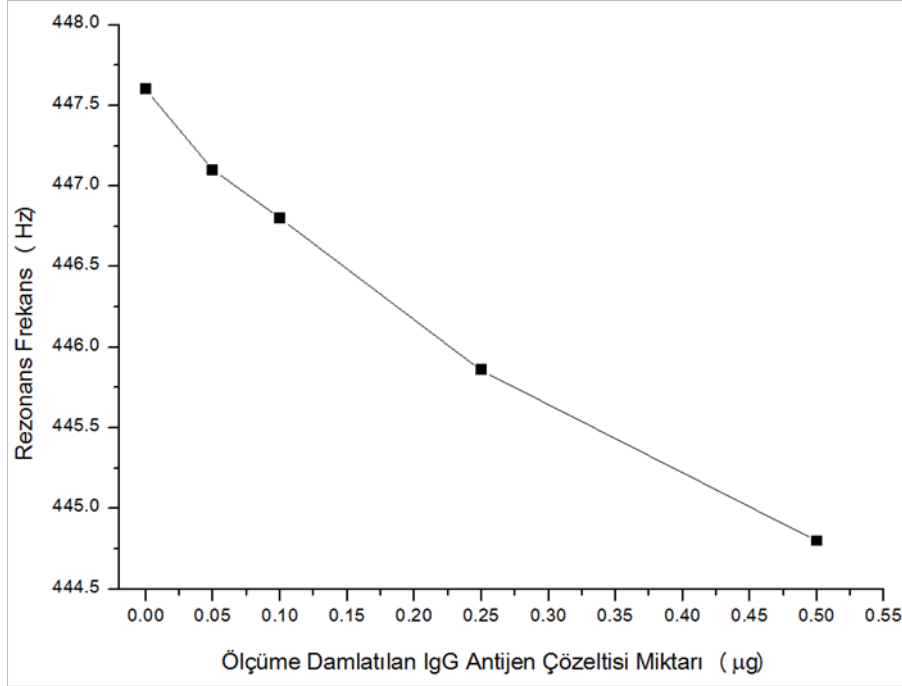
1. Damlatma 50 ppm (0.05 μ g antijen) olarak eklenmiş ve eklenen karışımın sensör yüzeyinde yayılması ile sensör rezonans frekansı azalmış ve rezonans frekansı ve bu frekans sinyali kaydedilmiştir.

Buradaki rezonans frekans kayması $\Delta f = 0.5$ Hz olarak elde edilmiştir. 2. damlatmada 100 ppm (0.10 μg antijen) eklenmiş ve buradaki değişim $\Delta f = 0.7$ Hz olarak elde edilmiştir. 3. damlatmada 250 ppm (0.25 μg antijen) eklenmiş ve buradaki değişim $\Delta f = 1$ Hz olarak elde edilmiştir. Burada zamana bağlı ölçümde (Şekil 5) çözelti eklendikten sonra frekansta azalma gözlenmiş ve daha sonra zamanla kararlı değerine ulaşmıştır.

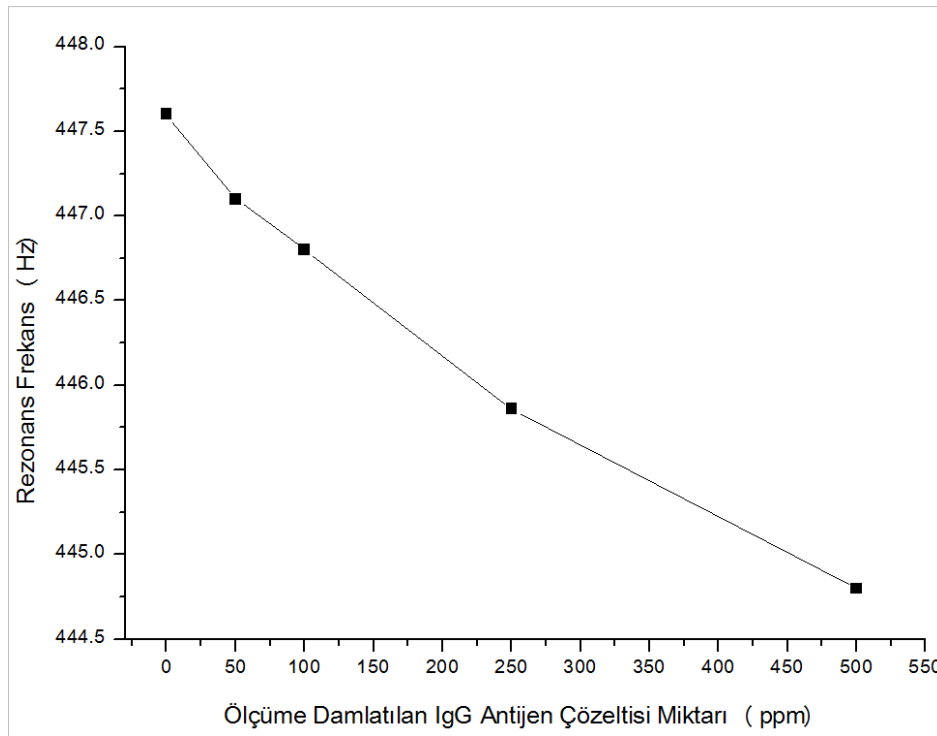


Şekil 5. Kantilever sensör üzerine sırasıyla eklenen antijenin zamana bağlı olarak sensör rezonans frekansına etkisi. Burada rezonans frekansındaki keskin düşüş sensöre damlatma yapıldıktan sonra çözeltinin etkisidir

IgG antijen dedektesi için bu aşamada yukarıda belirttiğimiz gibi havada ölçümü alınmış olan kantileverin üzerine farklı konsantrasyonlarda sırasıyla 1 μl antijen çözeltisi eklenmiştir (Tablo 1) ve daha sonra çözelti içindeki antijenler antikorlarla kantilever yüzeyinde bağ yapmaktadır ve buna bağlı olarak kantilever kütlelerinde artış ve rezonans frekansında azalma kaydedilmiştir, bu azalma grafikte Δf olarak verilmiştir. 1 μl (0.05 μg) antijen çözeltisi yaklaşık 0.5 Hz'lik bir değişime neden olmuştur, sonuçlar Şekil 6 ve 7'de verilmiştir. Sensör yüzeyine yine aynı miktarlarda (1 μl) antijen çözeltisi eklenmiştir ve rezonans frekansında ki değişim ölçülmüştür. Görüldüğü üzere kantilever yaklaşık, 0-500 ppm, 0-4 μl , 0-0.50 μg aralığında ölçülen antijen miktarlarına göre yaklaşık olarak doğrusal bir değişim göstermektedir.



Şekil 6. Kantileverin rezonans frekansının eklenen antijenin kütlesi ile değişimi



Şekil 7. Kantileverin rezonans frekansının sadece antijen miktarı ile değişimi

Sonuçlar

Bu çalışmada, serbest ucu 15 mm olan 2826MB Fe₄₀Ni₃₈Mo₄B₁₈ amorf ferromanyetik şeritler kantilever olarak kullanılmıştır. Yapılan çalışmalarda ortama IgG antikoru eklendiğinde kantilever kütlelerinde artış ve rezonans frekansında azalma kaydedilmiştir. Bu azalma bize doğrudan IgG algılanmasını göstermektedir. 1 µl (0.05 µg) antijen çözeltisi rezonans frekansında yaklaşık 0.5 Hz'lik bir değişime

neden olduğu gözlenmiştir. Ölçümler sonucunda çözelti içinde bulunan 50 ng miktarındaki IgG'nin rahatlıkla algılanabileceği gösterilmiştir.

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On ss -Lifting Modules In View of Singularity

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Research Article

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Abstract

In this essay we describe δ_{ss} -lifting modules as a singular version of ss -lifting ones. The focus of this study is to get a more general algebraic structure than ss -lifting modules. A module W is entitled δ_{ss} -lifting if for each $S \leq W$, there occurs a decomposition $W = X \oplus Y$ with $X \leq S$ and $S \cap Y \leq Soc_{\delta}(Y)$, where $Soc_{\delta}(Y) = \delta(Y) \cap Soc(Y)$. We examine the fundamental properties of this form of modules and also investigate a structure of a ring whose modules are all δ_{ss} -lifting. Finally, we give several characterizations for (projective) δ_{ss} -lifting modules and (amply) δ_{ss} -supplemented modules via δ_{ss} -perfect rings.

Keywords: Semisimple module, δ_{ss} -supplemented module, δ_{ss} -lifting module, Left δ_{ss} -perfect ring

Singülerlik Açısından ss -Lifting Modüller

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Öz

Bu makalede ss -yükseltilebilir modüllerin singüler versiyonu olan δ_{ss} -yükseltilebilir modülleri tanımlıyoruz. Çalışmanın amacı δ_{ss} -yükseltilebilir modüllerden daha genel bir cebirsel yapı elde etmektir. Bir W modülü, her $S \leq W$ alt modülü için, $Soc_{\delta}(Y) = \delta(Y) \cap Soc(Y)$ olmak üzere, $X \leq S$ ve $S \cap Y \leq Soc_{\delta}(Y)$, koşullarını gerçekleyen $W = X \oplus Y$ ayrışımına sahip ise W 'ya δ_{ss} -yükseltilebilir modül denir. Bu modüllerin temel özelliklerini araştırıyor ve üzerindeki her modülü δ_{ss} -yükseltilebilir olan bir halka yapısı arıyoruz. Sonunda ise, δ_{ss} -mükemmel halkalar aracılığı ile (projektif) δ_{ss} -yükseltilebilir ve (bol) δ_{ss} -tümlenmiş modüllerin bir takım karakterizasyonlarını veriyoruz.

Anahtar Kelimeler: Yarı basit modül, δ_{ss} -tümlenmiş modül, δ_{ss} -yükseltilebilir modül, Sol δ_{ss} -mükemmel halka

Introduction

Throughout the paper, we presume that R is an associative ring with unit and W is a unitary left R -module and we use the representations $S \leq W$ and $S \leq_{\oplus} W$ which indicate that S is a submodule of W and S is a direct summand of W , respectively.

By $S \trianglelefteq W$, we point that S is an *essential submodule* of W , that is, the intersection of S with whole submodules of W is nonzero, except for $\{0\}$. The *socle* of a module W is signified by $Soc(W)$ as the

intersection of whole essential submodules of W equivalently, the sum of whole simple submodules of W . By the notation $S \ll W$, a *small submodule* $S \leq W$ is pointed, that is, a proper submodule of W provided that $S + K \neq W$ for any proper submodule K of W . And the sum of whole small submodules of W is signified by $Rad(W)$. The *singular submodule* of a module W is signified by $Z(W)$ containing the elements of W whose annihilators are essential in R and W is called *singular* if $Z(W) = W$ [1].

In [1], Zhou contributed to literature the term of δ -small submodules as a generalized category of small ones. $S \leq W$ is called δ -small in W if $W = S + K$ implies $W = K$ for each $K \leq W$ with $\frac{W}{K}$ is singular and signified by $S \ll_{\delta} W$. And the sum of whole small submodules of W is signified by $\delta(W)$. As for δ -hollow modules are defined as the modules whose each proper submodule is δ -small [2]. Moreover in [3], $Soc_{\delta}(W)$ is identified as the intersection of $Soc(W)$ and $\delta(W)$. Hence $Soc_{\delta}(W)$ is the sum of each δ -small simple submodules of W .

A *supplement submodule* K of a submodule S in W is the minimal submodule with respect to $W = S + K$ which is equivalent to $W = S + K$ and $S \cap K \ll K$ and a *supplemented module* is defined as the module whose each submodule has a supplement. Also a submodule $S \leq W$ has *ample supplements* in W if each submodule $K \leq W$ with $W = S + K$, involves a supplement of S in W .

In [4], Koşan extended the notion of supplemented modules via singularity. A δ -supplemented module is defined as the module whose each submodule is of a δ -supplement. And a module W is named *amply δ -supplemented* if, S is of a δ -supplement K' in W with $K' \leq K$, where $W = S + K$ for any $K \leq W$.

In [5], Oshiro defined extending and lifting modules as a dual form of each other, which are the general forms of injective modules and projective supplemented modules, respectively. In order to obtain fundamental knowledge about supplements types one may refer to [6–10]. In summary, a module W is named *lifting* if, for each $S \leq W$, there occurs a decomposition $W = X \oplus Y$ such that $X \leq S$ and $S \cap Y \ll Y$. Motivated by this term, in [4] Koşan also defined δ -lifting modules as follows. A module W is called δ -lifting if, for each submodule $S \leq W$, there occurs a decomposition $W = X \oplus Y$ such that $X \leq S$ and $S \cap Y \ll_{\delta} Y$. A module W is named \oplus - δ -supplemented whose submodules are of a δ -supplement in W as a direct summand of W . For more information we refer to readers [1, 11–15].

In [3], the authors studied δ_{ss} -supplemented modules as a generalized type of ss -supplemented ones presented in [16]. A module W is named δ_{ss} -supplemented if for each submodule $S \leq W$ there occurs a δ_{ss} -supplement submodule K in W , where $S + K = W$, $S \cap K$ is semisimple and δ -small submodule of K . Moreover, amply δ_{ss} -supplemented modules are introduced. And by this way, the relations are indicated between these two new algebraic structures. The concept of δ_{ss} -perfect rings is contributed in the literature. The equivalent conditions are determined for a ring R to be δ_{ss} -perfect via some R -modules that has a projective δ_{ss} -cover. In [3] the authors restrict the definition of δ -supplemented modules to δ_{ss} -supplemented modules by replacing the condition of being δ -small submodule for δ -supplement submodules to the condition of being δ -small semisimple. Thus, a new module structure is constructed between ss -supplemented modules and δ -supplemented modules.

Inspired by [3, 17], in this paper, we define δ_{ss} -lifting modules and by this way a new structure is obtained among the category of ss -lifting modules and δ -lifting modules. Fundamental features are investigated for these modules. Firstly, we present matching conditions for a module to be δ_{ss} -lifting in Lemma 2. An another fact is that the direct summand of a δ_{ss} -lifting module saves the feature. δ_{ss} -lifting modules are clearly δ_{ss} -supplemented. However, a δ_{ss} -supplemented module W with $\delta(W) \leq Soc(W)$ is δ_{ss} -lifting. Suitable conditions are determined for the factor module of a δ_{ss} -lifting module to be

δ_{ss} -lifting in Proposition 3. Also some results on decompositions of δ_{ss} -lifting modules are obtained. Furthermore, some characterizations are given for projective (amply) δ_{ss} -supplemented modules and δ_{ss} -lifting modules via δ_{ss} -perfect rings in Theorem 4 and Theorem 5. As a consequence, a ring R is δ_{ss} -perfect if and only if ${}_R R$ is δ_{ss} -lifting if and only if ${}_R R$ is (amply) δ_{ss} -supplemented. A module W is δ_{ss} -lifting if and only if W is amply δ_{ss} -supplemented and each δ_{ss} -supplement S of W is of a decomposition $S = U \oplus V$ such that $U \leq_{\oplus} W$ and V is projective semisimple. In Proposition 7, it is proven that a projective module W is δ_{ss} -lifting if and only if $\frac{W}{Soc_{\delta}(W)}$ is semisimple and decompositions of $\frac{W}{Soc_{\delta}(W)}$ lift to decompositions of W .

δ_{ss} -Lifting Modules

Definition 1. A module W is named δ_{ss} -lifting if for each $S \leq W$, there occurs a decomposition $W = X \oplus Y$ with $X \leq S$ and $S \cap Y \leq Soc_{\delta}(Y)$, where $Soc_{\delta}(Y) = \delta(Y) \cap Soc(Y)$.

Owing to this concept, a new algebraic structure takes place between ss -lifting modules and δ -lifting modules.

Now the matching provisions for a module W to be δ_{ss} -lifting are given.

Lemma 1. The statements given below are equivalent:

1. For each $S \leq W$, there is a decomposition $W = X \oplus Y$ such that $X \leq S$ and $S \cap Y \leq Soc_{\delta}(W)$.
2. Each $S \leq W$ has the form $S = A \oplus B$ with $A \leq_{\oplus} W$ and $B \leq Soc_{\delta}(W)$.

Proof. (1) \Rightarrow (2) is evident.

(2) \Rightarrow (1) is similar to that of (3) \Rightarrow (2) of Lemma 3.3 in [1].

Lemma 2.

1. The implications given below are equivalent for a module W :
 - a. W is δ_{ss} -lifting.
 - b. For each $S \leq W$, there occurs submodules $X, Y \leq S$ provided $S = X \oplus Y$, $X \leq_{\oplus} W$ and $Y \leq Soc_{\delta}(W)$.
 - c. For each $S \leq W$, there occurs a submodule $X \leq_{\oplus} W$ provided $X \leq S$ and $\frac{S}{X} \leq Soc_{\delta}(\frac{W}{X})$.

(2) Every direct summand of a δ_{ss} -lifting module is δ_{ss} -lifting.

Proof. 1. (1a) \Rightarrow (1b) : It is obvious from Lemma 1.

(1b) \Rightarrow (1c) : Let $S \leq W$. By supposition, there occurs a decomposition of S provided $S = X \oplus Y$ with $X \leq_{\oplus} W$ and $Y \leq Soc_{\delta}(W)$. For the natural homomorphism $\pi : W \rightarrow \frac{W}{X}$, we have $\pi(Y) = \frac{Y+X}{X} = \frac{S}{X} \leq Soc_{\delta}(\frac{W}{X})$, since $Y \ll_{\delta} W$ since [1, Lemma 1.3] and [15, 20.3].

(1c) \Rightarrow (1a) : Let $S \leq W$. By (1c) there occurs a decomposition of W , such that $W = X \oplus Y$ with $X \leq S$ and $\frac{S}{X} \leq Soc_{\delta}(\frac{W}{X})$. Therefore, we have $W = S + Y$ and $S = X \oplus (Y \cap S)$. Because $\frac{W}{X} \cong Y$ and $\frac{S}{X} \cong S \cap Y$, then we get $S \cap Y \leq Soc_{\delta}(W)$. Hence, W is a δ_{ss} -lifting module.

2. Let W be δ_{ss} -lifting and $S \leq_{\oplus} W$. Thus, there occurs some $T \leq W$ such that $W = S \oplus T$. For any $X \leq S \leq W$, since W is δ_{ss} -lifting, there occurs a decomposition of W such that $W = Z \oplus Y$ with $Z \leq X$ and $X \cap Y \ll_{\delta} Y$. Therefore $S = Z \oplus (S \cap Y)$ is obtained such that $S \cap (X \cap Y) = X \cap (S \cap Y) = X \cap Y \ll_{\delta} S \cap Y$, since $S \leq_{\oplus} W$ and $S \cap Y \leq_{\oplus} S$.

A module W is called *strongly δ -local* if it is δ -local with a semisimple δ -radical [3].

Proposition 1. A strongly δ -local module is δ_{ss} -lifting.

Proof. Let W be a strongly δ -local module and $S \leq W$.

Case 1 : Let $S \leq \delta(W)$. Thus, S is semisimple as a submodule of $\delta(S)$. Therefore, $S \ll_{\delta} W$ by [3, Lemma 2.2]. Clearly, W has the decomposition $W = 0 \oplus W$ and $0 \leq S, S \cap W = S \ll_{\delta} W$.

Case 2 : Let $S \not\leq \delta(W)$. Then we have $W = S + \delta(W)$ from the maximality of $\delta(W)$. Because $\delta(W) \ll_{\delta} W$, there occurs a projective semisimple submodule D of $\delta(W)$ with $W = S \oplus D$. Hence W is δ_{ss} -lifting.

Proposition 2. A δ -lifting module W with $\delta(W) \leq Soc(W)$ is δ_{ss} -lifting.

Proof. For each $S \leq W$ we have $W = X \oplus Y$ such that $X \leq S$ and $S \cap Y \ll_{\delta} Y$. As a result, $S \cap Y$ is semisimple since $S \cap Y \leq \delta(W) \leq Soc(W)$. This verifies that W is δ_{ss} -lifting.

Remember that a module W is named *distributive* if for any submodules X, Y and Z of W , $X \cap (Y + Z) = (X \cap Y) + (X \cap Z)$. If for each $f \in End(W)$, $f(X) \leq X$, we say that X is a *fully invariant* submodule of W .

Now, the conditions are investigated to obtain when the factor module of a δ_{ss} -lifting module is δ_{ss} -lifting.

Proposition 3. Let W be a δ_{ss} -lifting module. For any $X \leq W$ the factor module $\frac{W}{X}$ is δ_{ss} -lifting if one of the statements given below are satisfied:

1. For any $S \leq_{\oplus} W$, $\frac{S+X}{X} \leq_{\oplus} \frac{W}{X}$.
2. W is a distributive module.
3. $f(X) \subseteq X$ for any idempotent $f = f^2 \in End(W)$. Particularly, X is a fully invariant submodule of W .

Proof. 1. Let $\frac{K}{X} \leq \frac{W}{X}$. Since $K \leq W$ and W is δ_{ss} -lifting there occurs a direct summand T of W with $T \leq K$ and $\frac{K}{T} \leq Soc_{\delta}(\frac{W}{T})$. It is clear that $\frac{T+X}{X} \leq_{\oplus} \frac{W}{X}$ and $\frac{T+X}{X} \leq \frac{K}{X} \leq \frac{W}{X}$. Since $\frac{K}{T} \leq Soc_{\delta}(\frac{W}{T})$, then $\frac{K}{T+X} \leq Soc_{\delta}(\frac{W}{T+X})$ by Lemma [1, Lemma 1.3]. Hence $\frac{W}{X}$ is δ_{ss} -lifting.

2. This condition is proved by using (1). Let $W = Y \oplus Z$. We have $\frac{W}{X} = \frac{Y+X}{X} + \frac{Z+X}{X}$ and by the assumption $\frac{Y+X}{X} \cap \frac{Z+X}{X} = \frac{(Y \cap Z)+X}{X} = 0_{\frac{W}{X}}$. Hence $\frac{Y+X}{X} \leq_{\oplus} \frac{W}{X}$ and so $\frac{W}{X}$ is δ_{ss} -lifting.

3. Let $W = A \oplus B$. By (1), we will show that the factor module $\frac{A+X}{X}$ is a direct summand of $\frac{W}{X}$. Let $\pi : A \oplus B \rightarrow A$ be the projection map with the kernel $(1 - \pi)(W) = B$. Then $\pi^2 = \pi \in End(W)$ and $\pi(W) = A$. From assumption $\pi(X) \leq X$ and $(1 - \pi)(X) \leq X$ is obtained. Thus, we have $\pi(X) = X \cap A$ and $(1 - \pi)(X) = X \cap B$. So we have $X = \pi(X) \oplus (1 - \pi)X = (X \cap A) \oplus (X \cap B)$. Then, $\frac{A+X}{X} = \frac{A \oplus (X \cap B)}{X}$ and $\frac{B+X}{X} = \frac{B \oplus (X \cap A)}{X}$ which implies $\frac{W}{X} = \frac{A \oplus (X \cap B)}{X} + \frac{B \oplus (X \cap A)}{X}$. In addition to these, $[A \oplus (X \cap B)] \cap [B \oplus (X \cap A)] = \{[A \oplus (X \cap B)] \cap B\} \oplus (X \cap A) = (X \cap B) \oplus (A \cap B) \oplus (X \cap A) = (X \cap B) \oplus (X \cap A) = X$, we have $\frac{A+X}{X} \leq_{\oplus} \frac{W}{X}$. Hence, W is δ_{ss} -lifting by (1).

In Lemma 2, we proved that being δ_{ss} -lifting is transferred to direct summands. But generally, the converse is not true. By Theorem 1, we present a way to verify this claim by adding suitable conditions. But firstly, we give the following useful lemma (see in [15, 41.14]).

Lemma 3. Let $W = X \oplus Y$. Then the implications given above are equivalent.

1. X is Y -projective.
2. For every $S \leq W$ with $W = T + Y$, there occurs a submodule $T' \leq T$ such that $W = T' \oplus Y$.

Theorem 1. Let $W = X \oplus Y$ be a module such that X is both self and Y -projective. If X and Y are δ_{ss} -lifting modules, then so is W .

Proof. Let $S \leq W$. Thus, for $X \cap (S + Y) \leq W$, as X is δ_{ss} -lifting, there occurs direct summands D, D' of X such that $D \leq X \cap (S + Y)$ and $X \cap (S + Y) \cap D' = (S + Y) \cap D' \ll_{\delta} X$. So we get $W = X \oplus Y = D \oplus D' \oplus Y = S + (D' \oplus Y)$. Since X is self and Y -projective, it is clear that X is W -projective. By taking into account the exact sequence $D \rightarrow D \oplus (D' \oplus Y) \rightarrow D' \oplus Y$, it is apparent that D is $D' \oplus Y$ -projective [15, 18.1/18.2]. Therefore by Lemma 3 there occurs some $S' \leq S$ such that $W = S' \oplus (D' \oplus Y)$. Thus, we can say $S \cap (W + D') = W \cap (S + D')$ for each submodule $W \leq Y$. Furthermore, since Y is δ -lifting, there exists $Y_1 \leq Y \cap (S + D') = S \cap (Y + D')$ such that $Y = Y_1 \oplus Y_2$ and $S \cap (Y_2 + D') = Y_2 \cap (S + D') \ll_{\delta} Y_2$ for any $Y_2 \leq Y$. Therefore that $W = S' \oplus (D' \oplus Y) = S' \oplus (D' \oplus Y_1 \oplus Y_2) = (S' \oplus Y_1) \oplus (Y_2 \oplus D')$ is obtained easily. Because $S' \leq S$ and $X \leq S \cap (D' \oplus Y) \leq S$, we get $S' \oplus Y_1 \leq S$ and so $W = S + (D' \oplus Y)$. In addition, $S \cap (Y_2 \oplus D') = Y_2 \cap (S \oplus D') \ll_{\delta} Y_2 \leq Y_2 \oplus D'$.

Corollary 1. Let X be a semisimple module and Y be a δ_{ss} -lifting module which is relatively projective with X , then $W = X \oplus Y$ is δ_{ss} -lifting.

Example 1. Let us consider the \mathbb{Z} -module $W = \frac{\mathbb{Z}}{2\mathbb{Z}} \oplus \frac{\mathbb{Z}}{4\mathbb{Z}}$. Since the simple \mathbb{Z} -module \mathbb{Z}_2 and \mathbb{Z} -module \mathbb{Z}_4 are strongly local, they are also ss -supplemented and so δ_{ss} -supplemented. Thus, W is a δ_{ss} -supplemented module as a finite direct sum of δ_{ss} -supplemented modules [3, Proposition 4.9]. Otherwise W is a δ_{ss} -lifting module since $\delta(W) \leq Soc(W)$ and W is δ -lifting [4, Lemma 2.6] although $\frac{\mathbb{Z}}{2\mathbb{Z}}$ is not $\frac{\mathbb{Z}}{4\mathbb{Z}}$ -projective.

Now we give some results on decomposition of a δ_{ss} -lifting module.

Proposition 4. The implications given below hold for a δ_{ss} -lifting module W .

1. $\frac{W}{Soc_{\delta}(W)}$ is semisimple.
2. Any $S \leq W$ with $S \cap Soc_{\delta}(W) = 0$ is semisimple.
3. W has a decomposition $W = X \oplus Y$ such that X is semisimple, Y is δ_{ss} -lifting module and $\delta(Y) \leq Y$.

Proof. 1. It is clear from [3, Proposition 4.7].

2. Because $S \cong \frac{S \oplus Soc_{\delta}(W)}{Soc_{\delta}(W)} \leq \frac{W}{Soc_{\delta}(W)}$ is semisimple from (1), then S is semisimple by [18].

3. It is clear from [4] and Lemma 2(2).

Theorem 2. Let W is a δ_{ss} -lifting module. Then W is of a decomposition $W = X \oplus Y$ such that $\delta(X) = X$, $\delta(Y) = Soc_\delta(Y)$ and X, Y are δ_{ss} -lifting modules.

Proof. As W is δ_{ss} -lifting, there occurs a decomposition $W = X \oplus Y$ for the submodules $\delta(W)$ of W such that $\delta(W) \leq X$ and $\delta(W) \cap Y \leq Soc_\delta(Y)$. Thus, we have $\delta(W) \cap Y = [\delta(X) \oplus \delta(Y)] \cap Y = \delta(Y) \oplus [\delta(X) \cap Y] = \delta(Y) = Soc_\delta(Y)$. Moreover, $X = \delta(W) \cap X = \delta(X) \oplus (X \cap \delta(Y)) = \delta(X)$ is got. Also, X and Y are δ_{ss} -lifting by Lemma 2(2).

Proposition 5. Let W be a δ_{ss} -lifting module and $\delta(W)$ is of an ss -supplement in W . Then W has a decomposition $W = X \oplus Y$ such that X, Y are δ_{ss} -lifting modules and $Soc_\delta(Y) = Soc(Y)$.

Proof. Let W be a ss -supplement of $\delta(W)$ in W . In this case $\delta(W) + W = W$ and $\delta(W) \cap W \leq Soc_s(W)$. As W is δ_{ss} -lifting, there exists a decomposition $W = X \oplus Y$ for the submodule W with $X \leq W$ and $W \cap Y \leq Soc_\delta(Y)$. Then $W = X \oplus (W \cap Y)$. For any submodule S of X , from assumption we get a decomposition $X = A \oplus B$ such that $A \leq_\oplus S$ and $S \cap B \ll_\delta B$ by Lemma 1. Hence, we get $S = A \oplus (B \cap S)$. Since $\delta(W) \cap W \ll W$ and $B \cap S \leq \delta(W) \cap W$, it is obtained that $S \cap B \ll W$. Therefore, $B \cap S$ is semisimple and small in B by [13]. Thus, X is an ss -lifting module. In addition to these, $W = \delta(W) + W = \delta(X) + \delta(Y) + X + (Y \cap W) = \delta(X) + \delta(Y) + X = \delta(Y) \oplus X = Y \oplus X$ and so $Soc_\delta(Y) = Soc(Y) \cap \delta(Y) = Soc(Y) \cap Y = Soc(Y)$ is obtained.

In [3], the authors defined the (projective) δ_{ss} -cover of a module as follows.

Definition 2. Let W be a module and P be a (projective) module. P is named a (projective) δ_{ss} -cover of W if there exists an epimorphism from P to W with a semisimple and δ -small kernel in P .

Theorem 3. Let $W = X + Y$. If $\frac{W}{X}$ is of a projective δ_{ss} -cover, then Y includes a δ_{ss} -supplement of X .

Proof. Let $\pi : Y \rightarrow \frac{Y}{X \cap Y} \cong \frac{X+Y}{X}$ be the natural homomorphism and let $f : P \rightarrow \frac{X+Y}{X}$ be a projective δ_{ss} -cover. Because of the projectivity P , there occurs a homomorphism $g : P \rightarrow Y$ satisfying $\pi g = f$, $Ker(f)$ is semisimple and δ -small in P . Then, it is clear that $W = X + g(P)$ and $X \cap g(P) = g(Ker(f))$. As $Ker(f) \ll_\delta P$ and $Ker(f)$ is semisimple, then $X \cap g(P) \ll_\delta g(P)$ and $X \cap g(P)$ is semisimple by [1, Lemma 1.3] and [18, Corollary 8.1.5].

Proposition 6. A projective module P is δ_{ss} -supplemented if and only if it is δ_{ss} -lifting.

Proof. It is clear from [3, Theorem 5.6].

Theorem 4. The implications given below are equivalent for a ring R :

1. R is a δ_{ss} -perfect ring.
2. Every R -module is δ_{ss} -supplemented.
3. Every projective R -module is δ_{ss} -supplemented.
4. Every projective R -module is δ_{ss} -lifting.
5. Every finitely generated projective R -module is δ_{ss} -lifting.

6. Every finitely generated projective R -module is δ_{ss} -supplemented.
7. Every finitely generated R -module is δ_{ss} -supplemented.
8. ${}_R R$ is δ_{ss} -supplemented.

Proof. (1) \implies (2) : It is clear from [3, Theorem 5.3].

(2) \implies (3) : It is obvious.

(3) \implies (4) : It is clear from Proposition 6.

(4) \implies (5) : It is clear.

(5) \implies (6) : It is clear from [3, Theorem 5.6].

(6) \implies (7) : Let W be a finitely generated module. Then W is a homomorphic image of a finitely generated free R -module, that is, $W \cong f(R^n)$ where $f : R^n \rightarrow W$ is epic for some $n \geq 0$. Hence, W is δ_{ss} -supplemented from [3, Proposition 4.9, Proposition 4.14].

(7) \implies (8) : It is apparent from implications.

(8) \implies (1) : If ${}_R R$ is δ_{ss} -supplemented, then R is a δ_{ss} -perfect ring by [3, Theorem 5.3].

Example 2. Let $Q = \prod_{i=1}^{\infty} \mathbb{Z}_2$ and R be the subring of Q generated by $\bigoplus_{i=1}^{\infty} \mathbb{Z}_2$ and 1_Q . Since $Soc(R) = \delta(R)$ is semisimple and δ -small in W [1, Example 4.1], then ${}_R R$ is strongly δ -local and δ_{ss} -supplemented from [3, Lemma 4.1]. Hence, ${}_R R$ is a δ_{ss} -lifting module by from Theorem 4 as ${}_R R$ is projective. Also it is not ss -lifting by [17, Theorem 5], as R is not semiperfect by [1, Example 4.1]

Example 3. Let R be a ring of polynomials over a field F in countably many commuting indeterminates x_1, x_2, \dots modulo the ideal generated by $\{x_1^2, x_2^2 - x_1, x_3^2 - x_2, \dots\}$ with $Rad(R) = \frac{\langle x_1, x_2, \dots \rangle}{\langle x_1^2, x_2^2 - x_1, x_3^2 - x_2, \dots \rangle}$. Since R is local and R has no minimal ideal we have $Rad(R) = \delta(R) \neq Soc(R) = 0$. Nevertheless, R is a δ -semiperfect ring [1] which is not δ_{ss} -perfect [3]. Finally, the R -module R is δ -lifting [4, Theorem 3.3] but not δ_{ss} -lifting.

In [13, Theorem 4.44], it was shown that a projective module P such that $\frac{P}{Rad(P)}$ is semisimple and $Rad(P) \ll P$ is semiperfect if and only if decompositions of $\frac{P}{Rad(P)}$ lift to decompositions of P . Motivated by this reality, we give the following useful proposition.

Proposition 7. The statements given below are equivalent for a projective module W .

1. W is δ_{ss} -lifting.
2. $\frac{W}{Soc_{\delta}(W)}$ is semisimple and for any $\bar{X} = \frac{A+Soc_{\delta}(W)}{Soc_{\delta}(W)} \leq_{\oplus} \frac{W}{Soc_{\delta}(W)}$, there exists a direct summand A of W such that $\bar{X} = \bar{A}$.

Proof. (1 \implies 2) : Let W be a δ_{ss} -lifting module. Since W is also δ_{ss} -supplemented, then from Proposition 4 $\frac{W}{Soc_{\delta}(W)}$ is semisimple. From assumption, there exists direct summands A, B of X with $X = A \oplus B$, with $A \leq_{\oplus} W$ and $B \leq Soc_{\delta}(W)$. Hence $\frac{X+Soc_{\delta}(W)}{Soc_{\delta}(W)} = \frac{A+Soc_{\delta}(W)}{Soc_{\delta}(W)}$ is obtained, i.e., $\bar{X} = \bar{A}$.

(2 \implies 1) : Let $S \leq W$. As $\frac{W}{Soc_{\delta}(W)}$ is semisimple, we have $\frac{S+Soc_{\delta}(W)}{Soc_{\delta}(W)} \leq_{\oplus} \frac{W}{Soc_{\delta}(W)}$ and there occurs a submodule $X \leq_{\oplus} W$ from assumption satisfying $\frac{S+Soc_{\delta}(W)}{Soc_{\delta}(W)} = \frac{X+Soc_{\delta}(W)}{Soc_{\delta}(W)}$. In this case $W = X \oplus Y$ for some $Y \leq (W)$ and so $\frac{W}{Soc_{\delta}(W)} = \frac{(X+Y+Soc_{\delta}(W))}{Soc_{\delta}(W)} = \frac{(S+Y+Soc_{\delta}(W))}{Soc_{\delta}(W)}$. Since $Soc_{\delta}(W) \ll_{\delta} W$ from [3,

Proposition 3.1(2)], then there exists a projective semisimple submodule of P of $Soc_\delta(W)$ such that $W = (S+Y) \oplus P$. Then, $S+Y$ is projective as a direct summand of W . From Lemma 3, $S+Y = S' \oplus Y$ with $S' \leq S$ is got. Thus, $W = S' \oplus (Y \oplus P)$ and even as $\frac{W}{Soc_\delta(W)} = \frac{(S+Soc_\delta(W))}{Soc_\delta(W)} \oplus \frac{(Y+Soc_\delta(W))}{Soc_\delta(W)}$, we have $S \cap (Y \oplus Soc_\delta(W)) \leq Soc_\delta(W)$. Hence, we get $S \cap (Y \oplus P) = S \cap Y \leq S \cap (Y \oplus Soc_\delta(W)) \leq Soc_\delta(W) \ll_\delta W$.

Definition 3 (see from [3]). A module W is called *amply δ_{ss} -supplemented* if T includes a δ_{ss} -supplement of S in W whenever $W = S + T$ for any $T \leq W$.

In [3, Proposition 4.2], it is given that a projective strongly δ -local module is amply δ_{ss} -supplemented. In that manner, it is possible to get a relation between amply δ_{ss} -supplemented modules and δ_{ss} -lifting modules.

Lemma 4. Let W be a δ_{ss} -lifting module. Then, W is amply δ_{ss} -supplemented.

Proof. Let $X, Y \leq W$ be submodules of W with $W = X + Y$. By Lemma 2, it is obtained that $Y = Y' \oplus Y''$, $Y' \leq_\oplus W$ and $Y'' \leq Soc_\delta(W)$. So we get $W = X + Y' + Y''$. Then, there occurs a projective semisimple submodule Y''' of Y'' with, $W = (X + Y') \oplus Y'''$ as $Y'' \leq Soc_\delta(W)$. Take $W = X + T$, where $T = Y' \oplus Y'''$. Then, $W = Y' \oplus Y^*$ and $X \cap T = T_1 \oplus S$ where $T_1 \leq_\oplus W$ and $S \leq Soc_\delta(W)$. Let $\pi' : W \rightarrow Y'$ the projection map. Then, $\pi'(S) \leq Soc_\delta(Y')$ and $S \leq T = Y' \oplus Y'''$. Thus, we have $S \leq \pi'(S) \oplus Y''' \ll_\delta Y' \oplus Y''' = T$. Let assume $T = T_1 \oplus T_2$ with the projection map $\pi : T \rightarrow T_2$. So we get $X \cap T = T_1 \oplus (T_2 \cap X)$ by modular law, as $T_1 \leq T_1 \oplus S \leq X$. Hence, $X \cap T_2 = X \cap T \cap T_2 \leq \pi(X \cap T) = \pi(T_1 \oplus S) = \pi(S) \leq Soc_\delta(T_2)$ as $S \leq Soc_\delta(W)$ and so $X \cap T_2 \leq \pi(X \cap T) = \pi(S)$ is semisimple and δ -small in T_2 . It follows that $W = X + T_2$ and $X \cap T_2 \leq Soc_\delta(T_2)$ where $T_2 \leq T \leq Y$. This means Y contains a δ_{ss} -supplement T_2 of X in T , that is, W is an amply δ_{ss} -supplemented module.

Remark 1. As a result of above lemma, we get the following relation for a module W .

W is δ_{ss} -lifting $\implies W$ is amply δ_{ss} -supplemented $\implies W$ is δ_{ss} -supplemented

Theorem 5. The statements given above are equivalent for a projective R -module W .

1. W is δ_{ss} -lifting.
2. W is amply δ_{ss} -supplemented.
3. W is δ_{ss} -supplemented.

Proof. (1) \implies (2) and (2) \implies (3) are clear by Remark 1.

(3) \implies (1) is clear by [3, Theorem 5.6], Proposition 6 and Lemma 4.

Corollary 2. The following implications are equivalent for a ring R .

1. ${}_R R$ is δ_{ss} -lifting.
2. ${}_R R$ is amply δ_{ss} -supplemented.
3. ${}_R R$ is δ_{ss} -supplemented.

In [19], a submodule K of $S \leq W$ is named δ -cosmall submodule of S in W if $\frac{S}{K} \ll_{\delta} \frac{W}{K}$. And S is called δ -coclosed if S does not include a proper δ -cosmall submodule in W , that is, if there occurs a submodule $K \leq S$ with $\frac{S}{K} \ll_{\delta} \frac{W}{K}$, this implies $S = K$.

Proposition 8. Any singular δ -coclosed submodule of a δ_{ss} -lifting module is a direct summand.

Proof. Suppose S be any singular δ -coclosed submodule of W . As W is δ_{ss} -lifting, S includes a direct summand K of W with $\frac{S}{K} \leq Soc_{\delta}(\frac{W}{K})$. Therefore, we have $\frac{S}{K} \ll_{\delta} \frac{W}{K}$ and so $S = K$ is obtained as S is δ -coclosed.

Proposition 9. Let W be an amply δ_{ss} -supplemented module whose δ_{ss} -supplement submodules are direct summands, then W is a δ_{ss} -lifting module.

Proof. Note that W is δ_{ss} -supplemented as it is amply δ_{ss} -supplemented. Thus, for any $S \leq W$, there occurs a δ_{ss} -supplement K in W satisfying $S + K = W$ and $S \cap K \leq Soc_{\delta}(K)$. Then, K is of a δ_{ss} -supplement contained in S with $K + L = W$ and $K \cap L \leq Soc_{\delta}(L)$. From assumption, L is also a direct summand of W for some $D \leq W$, that is, $W = L \oplus D$. Following, we have $S = L \oplus (S \cap D) = L + (S \cap K)$. Let us assume the projection map $\pi : W \rightarrow \frac{W}{L}$. Then we have $\pi(S \cap K) = \frac{(S \cap K) + L}{L} = \frac{(L + K) \cap S}{L} = \frac{S}{L} \cong S \cap D = \pi(S)$. Therefore, $\pi(S \cap K) \cong S \cap D \leq Soc_{\delta}(D)$ is got by [1, Lemma 1.3(2)] and [18, Corollary 8.1.5].

Proposition 10. Let W be an amply δ_{ss} -supplemented module whose δ_{ss} -supplement submodules are δ -coclosed. In that case, W is a δ_{ss} -lifting module if and only if each δ_{ss} -supplement submodule of W is a direct summand.

Proof. It is clear by Proposition 8 and Proposition 9.

Proposition 11. A module W is δ_{ss} -lifting iff W is amply δ_{ss} -supplemented and each δ_{ss} -supplement S of W is of a decomposition $S = U \oplus V$ satisfying $U \leq_{\oplus} W$ and V is projective semisimple.

Proof. (\implies) : It is clear from the necessity part of Proposition 3.1 given in [20].

(\impliedby) : As W is amply δ_{ss} -supplemented, each S of W is of a δ_{ss} -supplement K such that $S + K = W$ and $S \cap K \leq Soc_{\delta}(K)$. Therefore, there occurs a δ_{ss} -supplement K' of K included in S . In this case $K + K' = W$ and $K \cap K' \leq Soc_{\delta}(K')$. From assumption, K' is of a decomposition $K' = U \oplus V$ where $U \leq_{\oplus} W$ and V is projective semisimple. Thus, there occurs some $U' \leq (W)$ with $W = U \oplus U'$. By modular law, as $K' \leq S$ and $U \leq K' \leq S$, we have $S = S \cap W = S \cap (K + K') = K' + (S \cap K)$ and $S = S \cap W = S \cap (U \oplus U') = U \oplus (U' \cap S)$. Therefore, for the projection map $\pi : U \oplus U' \rightarrow U'$, $U' \cap S = \pi(S) = \pi(K') + \pi(S \cap K) = \pi(V) + \pi(S \cap K)$ and $\pi(K') + \pi(S \cap K) \leq Soc_{\delta}(U')$ since V is projective semisimple and $S \cap K \leq Soc_{\delta}(K)$ by [1, Lemma 2.2]; [18, Cor. 8.1.5] and [19, Lemma 1.2]]. Hence, W is δ_{ss} -lifting.

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Synthesis, Characterization, and Investigation of Antimicrobial Activities of New Naphthoquinone Compounds from 2-(butylthio)-3-chloronaphthalene-1,4-dione

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Research Article

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Abstract

In this study, the compound 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) was synthesized from the reaction of the compound 2,3-dichloro-1,4-naphthoquinone (**1**) with 1-butanethiol in alkaline medium. The synthesized compound 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) was used as the starting compound. As a result of the nucleophilic substitution of 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) with heterocyclic compounds containing nitrogen, sulfur, and oxygen atoms, a series of **10**, **11**, **12**, **13**, **14**, **15**, naphthoquinone derivative compounds were synthesized. The structures of the synthesized compounds were characterized by FTIR, ¹³C-NMR, ¹H-NMR, and Mass Spectroscopy techniques. The antimicrobial properties of the synthesized compounds were examined by performing antimicrobial studies with Gram-positive and Gram-negative bacteria. The compound 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) shows the highest antimicrobial activity, whereas the compound 2-(butylthio)-3-((4,5-dihydrothiazol-2-yl)thio)naphthalene-1,4-dione (**10**) exhibits the lowest antimicrobial activity. Compounds **3**, **11**, **12**, **13**, **14**, and **15** exhibited enhanced activity against Gram-positive bacteria, such as *B. subtilis* and *S. aureus*, as well as Gram-negative *E. coli* and *K. pneumoniae*. In addition, compounds **11**, **12**, and **14** exhibited activity against Gram-positive *B. subtilis* and *S. aureus*, as well as Gram-negative *E. coli*, *K. pneumoniae*, and *P. aeruginosa*. The study aims to enhance existing literature research and create new unknown compounds through synthesis.

Keywords: Substituted quinones, nucleophilic substitution, antimicrobial activity

2-(Butiltiy)-3-Kloronaftalen-1,4-Dion Bileşiğinden Yeni Naftakinon Bileşiklerin Sentezi, Karakterizasyonu ve Antimikrobiyal Aktivitelerinin İncelenmesi

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Öz

Bu çalışmada, 2,3-dikloro-1,4-naftakinon (**1**) bileşiğinin alkali ortamda 1-butantiyol ile reaksiyondan 2-(butiltiy)-3-kloronaftalen-1,4-dion (**3**) bileşiği sentezlendi. Sentezlenen 2-(butiltiy)-3-kloronaftalen-1,4-dion (**3**) bileşiği başlangıç bileşiği olarak kullanıldı. 2-(butiltiy)-3-kloronaftalen-1,4-dion (**3**) bileşiğinin azot, kükürt ve oksijen atomu içeren heterosiklik bileşikler ile nükleofilik süstitüsyonu sonucu bir seri **10**, **11**, **12**, **13**, **14**, **15**, naftakinon türevi bileşikler sentezlendi. Sentezlenen bileşiklerin yapıları FTIR, ¹³C NMR, ¹H NMR ve Mass Spektroskopisi ile

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karakterize edildi. Sentezlenen bileşiklerin Gram pozitif ve Gram negative bakteriler ile antimikrobiyal çalışması yapılarak antimikrobiyal özellikleri incelendi. 2-(butiltiyo)-3-kloronaftalen-1,4-dion (**3**) bileşiğinin antimikrobiyal aktivitesi en yüksek, 2-(butylthio)-3-((2,5-dihydrothiazol-5-yl) thio) naphthalene-1,4-dione (**10**) bileşiğinin antimikrobiyal aktivitesi en düşük olarak gözlenmiştir. **3**, **11**, **12**, **13**, **14** ve **15** bileşikleri, Gram-pozitif *B. subtilis* ve *S. aureus* ile Gram-negatif *E. coli*, *K. pneumoniae* 'ye karşı daha iyi aktivite göstermiştir. Ayrıca, **11**, **12** ve **14** bileşikleri Gram-pozitif *B. subtilis* ve *S. aureus* ile Gram-negatif *E. coli*, *K. pneumoniae* ve *P. aeruginosa*'ya karşı aktivite gösterdi. Bu çalışma ile literatürde olan çalışmaların geliştirilmesi ve bilinmeyen yeni bileşiklerin sentezlenmesi amaçlanmıştır.

Anahtar Kelimeler: Sübstitüe kinonlar, nükleofilik sübstitüsyon, antimikrobiyal aktivite

Introduction

Quinones are compounds with a cyclohexadiene dione structure. They are α , β -unsaturated ketones derived from the aromatic compounds dioxo derivatives. The first quinone compound was produced in 1838 by oxidizing Quinic acid. As a result, these compounds were named quinol [1, 2]. Compared to aromatics, quinones have two conjugated double bonds. They are electrophilic acceptors that are stabilized by conjugation. The reduction product of quinone can either aromatize or disrupt conjugation, depending on the structure of quinone and the position of the reduction [3]. It is better a series of oxidation and addition reactions form quinones. They can be synthesized through the oxidation of o-dihydroxy benzene to o-quinones in ether [2, 4], as well as through the oxidation of anilines and arenes [5]. Additionally, they can be produced through the Diels-Alder reaction of dienophiles and 1,3-dienes. Quinone compounds with four pi electrons in the ring exhibit similar properties to alpha and beta-unsaturated quinones [1, 6]. For several years, researchers have been studying compounds called 2-aryl(alkyl) amino-1,4-naphthoquinones. These compounds are formed when aryl amine and its derivatives react with 1,4-naphthoquinones [7]. 1,4-naphthoquinones can have a nitrogen atom [7, 8], sulfur [9], or an oxygen atom [10] at the 2-position or 2,3-position. The biological activity of these compounds has been analyzed by researchers. Antiproliferative activities of 2-chloro-3-arylsulfanyl-1,4-naphthoquinone, 2,3-bis-arylsulfanyl-1,4-naphthoquinone, and 12H-benzo[b] phenothiazine-6,11-diones and their analogs against cervical cancer cells were studied [9]. Reactions of 2,3-dichloro-1,4-naphthoquinone with heterocyclic compounds that contain nitrogen, sulfur, or oxygen are documented in literature. The number of studies on naphthoquinone-derived compounds has increased due to their biological activity. Novel compounds were synthesized using various methods to evaluate biological activity [11, 12]. Naphthoquinones are prevalent in the structure of vitamins, influencing their activities. Vitamin K1, which contains the 2-methyl-1,4-naphthoquinone structure and is found in plants, plays a vital role in maintaining the clotting properties of blood in humans. Vitamin K1 has various forms, such as K2 and K3, and the structure of these vitamins also contains quinones. The most well-known naphthoquinone is menadione. (also known as vitamin K₃ or 2-methyl-1,4-naphthoquinone). It is a redox cyclor and acts as a "destructive substrate" for numerous flavoproteins [13, 14]. These compounds are

known to exhibit antiviral, antifungal, antibacterial, antiproliferative, and antitumor properties. It is known that many drugs have a 1,4-naphthoquinone ring structure [15-20]. There are pigments such as Telephoric acid (permanganate color) and xylene in some phenanthrenequinones found in nature as animal and vegetable. Telephoric acid is found in fungi and lichens, and xylene is found as a green coating on overhanging branches of oaks and other hardwoods [16]. Quinones are essential compounds that occur naturally in plant and animal structures. Some of the quinones are used as bacteriostatic (phytol), some against malaria (hydrolapacol), and some as stimulants (plumbagin). Structural formulas of quinone compounds are available in Figure 1.

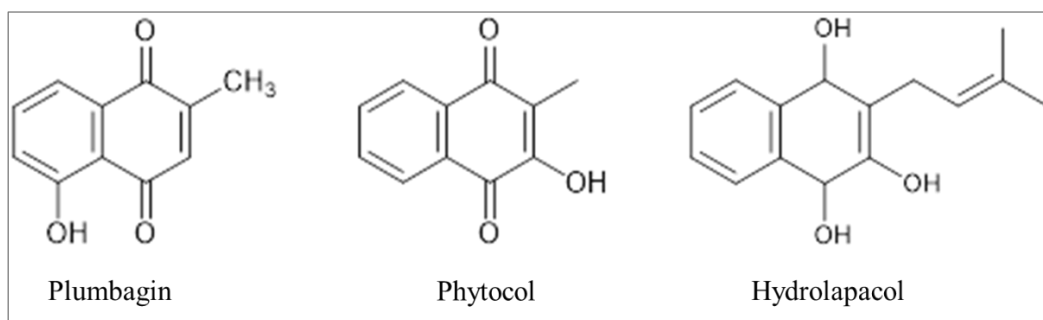


Figure 1. Naturally occurring quinones

Plastoquinone and ubiquinone are examples of biologically active quinones. Quinones catalyze biological reactions in some animals, plants, and microorganisms [21, 22]. In addition, the biological activities of certain quinones, such as fungicide, herbicide, nematocide, and insecticide properties, have been reported previously [16, 22, 23]. Daunomycin is an antibiotic that inhibits the development of various tumors. It is used to treat various tumors in animals. Streptonigrin is a compound known for its anticancer properties, while Mitosine is an antitumor antibiotic. Streptonigrin and Mitosine contain a benzoquinone ring, Plastoquinone and Ubiquinone are compounds with a hydroquinone structure, and Daunomycin contains an anthraquinone ring. Structural formulas are depicted in Figure 2. The bioactive properties of new naphthoquinone derivatives formed by naphthoquinones with groups containing nitrogen, sulphur, and oxygen atoms have increased the interest of organic chemists in naphthoquinones. Previous studies have shown that compounds derived from 1,4-naphthoquinone have cytotoxic, molluscicidal, antiallergic, antiproliferative, antileishmanial and antimalarial activities [24-27]. The compound 2-(butylthio)-3-chloronaphthalene-1,4-dione (2), a well-known substance based on existing studies, served as the starting material. New heterocyclic 1,4-naphthoquinone compounds were synthesized by nucleophilic substitution reaction of the starting material with heterocyclic compounds [15, 28], The structures of the new naphthoquinone compounds obtained were purified by column chromatography. The synthesized compounds were characterized by FT-IR, ^1H NMR, ^{13}C NMR, and mass spectroscopy. Finally, the antimicrobial activities of the synthesised compounds against gram-positive and gram-negative bacteria were investigated.

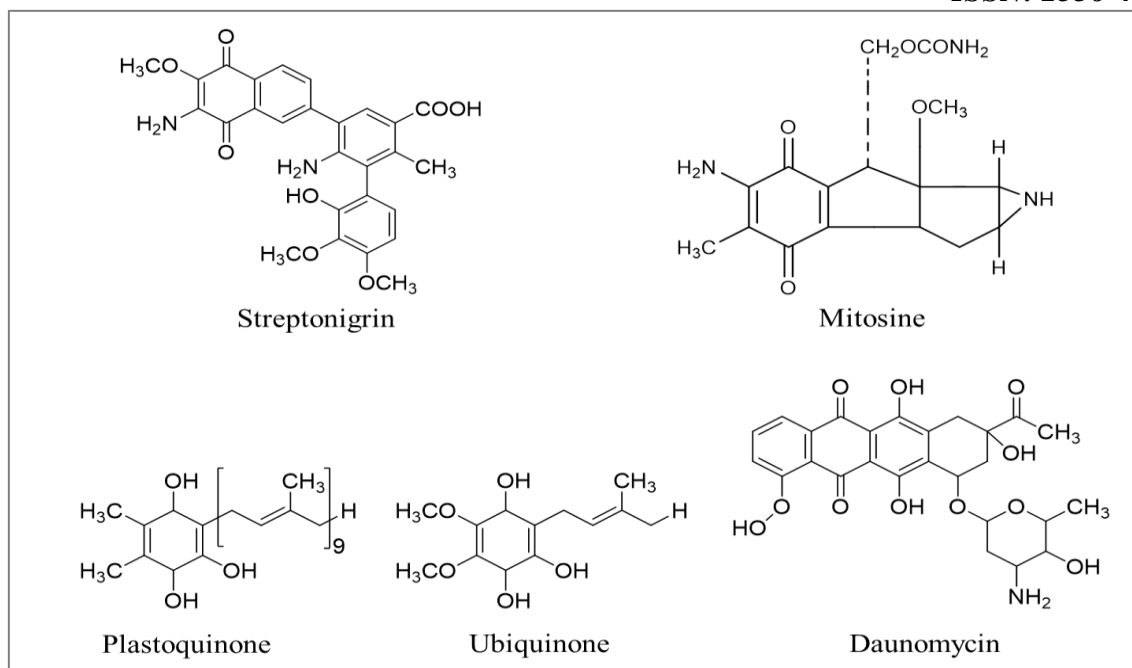


Figure 2. Quinone structures with biological activity

Experimental Section

Materials and Methods

The compounds used in the reactions are from Sigma Aldrich, with solvents purified by technical solvent and distillation, and using Na_2CO_3 and Acetonitrile from Merck. The progress of the reactions was monitored using thin-layer chromatography paper (TLC) purchased from Merck. Silica Gel 60 (Merck) was used for purification by column chromatography. Thin-layer chromatography paper was checked under ultraviolet light (254nm). There are various methods in the literature for the synthesis of new aryl group compounds from the compound 2,3-dichloro-1,4-naphthoquinone (**1**) [29]. ^1H NMR (400 MHz) and ^{13}C NMR (125 MHz) spectra were recorded in CDCl_3 on a Bruker BIOSPIN AVANCE III spectrometer. Mass spectra were obtained on a Thermo Scientific/TSQ Quantum Access Max LC/MS/MS spectrometer using the ESI technique. The IR studies were carried on a Thermo Scientific Nicolet 6700 FTIR spectrometer in the range of 400 to 4000 cm^{-1} . In this experiment, 2,3-dichloro-1,4-naphthoquinone (**1**) was dissolved in 50 mL of chloroform in a 100 mL reaction flask. Na_2CO_3 and 1-butanethiol were then added to the flask, and the mixture was stirred for 6 hours at room temperature. After completion of the reaction, 2-(butylthio)-3-chloronaphthalene-1,4-dione (**2**) was obtained [15, 28]. The resulting 2-(butylthio)-3-chloronaphthalene-1,4-dione (**2**) was the starting compound. Reactions of 2-(butylthio)-3-chloronaphthalene-1,4-dione (**2**) in chloroform/acetonitrile solvent with nucleophilic compounds containing (O-, N-, S-) at different molar ratios have been studied. After adding Na_2CO_3 to the reaction mixture at room temperature, they were stirred with a magnetic stirrer for 5-6 hours. The progress of the reactions was monitored by thin layer chromatography. After, they were extracted using chloroform and 200 mL of water (50 mL x 4). After treating the organic phase with sodium sulfate, it

was filtered to remove any remaining impurities. The crude products were purified using column chromatography after solvent recovery in the rotavapor. The obtained products were dried and made ready for the necessary analysis for characterization. [30, 31]. The Figure 3 shows the availability of naphthoquinone compounds (**10-15**) containing (O-, N-, S-) groups.

Microbial strains and in vitro antimicrobial activity studies

In the study of antimicrobial activity, various types of bacteria and fungi were used, including Gram-positive bacteria *Bacillus subtilis* ATCC 6623, *Staphylococcus aureus* ATCC 25923, Gram-negative bacteria *Escherichia coli* ATCC 25922, *Klebsiella pneumoniae* ATCC 70060, *Pseudomonas aeruginosa* ATCC 27853, as well as fungus *Candida albicans* ATCC 10231 and *Aspergillus niger* ATCC 16404. The broth microdilution method in 96 multi-well microtiter plates was utilized to determine the minimal inhibitory concentrations (MICs) of the tested compounds against the strains [32]. To assess the compound's antimicrobial activity, it was dissolved in DMSO to a concentration of 8192 µg/mL. The bacterial strains were incubated at 37°C in nutrient broth for 24 hours before obtaining the cultures. After being incubated for 24 hours at 28°C, the fungi were kept in nutrient broth. Suspensions of bacteria and fungi with a turbidity of approximately 10⁶ cells/mL were prepared. Control wells were also set up with pure microorganisms, pure media, and DMSO. In each well, 100 µL of the microorganism suspension and 100 µL of the compound being tested were added. Table 1. shows the minimum inhibitory concentration (MIC) in µg/mL, which was determined by observing the microplate with no microbial growth. Amoxicillin and Tetracycline served as a reference standards for antibacterial and Ketoconazole for antifungal activity.

Synthesis and Analysis

2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) [28]

2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) was synthesized from 2,3-dichloro-1,4-naphthoquinone (**1**) (1g, 4.4mmol) and 1-butanethiol (**2**) (0,39 g, 4.3 mmol) using a literature method. Red viscous oil. Yield: 0.88 g (% 71). R_f : 0.59 [(1:1) Petroleum Ether-CH₂Cl₂]; IR (ATR): ν = 3006 (C-H_{arom}), ν = 2977, 2959, 2923 (C-H), 1672, 1662 (C=O), 1589, 1520 (C=C); 813 (C-Cl).

2-(butylthio)-3-((4,5-dihydrothiazol-2-yl) thio) naphthalene-1,4-dione (**10**)

2-(butylthio)-3-((4,5-dihydrothiazol-2-yl) thio) naphthalene-1,4-dione (**10**) was synthesized from the reaction of 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) (0.25g, 0.89 mmol) with 2-thiazoline-2-thiole (**4**) (0.11g, 0.92mmol) using a literature method. Red viscous oil. Yield: 0.09 g (%28). R_f =0.43 [2:1] CHCl₃-Hexane]; IR (ATR): ν = 3072 (C-H_{arom}), ν = 2957, 2926 (C-H), 1652 (C=O), 1590, 1539 (C=C), 1271 (C-N); ¹H-NMR (499.74 MHz, CDCl₃): δ = 8.15, 7.81 (m, 4H, CH_{arom}), 4.55 (m, 2H, -NCH₂), 3.28, 3.25, 2.98 (m, 4H, SCH₂-), 1.47(s, 2H, -CH₂-), 1.00 (m, 2H, -CH₂-CH₃), 0.94 (m, 3H, CH₃); ¹³C-NMR (125.66 MHz, CDCl₃): δ = 174.52, 169.65 (C=O), 148.34 (C_{quinone}-S-), 138.89, 134.30,

129.38, 126.56, 116.66 (C_{naph}), 64.29 (NC), 45.82, 39.76 (SC), 33.88, 30.04, 21.74, 14.54 (SC-C), (CH_3 -C), 13.95 (CH_3 -); MS (+ESI): m/z 362.62 $[M]^+$. $C_{17}H_{17}NO_2S_3$ (M, 363.5 g/mol).

4-((3-(butylthio)-1,4-dioxo-1,4-dihydronaphthalen-2-yl) oxy) benzaldehyde (11)

4-((3-(butylthio)-1,4-dioxo-1,4-dihydronaphthalen-2-yl) oxy) benzaldehyde (**11**) was synthesized from the reaction of 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) (0.3g, 1.1 mmol) with 4-hydroxybenzaldehyde (**5**) (0.13g, 1.1 mmol) using a literature method. Dark red viscous oil. Yield: 0.08 g (%20). R_f = 0.57 [$CHCl_3$]; IR (ATR): ν = 3065, 3015 ($C-H_{arom}$), ν = 2958, 2927 (C-H), 1764, 1633 ($C=O$), 1590, 1538 ($C=C$); 1H -NMR (499.74 MHz, $CDCl_3$): δ = 8.11, 7.75 (m, 8H, CH_{arom}), 9.78 (s, 1H, $CH_{aldehyd}$), 3.21 (m, 2H, SCH_2 -), 1.62 (m, 2H, $-CH_2$ -), 1.44 (m, 2H, $-CH_2-CH_3$), 0.96 (m, 3H, CH_3); ^{13}C -NMR (125.66 MHz, $CDCl_3$): δ = 178.62, 170.70 ($C=O$), 182.11 ($C=O_{aldehyd}$), 154.62 (C_{naph-O}), 134.79, 133.34, 127.20, 126.53, 122.34 (C_{benzen} , C_{naph}), 32.36, 29.70, 21.79 (CH_2), 13.64 (CH_3); MS (+ESI): m/z 277,2 $[M-C_4H_9S]^+$. $C_{21}H_{18}O_4S$ (M, 366.4 g/mol).

2-(butylthio)-3-(naphthalen-1-ylamino) naphthalene-1,4-dione (12)

2-(butylthio)-3-(naphthalen-1-ylamino) naphthalene-1,4-dione (**12**) was synthesized from the reaction of 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) (0.32g, 1.1 mmol) with 1-naphthylamine (**6**) (0.16g, 1.1 mmol) using a literature method. Dark red viscous oil. Yield: 0.12 g (%28). R_f = 0.39 [(1:1) Petroleum Ether $-CH_2Cl_2$]; IR (ATR): ν = 3074, 3009 ($C-H_{arom}$), ν = 2958, 2926, 2885, 2856 (C-H), 1737, 1667 ($C=O$), 1592 ($C=C$), 1174 (C-N); 1H -NMR (499.74 MHz, $CDCl_3$): δ = 8.14, 8.10, 8.05, 7.78, 7.68, 7.55 (m, 11H, CH_{arom}), 4.03 (s, 1H, NH), 2.40 (m, 2H, SCH_2 -), 1.71 (m, 2H, $-CH_2$ -), 1.26 (m, 2H, $-CH_2-CH_3$), 0.91 (m, 3H, CH_3); ^{13}C -NMR (125.66 MHz, $CDCl_3$): δ = 173.56 ($C=O$), 151.56 (C_{naph-N}), 139.24, 128.41, 126.82, 124.46, 117.02, 114.07 (C_{benzen} , C_{naph}), 66.79 (S-C), 38.72, 33.99, 28.91 (CH_2), 14.04 (CH_3); MS (+ESI): m/z 387,87 $[M]^+$. $C_{24}H_{21}NO_2S$ (M, 387.5 g/mol).

6-(butylthio)-10-methyl-5H-benzo[a]phenoxazin-5-one (13)

6-(butylthio)-10-methyl-5H-benzo[a]phenoxazin-5-one (**13**) was synthesized from the reaction of 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) (0.33g, 1.1 mmol) with 2-amino-4-methyl phenol (**7**) (0.15g, 1.2 mmol) using a literature method. Red viscous oil. Yield: 0.17 g (%42.5). R_f = 0.43 [$CHCl_3$]; IR (ATR): ν = 3070, 3033 ($C-H_{arom}$), ν = 2958, 2929, 2875 (C-H), 1736 ($C=O$), 1636 ($C=C$), 1594 ($C=N$), 1280 (C-O), 1221 (C-N); 1H -NMR (499.74 MHz, $CDCl_3$): δ = 8.63, 8.29, 8.25, 7.73, 7.55, 7.23 (m, 7H, CH_{arom}), 3.97 (t, 2H, SCH_2 -), 3.10, 2.33 (m, 4H, $-CH_2$ -), 1.28, 0.86 (m, 6H, CH_3); ^{13}C -NMR (125.66 MHz, $CDCl_3$): δ = 173.47 ($C=O$), 150.28 ($C_{naph=N}$), 145.87 (C_{naph-S}), 142.21 (C_{naph-O}), 135.34, 131.51, 129.47, 124.55, 115.41 (C_{benzen} , C_{naph}), 66.74 (S-C), 38.70, 33.95 (CH_2), 22.94 ($C_{phenyl-CH_3}$), 14.01 (CH_3); MS (+ESI): m/z 349,57 $[M]^+$, 371,80 $[M+Na]^+$. $C_{21}H_{19}NO_2S$ (M, 349.4 g/mol).

6-(butylthio)-10-chloro-5H-benzo[a]phenoxazin-5-one (14)

6-(butylthio)-10-chloro-5H-benzo[a]phenoxazin-5-one (**14**) was synthesized from the reaction of 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) (0.33g, 1.2 mmol) with 2-amino-chlorophenol (**8**) (0.17g, 1.2 mmol) using a literature method. Red solid: 0.19 g (% 30). $R_f = 0.58$ [CH_2Cl_2]; Melting point. 146-148°C; IR (ATR): $\nu = 3078, 3054, 3007$ (C-H_{arom}), $\nu = 2959, 2929, 2871, 2859$ (C-H), 1736 (C=O), 1640 (C=C), 1596 (C=N), 1260 (C-O), 1173 (C-N), 782 (C-Cl); $^1\text{H-NMR}$ (499.74 MHz, CDCl_3): $\delta = 8.57, 8.25, 7.70, 7.40, 7.28$ (m, 7H, CH_{arom}), 3.14 (t, 2H, SCH₂-), 1.62, 1.47 (m, 4H, -CH₂-), 0.92 (m, 3H, CH₃); $^{13}\text{C-NMR}$ (125.66 MHz, CDCl_3): $\delta = 180.74$ (C=O), 149.24 (C_{naph}=N), 147.00 (C_{naph}-S), 142.78 (C_{naph}-O), 133.16, 132.12, 130.93, 126.38, 124.70, 116.67 (C_{benzen}, C_{naph}), 32.94 (S-C), 32.24, 21.90 (CH₂), 13.71 (CH₃); MS (+ESI): m/z 369,52 [M]⁺. C₂₀H₁₆ClNO₂S (M, 369.9 g/mol).

2-((4-aminophenyl) amino)-3-(butylthio) naphthalene-1,4-dione (15)

2-((4-aminophenyl) amino)-3-(butylthio) naphthalene-1,4-dione (**15**) was synthesized from the reaction of 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) (0.25g, 0.9 mmol) with phenylenediamine (**6**) (0.1g, 0.9 mmol) using a literature method. Purple viscous oil: 0.11 g (%39). $R_f = 0.53$ [(1:1)EtAc- Petroleum Ether]; IR (ATR): $\nu = 3086, 3035$ (C-H_{arom}), $\nu = 3453, 3318$ (N-H, NH₂), $\nu = 2957, 2925, 2854$ (C-H), 1664, 1628 (C=O), 1591, 1546 (C=C), 1284, 1268 (C-O), 1015 (C-N), 826 (N-H)); $^1\text{H-NMR}$ (499.74 MHz, CDCl_3): $\delta = 8.16, 7.73, 6.91, 6.89, 6.68$ (m, 8H, CH_{arom}), 7.28 (s, 2H, C_{phenyl}-NH), 4.29 (s, 2H, NH₂), 2.61 (t, 2H, SCH₂-), 1.35, 1.26, (m, 4H, -CH₂), 0.83 (t, 3H, CH₃); $^{13}\text{C-NMR}$ (125.66 MHz, CDCl_3): $\delta = 180.80, 180.73$ (C=O), 146.14 (C_{naph}-N), 143.95 (C_{naph}-S), 134.52, 132.44, 130.65, 129.83, 126.55, 114.91 (C_{phen}, C_{naph}), 33.82 (S-C), 31.55, 21.87 (CH₂), 13.65 (CH₃); MS (+ESI): m/z 352,65 [M]⁺. C₂₀H₂₀N₂O₂S (M, 352.5 g/mol).

Antimicrobial activities

The MIC values of the tested compounds against two Gram-positive and three Gram-negative bacterial strains, as well as two fungal strains, were determined and are provided in Table 1.

Table 1. The minimum inhibition concentrations (MIC's) of the synthesized compound

Sample	Minimum inhibition concentration (µg/mL)						
	Gram-staining-positive			Gram-staining-negative		Fungi	
	<i>B. subtilis</i>	<i>S. aureus</i>	<i>E. coli</i>	<i>K. pneumoniae</i>	<i>P. aeruginosa</i>	<i>A. niger</i>	<i>C. albicans</i>
3	4	32	8	64	8	2	4
10	64	256	256	1024	1024	512	1024
11	128	256	512	512	512	256	128
12	256	128	256	256	512	256	128
13	64	128	256	256	64	128	256
14	128	256	512	512	256	256	512
15	64	128	64	512	256	512	512
Amoxicillin	>1024	>1024	>1024	>1024	>1024	-	-
Tetracycline	4	64	64	64	64	-	-
Ketoconazole	-	-	-	-	-	1	2

Compound 3 displayed superior antimicrobial activity against all tested strains, while compound 10 exhibited the lowest activity. Table 1 shows that compounds 3, 11, 12, 13, 14, and 15 were more effective against *B. subtilis*, *S. aureus*, *E. coli*, *K. pneumoniae*, and *P. aeruginosa* than Amoxicillin. The 11, 12 and 14 compounds showed activity against the Gram-positive *B. subtilis* and *S. aureus*, and the Gram-negative *E. coli*, *K. pneumoniae* and *P. aeruginosa*, but at levels lower than the Tetracycline reference used. The synthesized compounds showed activity against fungi, but lower than the ketoconazole reference used.

Results and Discussion

Compounds **3**, **10**, **11**, **12**, **13**, **14**, and **15** were obtained via nucleophilic substitution of 2,3-dichloro-1,4-naphthoquinone (**1**) with heterocyclic compounds containing nitrogen, sulphur, and oxygen atoms in an appropriate environment (Figure 3). Compounds **10**, **11**, **12**, and **13** were prepared by reacting compound **3** with compounds **4**, **5**, **6**, and **7** in chloroform solvent using Na_2CO_3 as a catalyst. On the other hand, compounds **14** and **15** were synthesized by reacting compound **8** with compounds **8** and **9** in the presence of acetonitrile solvent and Na_2CO_3 as a catalyst. Based on the analysis, it was concluded that compounds **3**, **10**, **13**, and **14** have a red, viscous, oily physical property. On the other hand, compounds **11** and **12** have a dark red, viscous, oily physical property, while compound **15** has a purple-colored viscous, oily physical property. The synthesized compounds' structure was confirmed by taking its mass spectrum. Further, ^{13}C NMR, ^1H NMR, and FTIR spectroscopy were employed to determine the positions of the substituent groups in the structure and the atoms to which they were connected. The chemical shift of the NCH_2 proton in the thiazole ring of compound **10**, formed by the reaction of 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) with 2-thiazoline-2-thiol, was around 4.55 ppm and the molecular ion mass was found to be 362.62 $[\text{M}]^+$ confirms. The ion peaks of molecules **11**, **12**, **13**, **14**, and **15** are observed at 277.2 $[\text{M}-\text{C}_4\text{H}_9\text{S}]^+$, 387.87 $[\text{M}]^+$, 349.57 $[\text{M}]^+$, 369.52 $[\text{M}]^+$ and 352.65 $[\text{M}]^+$ respectively. The structure is confirmed by the chemical shift of two carbonyl groups belonging to the naphthoquinone compound at 178.62 and 170.70 ppm in ^{13}C NMR, and a carbonyl group belonging to one aldehyde group at 182.11 ppm in the molecule formed by the binding of the aldehyde compound in compound **11** to naphthoquinone. The absorption stretch band in the (C-N) group formed by the binding of the amine group in compound **12** to naphthoquinone shows a chemical shift of 1174 cm^{-1} in FTIR and 4.03 ppm singlet in the NH proton ^1H NMR. The NH stretching band of compound **12** could not be detected in FTIR spectroscopy. The NH stretching band of secondary amines is weak and may overlap with aromatic bands. The FTIR absorption band of compound **13** shows the presence of C-N and C=N groups at 1221 and 1594 cm^{-1} , respectively. In addition, a shift of one carbonyl group at 173.47 ppm in ^{13}C NMR confirms the structure. Similarly, the presence of C-N and C=N groups in compound **14** at 1173 and 1596 cm^{-1} absorption bands in FTIR and a shift of one carbonyl group at 180.74 ppm in ^{13}C -NMR confirms the structure. Compounds **14** and **15** were found to undergo cyclization. The NH_2 group

absorption band formed by the bonding of the amine group in compound **15** to naphthoquinone is 3413 cm^{-1} , and the absorption stretch band in the (C-N) group is around 1015 cm^{-1} in FTIR, and the shift of two carbonyl groups at 180.80 and 180.73 ppm in ^{13}C NMR confirms the structure. The biological activity of the synthesized compounds was studied, and it was found that three compounds (**3,13,15**) had the highest antimicrobial activity, while **10** compounds had the lowest antimicrobial activity. Although compound 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) had high antimicrobial activity, the attachment of the 2-thiazoline-2-thiol group significantly decreased its activity. Other aromatic compounds that bind to 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) did not significantly reduce its antimicrobial activity. Compounds **3, 11, 12, 13, 14,** and **15** exhibited superior activity against Gram-positive bacteria *B. subtilis* and *S. aureus*, as well as Gram-negative *E. coli* and *K. pneumoniae*. Compounds **11, 12,** and **14** also showed activity against Gram-staining-positive *B. subtilis* and *S. aureus* and Gram-staining-negative *E. coli*, *K. pneumoniae*, and *P. aeruginosa*. Studies have also shown that the compounds formed due to vinylic substitution reactions have dyestuff properties, which can be utilized for fabric dyeing [33, 34]. The synthesis process and resulting chemical compounds are depicted in Figure 3.

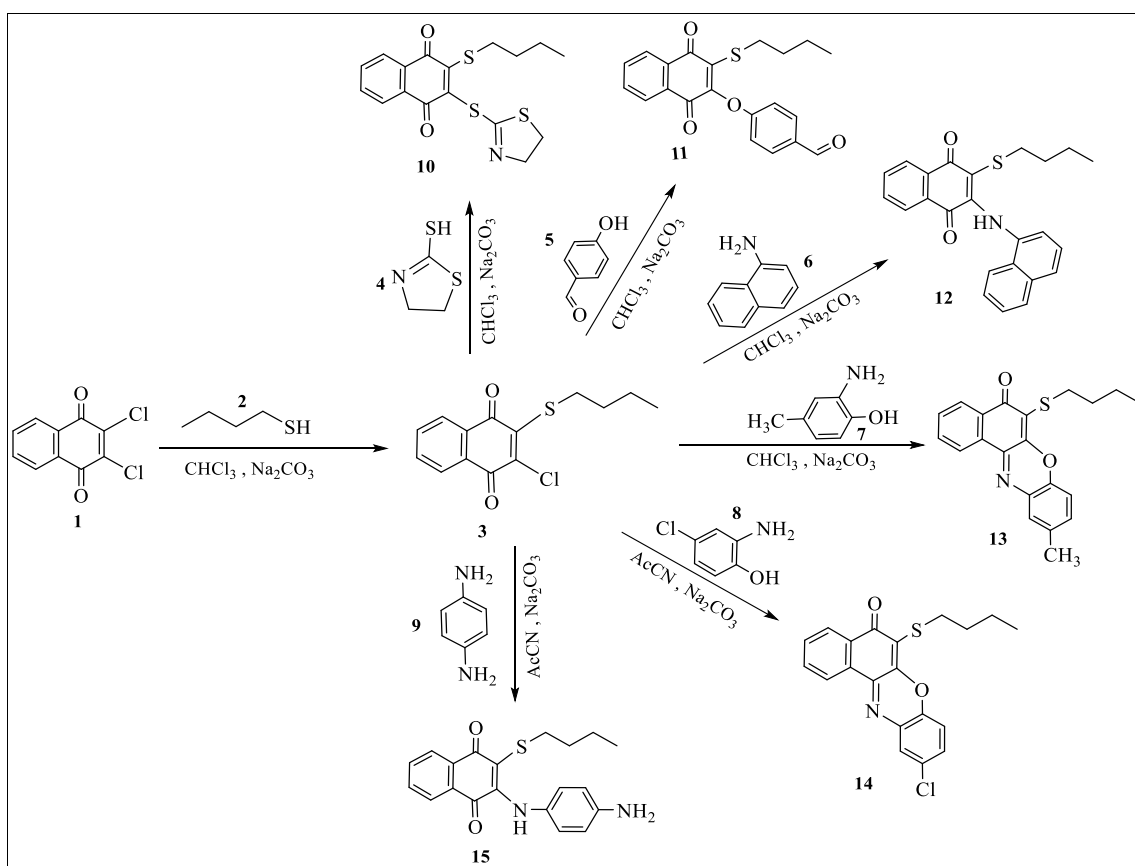


Figure 3. Compounds synthesized from 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) [28]

Conclusion

The compound 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) was synthesized from the reaction of the compound 2,3-dichloro-1,4-naphthoquinone (**1**) with 1-butanethiol in alkaline medium, resulting in the displacement of chloro atom number 1 in its structure by a nucleophilic substitution reaction. The synthesized compound was used as a starting material in subsequent reactions. Compounds **10-15** were obtained by reaction of 2-(butylthio)-3-chloronaphthalene-1,4-dione (**3**) with heterocyclic compounds containing nitrogen, sulphur, and oxygen. The resulting compounds were subjected to four different characterisation methods, including FTIR, ¹H-NMR, ¹³C-NMR, and mass spectroscopy. Antimicrobial activity was evaluated for all compounds against *Bacillus subtilis*, *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Pseudomonas aeruginosa*. The study revealed that three compounds were found to have the highest antimicrobial activity, while ten compounds had the lowest. Replacing the chlorine atom in the naphthoquinone molecule with aromatic and heteroatoms changes its antimicrobial activity. While the binding of naphthoquinone to thiazoline decreased its activity, the binding of aromatic compounds increased the activity. Although the newly synthesized naphthoquinone compounds are soluble in organic solvents such as chloroform and dichloromethane, their solubility in water is low due to their dense and oily nature. The scientists aimed to improve the existing knowledge on the production of naphthoquinone, a compound with significant applications in various fields.

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Authors Contribution The author read and approved the final manuscript

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A Study on the Expansion of Graphite Layers Via In-Situ Polymerization of Melamine

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Research Article

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Abstract

Graphene, renowned for its honeycomb lattice structure formed by densely packed sp^2 hybridized carbon atoms, possesses exceptional electronic, thermal, chemical, and mechanical properties. The van der Waals-coupled graphene layers give rise to the well-known AB stacking, forming graphite. Despite the existence of several methods for graphite production, the production of graphene on a large scale remains challenging due to the lack of efficient techniques and the introduction of structural defects during the production process. Exfoliated graphite (EG), a potential solution, is typically derived from the thermal treatment of graphite intercalation compounds (GICs). Melamine, notably displaying significant expansion properties at low temperatures, has been used as an intercalation compound in limited studies. This study investigates the potential of melamine to induce the expansion of graphene layers when incorporated into graphite and subjected to thermal treatment. Raman and X-ray diffraction analyses were employed to assess structural changes.

Keywords: Graphite, expansion of graphite, $g-C_3N_4$, thermal treatment

Melaminin Yerinde Polimerizasyonu ile Grafit Katmanlarının Genişletilmesi Üzerine Bir Çalışma

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Öz

Yoğun bir şekilde paketlenmiş olup sp^2 hibritlenmiş karbon atomlarından oluşan bal peteği kafes yapısıyla bilinen grafen, olağanüstü elektronik, termal, kimyasal ve mekanik özelliklere sahiptir. Van der Waals ile birleştirilmiş grafen katmanları, iyi bilinen AB istiflenmesine yol açarak grafit oluşturur. Grafit üretimi için çeşitli yöntemlerin varlığına rağmen, büyük ölçekte grafen üretimi, etkili tekniklerin bulunmaması ve üretim süreci sırasında yapısal kusurların ortaya çıkması nedeniyle zorlu olmaya devam ediyor. Potansiyel bir çözüm olan pul pul dökülmüş grafit (EG), tipik olarak grafit interkalasyon bileşiklerinin (GIC'ler) ısıtılmasından üretilmektedir. Özellikle düşük sıcaklıklarda önemli genişleme özellikleri sergileyen melamin, sınırlı çalışmalarda bir ara bileşik olarak kullanılmıştır. Bu çalışmada melaminin grafit içerisine dahil edilip ısıtılmasına tabi tutulduğunda grafen katmanlarının genişlemesini tetikleme potansiyeline odaklanılmıştır. Yapısal değişiklikleri değerlendirmek için Raman ve X-ışını kırınım analizleri kullanılmıştır.

Anahtar Kelimeler: Grafit, grafitin genişlemesi, $g-C_3N_4$, ısıtılma işlemleri

Introduction

The honeycomb lattice structure formed by tightly packing sp^2 hybridized carbon atoms makes graphene an incredibly attractive material, with extraordinary electronic, thermal, chemical, and mechanical properties [1]. Van der Waals-coupled graphene layers shift in the horizontal plane, leading to the well-known AB stacking, which forms graphite [2]. Graphite can be produced through various methods, including micro-mechanical exfoliation of highly ordered pyrolytic graphite, epitaxial growth, chemical vapor deposition, and reduction of graphene oxide (GO). [3-5]. Graphene and its derivatives are promising candidates as components for applications in the field of energy storage and energy conversion materials, thermally and electrically conductive reinforced nanocomposites, nanoelectronics, and sensors, among many others [6]. Despite its outstanding physical properties, graphene's large-scale production is hindered by a lack of effective methods. Additionally, the production methods often introduce structural defects that significantly weaken its mechanical properties and other physical characteristics [7, 8]. Significantly larger amounts of graphene can be produced by physical and chemical exfoliation of bulk graphite [9-11], which has been extensively studied in the past, is cheap and scalable [12]. Exfoliated graphite (EG) is usually produced through the thermal treatment of graphite intercalation compounds (GICs) [13, 14]. Many approaches have been developed for the mass production of GICs, as well as the exfoliation of high-quality graphene using GICs [15]. Despite being a promising intercalation compound with its high expansion property, melamine has only been used in two studies. Reinheimer et al. patented the use of thermally expandable graphite intercalation compounds for producing fire-protection seals and their production method [16]. Duan et al., [17] discussed the synthesis of core-shell expandable graphite/melamine-formaldehyde particles and their flame-retardant applications. The transformation mechanism and the expansion of melamine to graphitic- C_3N_4 with the increasing temperature can be seen in somewhere else [18]. Since the thermal expansion of melamine occurs at relatively lower temperatures than graphite, it is thought that the penetrated melamine molecules in the graphite layers may force the expansion of graphene layers with the formation of the $g-C_3N_4$ structure by thermal treatment. To test the hypothesis, we exposed both pristine graphite and a melamine-graphite admixture to thermal treatment. The expansion of graphite layers was investigated by using X-ray diffraction and Raman techniques.

Experimental

The graphite-melamine mixtures were prepared by a simple mixing in solution technique. Graphite powder (Supelco) and melamine (Merck) were mixed in 50 mL water for 6 hours at room temperature. The solution was filtered under vacuum and dried at 105°C for 18h. The collected powders were placed in an alumina boat. The sample-loaded boat put in a stainless-steel reactor and exposed to thermal treatment. The sample definitions and experimental conditions are given in Table 1. Raman spectra were measured on a WITech alpha 300R with 532 nm DPSS laser excitation. A PANalytical Empyrean X-

ray diffractometer with CuK α radiation source was used to determine crystallographic structure of the samples.

Table 1. Sample definitions and experimental conditions

Sample	Material	Experimental Conditions
TTG	Pristine Graphite	650°C - 2h - 5°C/min
TTG2M1	Graphite + Melamine (2:1 w/w)	650°C - 2h - 5°C/min

Results and Discussion

Raman Analysis

Figure 1 shows the Raman spectra of all samples. All Raman spectra were analyzed to determine the peak positions, peak widths, and peak areas, using Lorentzian-peak-fit profiles. Table 2 represents the Raman features of pristine graphite and synthesized samples. As seen in the Figure 1 and Table 2, the typical peaks of the graphite lattice, G band at 1575 cm⁻¹ which arises from the in-plane C-C bond stretching in sp² hybridized carbon systems in the first order region, and 2D band at 2680 cm⁻¹ in the second order region were detected. In addition, a weak disorder band caused by the graphite edges (D band) at approximately 1355 cm⁻¹ was observed for pristine graphite. Compared to pristine graphite the thermal treatment led to a decrease in the peak intensity, and redshift in the peak positions of D, G, and 2D bands for the sample TTG. For the melamine-added sample (TTG2M1), an increase in the peak intensity for the D band, and an decrease in the peak intensity for the G and S1 bands were observed. In addition, redshift in the peak positions to the higher wavenumber can be clearly seen for all bands from Figure 1. D band was strongly influenced by melamine adding; a well-defined symmetric D peak in graphite became broader and asymmetric for the sample TTG2M1. A new relatively strong band at ≈ 1620 cm⁻¹ appeared by the development of the D band. The intensity increase in both bands suggests that the melamine addition introduces a significant number of structural defects into the graphite lattice. Since the shift in the peak positions in Raman spectroscopy related to the length of chemical bonds and symmetry of molecules [19], it is obvious that the possible polymerization of melamine into g-C₃N₄ caused a significant change in the molecular chemistry of graphite layers. The observed redshift in the G and S1 bands with both the thermal treatment and melamine addition can be explained by the expansion of resulting material or improved crystallinity. Due to the hypothesis of this work, the d-spacing of graphite and composite materials was calculated by the XRD analysis.

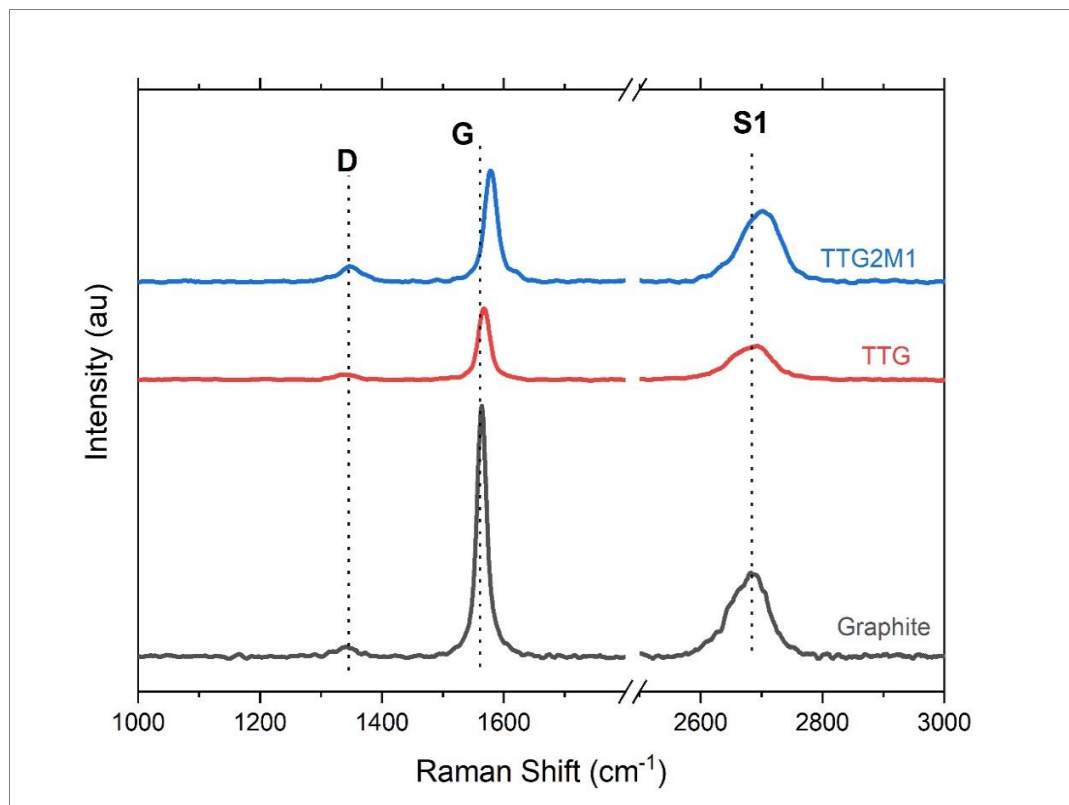


Figure 1. Raman spectra ($1000\text{-}3000\text{ cm}^{-1}$) of the synthesized materials and pristine graphite

As seen in Table 2, clear redshift in the D, G, and 2G bands was calculated for all samples. The FWHM of the G band was calculated as 18.04 to 20.64 and 23.03 for pristine graphite, TTG, and TTG2M1, respectively.

Table 2. Raman features of pristine graphite and synthesized powders

Sample	D Band			G Band			S1 Band		
	Position	FWHM	Area	Position	FWHM	Area	Position	FWHM	Area
Graphite	1340.06	40.93	4665	1563.93	18.04	51770	2680.65	64.25	62658
TTG	1339.37	35.55	2297	1567.72	20.64	17206	2683.91	69.58	27690
TTG2M1	1347.92	44.15	7770	1578.89	23.03	29859	2698.95	65.31	55385

Compared to pristine graphite, only thermal treatment resulted in a 3.79 cm^{-1} redshift, while the addition of melamine and thermal treatment resulted in a 14.96 cm^{-1} redshift in the G band. Similarly, the expanding of the resulting material or improved crystallinity may be responsible for the redshift. Moreover, the melamine loading led to a broadening in the G band (increase in the FWHM), is evidence for the weakened of van der Waals forces between graphite layers [20]. The increasing degree of amorphization with melamine loading and thermal treatment is responsible of the broadening and redshift in G band [21]. As a result, it can be said that the redshift in the graphite peak (G band) and defect peak (D band) usually refers to p-type doping, expanding, and the compressed lattice of material.

The shift in the peak positions is evidence of the change of the chemical bond length of molecules by the thermal treatment and further melamine adding.

XRD Analysis

The pristine, thermally treated pristine, and melamine-loaded graphite samples were analyzed by XRD in the 20° - 35° region with a slow scan rate. As shown in Figure 2 and Table 3 below, the sample TTG had a broader peak at 2θ of 26.33° , in comparison to that of pristine graphite (26.37°) which corresponded to a d-spacing of 3.385 \AA (TTG) and 3.380 \AA (Pristine Graphite). Due to the increasing d-space, it can be said that the spacing between the graphene layers was increased with the thermal treatment. In the case of melamine addition (TTG2M1), the peak positions shifted to higher 2θ degrees due to the decreasing d-spacing. This may be related to the formation of C_3N_4 between the graphene layers. In addition, an increase in the full width of half maximum (FWHM) values which is directly proportional to the crystal size according to Scherrer's formula was observed for the TTW sample.

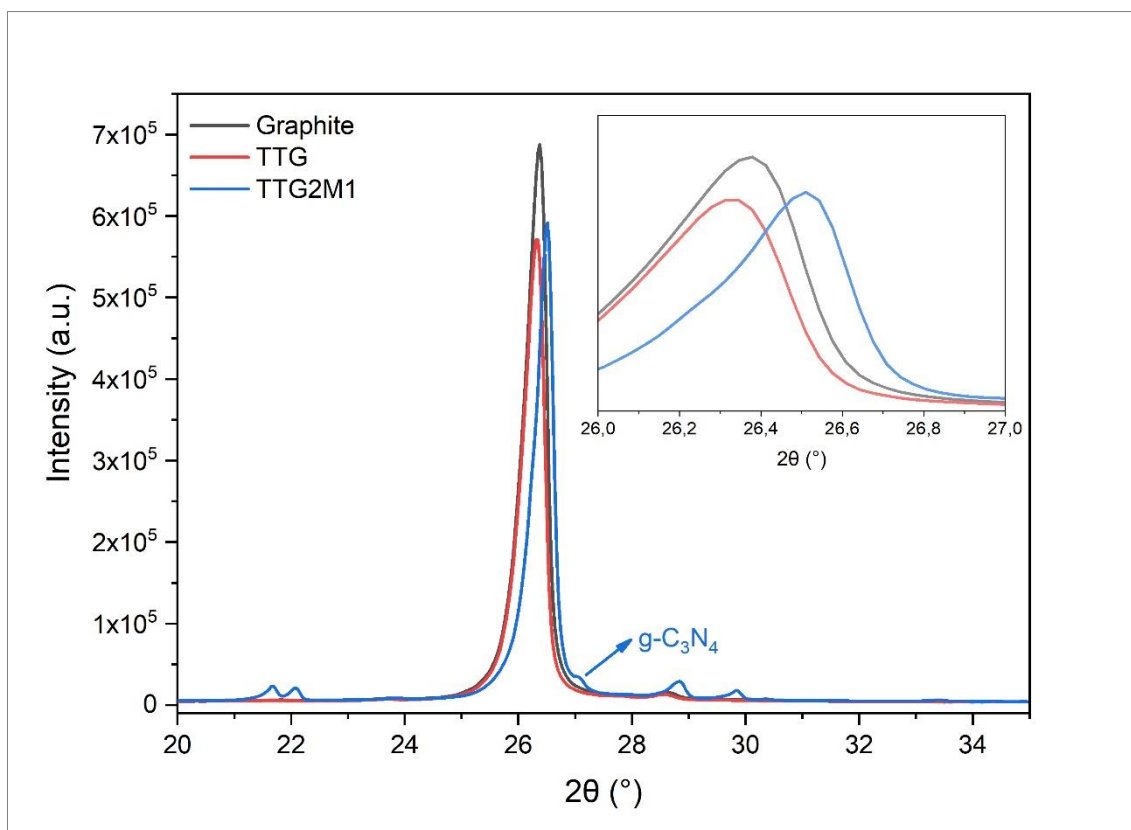
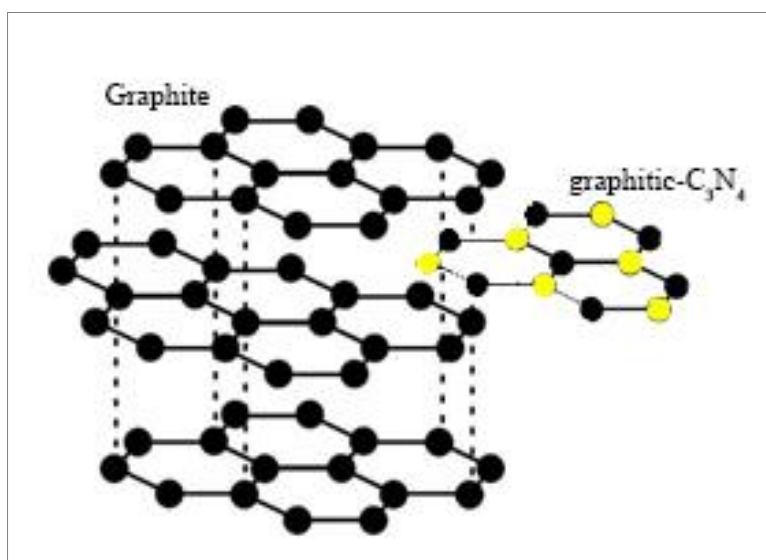


Figure 2. XRD patterns of pristine and modified graphite samples

Figure 3 shows the illustrated possible molecular structure of $g-C_3N_4$ /Graphite. Since the pristine graphite and C_3N_4 have the major peak at same 2θ degrees (≈ 26), and low crystallinity, it is very hard to prove the formation of the C_3N_4 structure by XRD. However, the TTG2M1 samples had some different peaks, which are pointed as C_3N_4 by the library search&match, esp. the peak around 27.1° .

Table 3. Main peak properties of pristine and modified graphite samples

Sample	Pos. [°2 θ]	FWHM Left [°2 θ]	d-spacing [Å]
Graphite	26.3701	0.3572	3.37987
TTG	26.3276	0.3897	3.38523
TTG2M1	26.5047	0.1948	3.36300

Figure 3. Illustration of the possible molecular structure of g-C₃N₄/Graphite composite

Because of its extensive range of applications, including composites and coatings, electronics, energy, membranes, sensors, and more, significant efforts are underway to acquire graphene with specific desired properties. Furthermore, an economically feasible, and scalable amount of graphene can be produced from exfoliated graphite (EG) which is usually produced by the thermal treatment of graphite intercalation compounds (GICs). Skowroński and Krawczyk focused on the electrochemical activity towards hydrogen sorption/desorption capacity of EG synthesized by using NiCl₂ as the intercalation compound [22]. It is reported that the sample exfoliated with NiCl₂, and heat treated at 800°C in air for 25 min showed the highest hydrogen storage capacity [22]. They concluded that this is resulted from the process of secondary exfoliation leading to the formation of porous graphite and simultaneous eruption of the NiCl₂ intercalate the transformation into nickel oxide [22]. Ka and Oh reported the synthesis of expanded graphite with a d-spacing of 0.404 nm from meso carbon micro beads (MCMB) via heat treatment of an oxidized form of MCMB [23]. As reported in this study, the BET surface area of the expanded graphite (21.8 m²/g) is about 10-fold larger than the pristine material, however, it is quite small for an electrode material in capacitor applications [23]. Despite the small surface area, the expanded graphite electrode material has shown a promising capacitor behavior with a charge–discharge coulombic efficiency of >99% up to a working voltage of 3.7 V [23]. Morales et al. [24] reported the synthesis of few-layer graphene by an electrochemical treatment followed by microwave-assisted thermal expansion. Due to the Raman spectra presented in this work, it is reported that the sp² carbon

structure did not change with the selection of the appropriate conditions [24]. An et al. [25] reported the synthesis of spheroidized graphite-derived multi-layered graphene from a battery-grade spheroidized natural graphite powder by using sulfuric acid and hydrogen peroxide as the intercalant and oxidant under microwave irradiation at 800W. It is found that the degree of graphitization calculated from the XRD results is 100% for the spheroidized natural graphite while it is 98.8% and 87.2%-95.3 for flake natural graphite and meso carbon microbead (MCMB), respectively [25]. It is concluded that the selected microwave conditions are inefficient and the selected GIC agents are not effective for the MCMB as a starting material [25]. The importance of the starting material, temperature, and the selection of intercalation species is also reported by Murugan et al. [26]. According to the results given in the brief literature summary presented above, it can be said that the selected experimental parameters in this work are appropriate for the synthesis for the expansion of graphite.

Conclusion

This study reveals the potential of melamine-induced expansion and structural modification in graphite layers, driven by thermal treatment. The observed changes in Raman and XRD analyses underscore the significant impact of melamine on the chemistry and structure of graphene, opening new avenues for advanced material development and applications. Moreover, an expanded form of graphite can be used for hydrogen storage, thermal energy storage, fuel cells, batteries, supercapacitors, sensors, etc.

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Authors Contribution The author read and approved the final manuscript

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An Investigation on Flow Structure and Heat Transfer Characteristics of Confined Impinging Twin Jets

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Research Article

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Abstract

An investigation into the heat transfer performance and flow characteristics of circular twin jets was conducted using both numerical and experimental methods. The jets emanated from the lower surface and were confined to impinge perpendicularly on the upper surface. To simulate the bidimensional impinging twin jet flow field with powerful turbulence and heat transfer, Realizable $k-\epsilon$ and Standard $k-\omega$ turbulence models were employed. Reynolds numbers ranging from 30000 to 50000 were used in both simulations and experiments, with jet-to-jet spacing ranging from 0.5 to 2 and nozzles to target impingement plate spacing in the same range. Sub-atmospheric pressure regions were detected on the impingement surface in experimental measurements for spacing up to 1, whereas numerical results suggested that they could be found at all nozzle to target impingement plate spacings studied. A correlation was discovered between the peaks in coefficients of heat transfer on the target surface and the sub-atmospheric regions in pressure distributions.

Keywords: Twin impinging jet, sub-atmospheric region, turbulence models, pressure coefficient, Nusselt distribution

Sınırlandırılmış Çarpan İkiz Jetlerin Akış Yapısı ve Isı Transferi Karakteristikleri Üzerine Bir İnceleme

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Öz

Sayısal ve deneysel yöntemler kullanılarak dairesel ikiz jetlerin ısı transferi performansı ve akış karakteristikleri üzerine bir araştırma gerçekleştirildi. Jetler alt yüzeyden yayılmış ve üst yüzeye dik olarak çarpmak üzere sınırlandırılmıştır. İki boyutlu çarpan ikiz jet akış alanındaki güçlü türbülans yapılarını ve ısı transferini simüle etmek için Realizable $k-\epsilon$ ve Standard $k-\omega$ türbülans modelleri kullanılmıştır. Hem simülasyonlarda hem de deneylerde 30000 ila 50000 arasında değişen Reynolds sayıları kullanılmış, jetler arası mesafe 0.5 ila 2 arasında değişmiş ve lüleler ile hedef çarpma levhası arası mesafe de aynı aralıkta olmuştur. Deneysel ölçümlerde açıklığın 1'e kadar olduğu durumlar için hedef çarpma yüzeyinde atmosfer altı basınç bölgeleri tespit edilirken, sayısal sonuçlar bunların incelenen tüm lüle hedef levha aralıklarında bulunabileceğini göstermiştir. Hedef yüzeydeki ısı transferi katsayılarındaki tepe noktaları ile basınç dağılımlarındaki atmosfer altı bölgeler arasında bir korelasyon keşfedilmiştir.

Anahtar Kelimeler: İkiz çarpan jet, sub-atmosferik bölge, türbülans modelleri, basınç katsayısı, Nusselt dağılımı

Introduction

The highly attractive rate of local heat and mass transfer performance of single or multi-array impinging jets have made them a popular choice for a wide array of industrial applications. Jet impingement finds applications in a variety of industries, such as glass shaping and tempering, fabric and cardboard drying, airfoil deicing, turbine blade and computer electronics cooling. In the last three decades, the investigation of flow fields and structures as well as heat transfer performance via single or multiple jets impingement has remained an energetic area of research, with both numerical and experimental studies being conducted. While high heat transfer coefficients are offered by impinging single jets in the stagnation zone, the performance of cooling decreases dramatically beyond the impinging zone. In the cooling process carried out with multiple jets, a single jet can be used or multiple jets can be used simultaneously. While the use of a single jet increases the heat transfer in a certain region, the use of multiple jets makes the distribution of heat transfer more homogenous on the surface to be cooled. In consequence, impinging jets are often favoured in arrays in a variety of applications. In such cases, effective temperature reduction heavily relies on the interplay among the jets within the array. There are many studies and applications in the literature that pay attention to the characteristics of flow structure and performance of heat and mass transfer in jet impingement of twin patterns. In most of these studies, the flow is laminar character. Studies on turbulent impinging multi-jets are very few. The studies on this subject are mostly in the form of numerical analyses. In a study they conducted, Barata et al. [1] investigated the turbulent jets impingement of single and twin types with confining plates through a cross flow and observed that both configurations had a similar pattern with significant jet penetration. Chuang et al. [2] utilized a bidimensional (2D) mathematical model to examine compressible and unsteady flow properties of twin-slot jet impingement amid two plates. In their research, Chuang and Nieh [3] utilized the PHOENICS code to explore impinging square twin jets flow's three-dimensional (3D) turbulent structure without cross flow. In their comprehensive literature review, Polat et al. [4] noted that the Standard k- ϵ model with miscellaneous wall functions is inadequate for accurately predicting stagnation heat transfer and suggested that k- ϵ models with low Reynolds number and strong streamline curvature pose a challenge for testing advanced turbulent models in jet impingement flows, pressure gradient, and recirculating zones. In their study, Shi et al. [5] examined the influence of turbulence models, turbulence intensity, Reynolds number (Re), close wall applications, and boundary conditions in a slot jet for heat transfer. The study utilized both the Standard k- ϵ and Reynolds Stress (RSM) models. To simulate turbulent flow and analyze heat transfer performance from confined multi-array slot jets impingement in a 2D environment, Seyedein et al. [6] utilized a mathematical technique. Dianat et al. [7] utilized the Standard k- ϵ turbulence model to foresee the behavior of nonsymmetric and bidimensional impinging turbulent jets. Numerical analysis was carried out by Fernandez et al. [8] to study the turbulence flow behavior of an impinging twin-plane jet perpendicularly on a flat surface. The study employed both Realizable and Standard k- ϵ and Standard k- ω turbulence models. According to

the researchers' conclusion, these models failed to provide an accurate prediction of the flow in the zone of the impact. Miao et al. [9] examined the structure and characteristics of the fluid flow and heat transfer performance of a confined circular jet array orthogonal to a flat plate, at various cross-flow orientations. Distributions of Nusselt number figured out by them overall on the flat plate. In their study, Qui et al. [10] developed a numerical model for a 2D configuration an opposed jet to investigate the flow characteristics and blending performance of opposed laminar jet flows. Attalla and Specht [11] conducted an experimental study on convective heat transfer performance on a flat plate using a multi-jet system. The study concluded that, they observed that the use of a multi-array jet system leads to an increase in both local and mean heat transfer rates compared to a single nozzle. Aldabbagh and Mohamad [12] numerically analyzed the effects of jet to target impingement plate spacing in an impinging laminar square jet array confined with a plate. A numerical study was conducted by Dagtekin and Oztop [13] to investigate the impact of distance from floor to wall, Reynolds number and distance of jet-to-jet for two jets on fluid flow structure, characteristics and heat transfer performance. In the impingement of twin square laminar jets, the performance of heat transfer and also structure of fluid flow were investigated numerically by Aldabbagh and Sezai [14]. According to the obtained outcomes, the flow pattern of impinging twin square jets on a preheated target surface was significantly influenced by the distance between the jets and the target impingement plate, as reported by the study conducted by them. The interplay between the boundary layer of the wall jet and the free shear layer was studied experimentally by Ho and Hsiao [15] using a specific technique. By utilizing an experimental approach, Siclari et al. [16] studied the formation of upwash and stagnation lines in two impinging jets. Tanaka [17] observed a unique characteristic in the twin jet's 2D parallel flow, which was the formation of a region of sub-atmospheric pressure amid the jets due to the turbulent fluid flow entrainment. Abdel-Fattah [18] reported that a region of sub-atmospheric pressure appeared on the impingement surface in the impinging twin round jet flow, and this effect decreased as the nozzle to target impingement plate spacing increased. Mikhail et al. [19] explained that as the jet-to-jet spacing decreases, the average Nusselt number of a twin jet system increases. Barata [20] conducted laser doppler measurements to investigate structures, fields and characteristics of the flow generated by impinging twin jets on a ground plane. The results of the study revealed the presence of a complicated 3D scarf vortex that forms round about the impinging jets. An experimental investigation conducted by Dong et al. [21] on the heat transfer performance and wall pressure features of a vertical laminar twin air jet impinging on a horizontal flat plate. Their study aimed to interpret the impact of the twin jets on heat transfer and pressure distribution by examining their interactions with the plate's surface. An experimental investigation was carried out by Saad et al. [22] on the flow structure and heat transfer performance of impinging confined single and multi-slot jet flows. They stated that multiple jets exhibit single jet characteristics at values of 1.5 and higher than the nozzle spacing ratio. Özmen [23] experimentally investigated the flow fields and structures for a confined twin air jet impinging on a flat surface. He

determined that sub-ambient pressure regions are formed on both the impingement and confining surface and that the pressure distributions on the surfaces are influenced by the nozzle to target impingement plate spacing and the distance of nozzle to nozzle. Buchlin [24], in his study of impinging array jet flow, stated that nozzle to target impingement plate and nozzle to nozzle distances have a direct effect on jet characteristics. Polat et al. [25] carried out a comprehensive literature survey on heat transfer in impinging jet flows, including both experimental and numerical studies. They pointed out that low Reynolds number k - ϵ turbulence models, which are among the turbulence models used in numerical studies, predict the heat transfer at the stagnation point more accurately than the Standard k - ϵ turbulence model. Özmen and İpek [26] experimentally and numerically investigated the flow fields and structures furthermore heat transfer performance of jet flow generated by multiple slot jets impinging on a target flat surface. They highlighted that there is a significant correlation between the sub-ambient pressure regions formed on the impingement surface and the secondary peaks in the Nusselt distributions. Özmen and Baydar [27] numerically investigated the flow fields and structure furthermore heat transfer performance of confined jet array flow impinging on a surface. They stated that both pressure distributions and Nusselt distributions throughout the target impingement surface are significantly influenced by the nozzle to target impingement plate spacing. Afroz and Sharif [28] numerically analyzed the cooling of a constant temperature surface by an inclined impinging twin slot jet using different jet-target impingement plate distances, Reynolds numbers and turbulence models. Yousefi-Lafouraki et al. [29] numerically modelled and investigated effects of the flow and heat transfer in their study where both the impingement plate and the confining plate are inclined. The study carried out at low inclination angles showed that the mean Nusselt number increases with increasing inclination angle. Al-Rmah and Mohamad [30] with six-in-line jet outlets different channel heights and nozzles in a double-pass channel effects of widths on heat transfer and flow structure Reynolds number numerically in the range of 100 to 400 analyzed. Guongeng et al. [31] experimentally observed the effects of different values of jet-cross-flow velocity ratios and different channel heights on the local and mean. Nusselt numbers for a flow region subjected to cross-flow with a series of sequential jets. Lam and Prakash [32] investigated two-dimensional and numerical refrigeration of split heat sources by a pair of air jets for duct heights and velocity ratios of the jets; they analyzed in detail the effects of the relevant parameters on the local and mean Nusselt number variation and entropy production and determined the optimum velocity ratios. Paulraj et al. [33] numerically investigated the effects of duct height and distance between blocks on convection heat transfer in cooling of discrete blocks with constant surface temperature by slot jets in the range of Reynolds number between 30 and 300, focusing on the velocity profiles around the blocks and the variation of local and mean Nusselt numbers on the surfaces of the blocks. Kaya [34] numerically investigated the effect of surface shape (flat, zigzag, rectangular, trapezoidal) on convection heat transfer from a heated target impingement plate cooled by a pair of circular jets and determined that convection heat transfer characteristics are significantly influenced by

surface shape. Martinez-Filgueira et al. [35] investigated the effects of the fluid exiting from different nozzles on the wall shear stress and heat transfer in the cooling process performed with multiple impinging jets; they compared the effects of different turbulence models on the results. Demircan and Türkoğlu [36], numerically investigated the effects of oscillation characteristics on the flow structure and heat transfer performance in an impinging slot jet and stated that jet oscillation has no influence on the stagnation Nusselt number for $H/W < 1.5$. Bölek and Bayraktar [37] numerically carried out on the flow structure and heat transfer performance of a jet impinging on different types of impact surfaces. Çalışır et al. [38] numerically examined the flow structures of a series of circular impinging air jets on triangular and square ribbed surfaces. Several investigations [2, 39-44] on impinging single and twin jet flows have reported satisfactory consistency between numerical predictions and experimental results. The flow field resulting from jet impingement on a target impingement plate surface, as well as the wall jet flow developed downstream between twin jets, are highly complex phenomena. This study aims to investigate the flow fields of confined impinging twin jets employing both experimental and numerical techniques. In this current study, the influence of multifarious jet flow specifications, such as spacings of jet-to-jet and nozzle to target impingement plate, on the flow features of impinging twin jets confined with plate were experimentally and numerically examined. The examined flow parameters included pressure distribution of surface, Nusselt distribution, turbulence intensity and axial mean velocity. The experiments were conducted at Reynolds numbers of 30000, 40000, and 50000, while the spacings of nozzle to target impingement plate were set to 0.5, 1, and 2, and the distance between jets were set to 0.5, 1, and 2 as well. The major objective of this investigation is to evaluate the effectiveness of assorted turbulence models in forecasting the heat transfer performance and flow features of confined impinging twin-jets configurations by contrasting them with the experimental results obtained in the present study. The second goal of the study is to establish a connection between the flow characteristics of the confined impinging twin jets and the corresponding heat transfer distributions. It is anticipated that the results and outcomes of this study will provide valuable data for further investigations in this field.

Materials and Methods

Numerical Study

Mathematical Model

In this study, a steady state, turbulent and Newtonian air flow with bank on temperature fluid features was assumed. To obtain a mathematical solution for the mean flow and thermal fields, it is required to solve the Reynolds Average Navier-Stokes (RANS) equations and the time-averaged energy equations. Below is the form of these equations, written for 2D incompressible flow in cylindrical coordinates with the continuity equation included, mass continuity:

$$\frac{\partial}{\partial z}(\rho u) + \frac{1}{r} \frac{\partial}{\partial r}(r \rho v) = 0 \tag{1}$$

z-momentum

$$\frac{\partial}{\partial z}(\rho u u) + \frac{1}{r} \frac{\partial}{\partial r}(r \rho v u) = -\frac{\partial p}{\partial z} + \frac{\partial}{\partial z} \left(\mu_{eff} \frac{\partial u}{\partial z} \right) + \frac{1}{r} \frac{\partial}{\partial r} \left(r \mu_{eff} \frac{\partial u}{\partial r} \right) + S^u \tag{2}$$

r-momentum:

$$\frac{\partial}{\partial z}(\rho u v) + \frac{1}{r} \frac{\partial}{\partial r}(r \rho v v) = -\frac{\partial p}{\partial r} + \frac{\partial}{\partial z} \left(\mu_{eff} \frac{\partial v}{\partial z} \right) + \frac{1}{r} \frac{\partial}{\partial r} \left(r \mu_{eff} \frac{\partial v}{\partial r} \right) + S^v \tag{3}$$

energy:

$$\rho C_p \left(u \frac{\partial T}{\partial z} + v \frac{\partial T}{\partial r} \right) = k \left[\left(\frac{\partial^2 T}{\partial z^2} \right) + \left(\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial T}{\partial r} \right) \right) \right] + \mu \Phi \tag{4}$$

The origin terms (S^u and S^v) and the viscous loss function (Φ) in the equations can be expressed by the following formulas.

$$S^u = \frac{\partial}{\partial z} \left(\mu_{eff} \frac{\partial u}{\partial z} \right) + \frac{1}{r} \frac{\partial}{\partial r} \left(\mu_{eff} r \frac{\partial v}{\partial z} \right) \tag{5}$$

$$S^v = \frac{\partial}{\partial z} \left(\mu_{eff} \frac{\partial u}{\partial r} \right) + \frac{1}{r} \frac{\partial}{\partial r} \left(\mu_{eff} r \frac{\partial v}{\partial r} \right) - 2 \mu_{eff} \frac{v}{r^2} \tag{6}$$

$$\Phi = \left\{ 2 \left[\left(\frac{\partial v}{\partial r} \right)^2 + \left(\frac{v}{r} \right)^2 + \left(\frac{\partial u}{\partial z} \right)^2 \right] + \left(\frac{\partial v}{\partial z} + \frac{\partial u}{\partial r} \right)^2 - \frac{2}{3} (\nabla \cdot V)^2 \right\} \tag{7}$$

Mathematical solutions were performed using both the Realizable k-ε and Standard k-ω turbulence models. Two equation turbulence models utilize the Boussinesq close resemblance to establish a relationship between the stresses of Reynolds and the average velocity gradients. The Realizable k-ε model attempts to address some of the limitations of traditional k-ε models by incorporating the physical nature of turbulent flows into the calculation of normal stress, thereby reducing some of the mathematical constraints. The Realizable k-ε model calculates the turbulent kinetic energy [k (m²/s²)] and rate of dissipation [ε (m²/s³)] using the following equations:

turbulence kinetic energy (k):

$$\frac{\partial}{\partial z}(\rho u k) + \frac{1}{r} \frac{\partial}{\partial r}(r \rho v k) = \frac{\partial}{\partial z} \left(\Gamma_k \frac{\partial k}{\partial z} \right) + \frac{1}{r} \frac{\partial}{\partial r} \left(r \Gamma_k \frac{\partial k}{\partial r} \right) + S^k \tag{8}$$

turbulence dissipation rate (ε):

$$\frac{\partial}{\partial z}(\rho u \varepsilon) + \frac{1}{r} \frac{\partial}{\partial r}(r \rho v \varepsilon) = \frac{\partial}{\partial z} \left(\Gamma_\varepsilon \frac{\partial \varepsilon}{\partial z} \right) + \frac{1}{r} \frac{\partial}{\partial r} \left(r \Gamma_\varepsilon \frac{\partial \varepsilon}{\partial r} \right) + S^\varepsilon \tag{9}$$

In the foregoing equations, the radial (r) and axial (z) velocity vector elements are represented as u and v , fluid density symbolize with ρ , and the effective viscosity is μ_{eff} for momentum transport given as below

$$\mu_{eff} = \mu + \mu_t \tag{10}$$

The molecular viscosity, μ , and the "turbulent" viscosity, μ_t , are related through the following expression:

$$\mu_t = C_\mu \rho k^2 / \varepsilon \tag{11}$$

The exchange coefficients that account for the effects of turbulence on the transport of turbulent kinetic energy [k] (m^2/s^2) and rate of dissipation (ε) are expressed by the following equations

$$\Gamma_k = \mu + \frac{\mu_t}{\sigma_k} \tag{12}$$

$$\Gamma_\varepsilon = \mu + \frac{\mu_t}{\sigma_\varepsilon} \tag{13}$$

Where σ_k and σ_ε are the turbulent Prandtl/Schmidt numbers. S^k and S^ε perform source terms for k and ε . The following expressions provide them

$$S^k = \mu_t \left[2 \left\{ \left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial r} \right)^2 + \left(\frac{v}{r} \right)^2 \right\} + \left\{ \frac{\partial v}{\partial z} + \frac{\partial u}{\partial r} \right\}^2 \right] - \rho \varepsilon \tag{14}$$

$$S^\varepsilon = C_1 \frac{\varepsilon}{k} \mu_t \left[2 \left\{ \left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial r} \right)^2 + \left(\frac{v}{r} \right)^2 \right\} + \left\{ \frac{\partial v}{\partial z} + \frac{\partial u}{\partial r} \right\}^2 \right] - C_2 \rho \frac{\varepsilon^2}{k} \tag{15}$$

Constant are employed with standard values: $C_1=1.44$, $C_2=1.9$, $C_\mu = 0.09$, $\sigma_k = 1.0$, $\sigma_\varepsilon = 1.2$. The Standard $k-\omega$ model is a turbulence model that utilizes transport equations for turbulent kinetic energy (k) and rate of specific dissipation [$\omega=\varepsilon/k$] ($1/s$). The transport equations for k and ω are given as follows:

$$\frac{\partial}{\partial z}(\rho u k) + \frac{1}{r} \frac{\partial}{\partial r}(r \rho v k) = \frac{\partial}{\partial z} \left(\Gamma_k \frac{\partial k}{\partial z} \right) + \frac{1}{r} \frac{\partial}{\partial r} \left(r \Gamma_k \frac{\partial k}{\partial r} \right) + S^k \tag{16}$$

specific dissipation rate:

$$\frac{\partial}{\partial z}(\rho u \omega) + \frac{1}{r} \frac{\partial}{\partial r}(r \rho v \omega) = \frac{\partial}{\partial z} \left(\Gamma_\omega \frac{\partial \omega}{\partial z} \right) + \frac{1}{r} \frac{\partial}{\partial r} \left(r \Gamma_\omega \frac{\partial \omega}{\partial r} \right) + S^\omega \tag{17}$$

The turbulent viscosity for this model is defined by

$$\mu_t = \frac{\rho k}{\omega} \tag{18}$$

The exchange coefficients that affect the equations for k and ω in this model can be expressed as follows;

$$\Gamma_k = \mu + \frac{\mu_t}{\sigma_k} \tag{19}$$

$$\Gamma_\omega = \mu + \frac{\mu_t}{\sigma_\omega} \tag{20}$$

For this situation, the turbulent Prandtl/Schmidt numbers are $\sigma_k = \sigma_\omega = 2.0$. S^k and S^ω act as source terms for k and ω . Following expressions are providing them

$$S^k = \mu_t \left[2 \left\{ \left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial r} \right)^2 + \left(\frac{v}{r} \right)^2 \right\} + \left\{ \frac{\partial v}{\partial z} + \frac{\partial u}{\partial r} \right\}^2 \right] - \beta^* \rho k \omega \tag{21}$$

$$S^\omega = \frac{\omega}{k} \mu_t \left[\left\{ \left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial r} \right)^2 + \left(\frac{v}{r} \right)^2 \right\} + \left\{ \frac{\partial v}{\partial z} + \frac{\partial u}{\partial r} \right\}^2 \right] - \beta \rho \omega^2 \tag{22}$$

Constant are employed with standard values: $\beta^* = 0.09$ and $\beta = 0.072$.

Flow Structure and Boundary Conditions

Figure 1 illustrates a delineative view of the computational domain and twin jets configuration, providing details on the major dimensions, prescribed boundary conditions and the flow field. Two dominant main jet flows are expelled upward from nozzles with a diameter of $D=25$ mm and a velocity of U_0 , which in turn entrain the surrounding flow into the computational domain. At a distance of H from the nozzles, the twin jets will collide perpendicularly with a plate, causing the fluid flow direction to expand into the surrounding area. The distance between the two jet nozzles is represented by L . Impingement twin jet flows may be separated into five different flow regions: (1) the free jet, (2) combined wall jet, (3) jet impingement, (4) lower wall jet and (5) downwash fountain regions. At a distance far from the target impingement plate, referred to as the free jet region, the flow is primarily affected by axial velocity and relatively unaffected by impingement. In the unified wall jet zone, the ascendant velocity component exhibits a radial pattern, causing the boundary layer to thicken as it extends outward. Notably, the impingement zone of the twin jets, situated between free and wall jet zones, experiences significant alterations in the flow direction. The target impingement plate has two distinct stagnation points, both of which are located along the axis of the nozzles. At the midpoint between the twin jets, the secondary stagnation point coincides with the primary stagnation points along the direction of the nozzle axes. This center point location is where the flow is relatively stagnant, and the primary stagnation points align with the nozzle axes. Near the midpoint of the two jets, there exists a region known as the lower wall jet region. The region of downwash fountain is formed due to the encounter of the two individual jets as they impinge on the target surface.

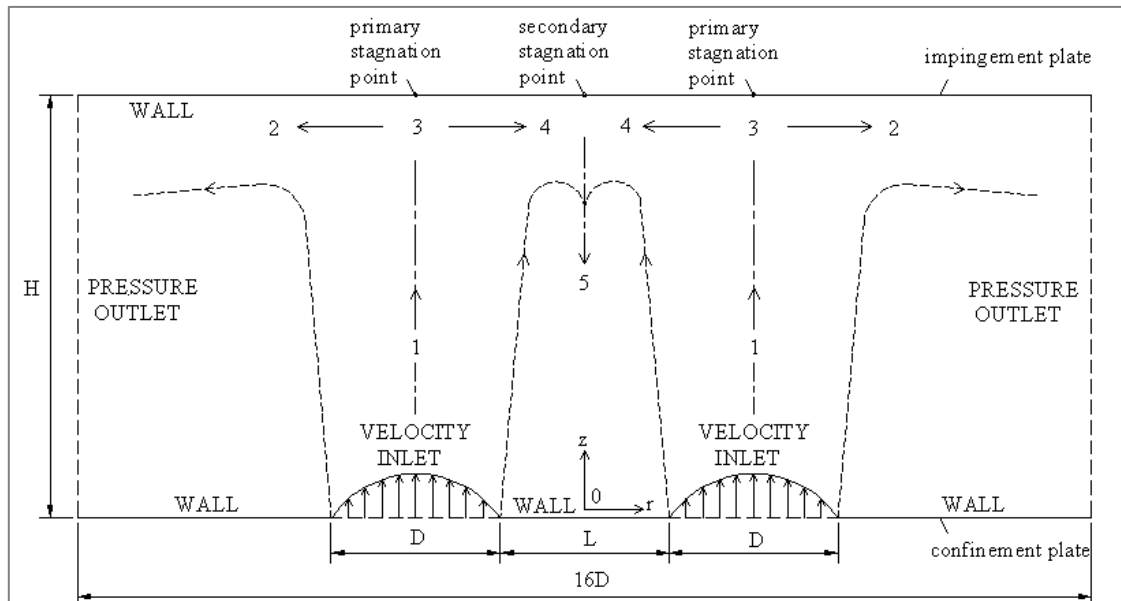


Figure 1. An illustration depicting the computational domain and twin jet configuration

The x-directional computational domain is approximately 16 times the nozzle diameter ($16D$) in length. To preserve both geometric and physical symmetry, numerical solution was performed only for the flow structure and field within the half domain. The computational domain was bounded by several specified boundary conditions. The target impingement plate was considered to have a constant temperature of $T_w = 323$ K and an isothermal wall condition was applied. Assuming that the confinement plate temperature was equal to the jet exit temperature, T_j was kept constant at 300 K. No-slip conditions were enforced on all walls, while the average velocity and turbulence profiles recorded at the outlet of the nozzles were employed as the velocity input parameters of the calculation domain. At the outlet planes, pressure outlet boundary conditions were deemed.

Numerical Solution Process

An implicit formulation with a segregated solver was used for solving the governing equations, employing a finite volume discretization method through the FLUENT 6.3.26 software. Central difference scheme used for approximating diffusion terms in the equations for the 2D simulations while second-order upwinding was employed for the convective terms. To establish a connection between the pressure and velocity fields, the SIMPLEC string was employed, which includes a face flux correction using modified equations. By utilizing a modified correction equation, the convergence rate is increased during the SIMPLEC procedure. To solve the pressure field, a conventional discretization method was employed. Other variables such as turbulent kinetic energy, momentum, rate of dissipation in turbulence and energy equation were solved using a second order discretization technique. High degree of accuracy particularly for complex flows involving separation is presenting by second order discretization scheme. One of the wall functions is enhancement wall treatment was employed to ensure reasonably accurate predictions. To ensure convergence, a residuals convergence criterion of 1×10^{-6} was applied to all

dependent variables and the sensitivity of grid distributions and numbers were tested for each case to procure the attainment of results independency from grid structure. Figure 2 displays the influence of the mesh density. The mesh was fine-tuned for every L/D and H/D value until negligible differences were observed and a finer computational grid with about 6000 cells in the whole computational domain was considered adequate. The estimation for the total discretization uncertainty was below 5%.

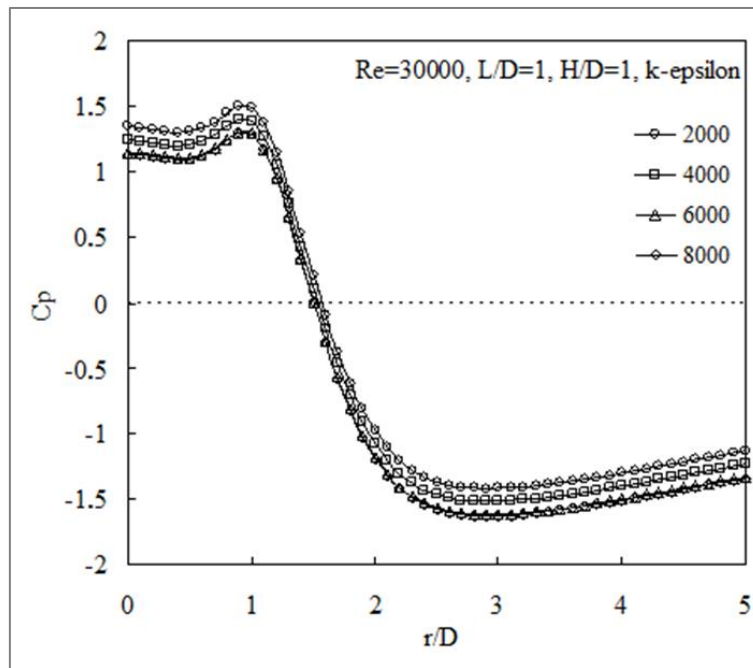


Figure 2. Influence of the mesh density

Experimental Study

The experimental apparatus schematized in Figure 3 and used for flow visualization and measurements consisted of a TE.88/3961 serial number system from Plint and Partners Ltd. The system was equipped with sensors to measure axial mean velocity, surface pressure and turbulence. Twin nozzles mounted vertically to a target impingement plate and a visualization system was employed to represent the flow of air exiting. The air was then directed to impinge on a flat plate mounted vertically to the jet axes in several distances from the confinement plate. The regulated supply air via a valve and was provided by a radial blower located under the main plate. To achieve a consistent flow towards the nozzles, a gauze screen was installed in the plenum chamber where the fan was connected. The nozzles had a diameter of 25 mm and a length of 50 mm, with slightly rounded inlets. Constructed from plexiglass, the impingement and confinement plates had a thickness of 5 mm and a diameter of 400 mm.

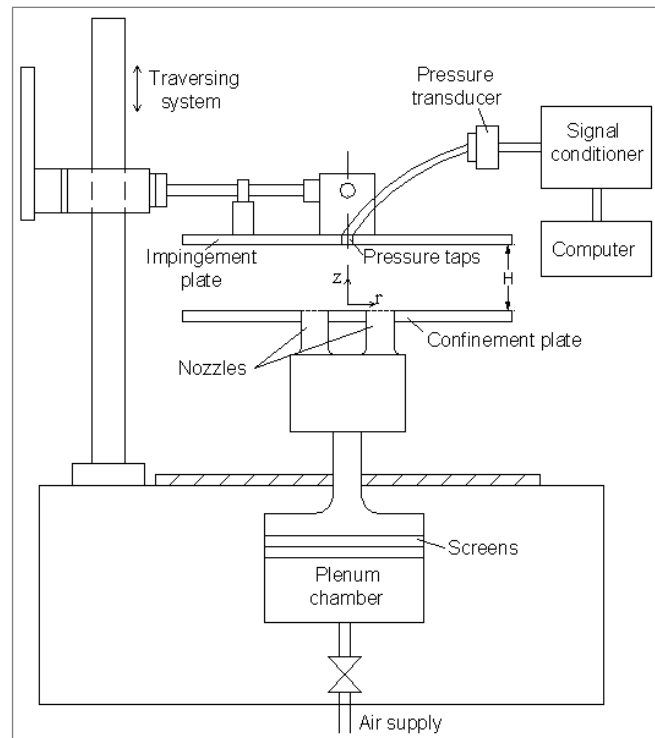


Figure 3. Schematic of the experimental apparatus

The smoke-wire technique [45, 46] was utilized to help visualize the flow structure and field. A stainless-steel wire with a diameter of 0.2 mm is placed opposite the nozzle outlet. Paraffin oil was used to coating the smoke wire and then DC current was applied to heat it by the Joule effect. The visualized flow pattern was successively photographed with a camcorder. Since this technique is also limited to low Reynolds numbers, flow visualization was executed at $Re=4800$. Visualization of flow behavior is very difficult at high Reynolds numbers. The hot wire anemometer TSI IFA-100 was used for one dimensional measurement of average velocity and turbulence in combination with a TSI 1220-20 hot film single probe. The data acquisition system interfaced with the hot-wire anemometer was used to collect 4096 samples at a rate of 1024 samples per second. A computer was used for data analysis. During the acquisition process, a filter with a cutoff frequency of 300 Hz was utilized to apply a low-pass effect on the data. At a Reynolds number of 30000 and $L/D=1$ and $H/D=1$, measurements of average velocity and turbulence were conducted. The tests were carried out at jet outlet velocities of up to 30 m/s, which ensured that compressibility effects remained neglect able. The Reynolds number was dependent on the diameter (D) of nozzle and the measured outlet velocity (U_o) of nozzle, which was determined using hot-wire anemometry. Turbulence intensity was kept below 1.5% even when testing jet velocities of 18, 24, and 30 m/s. A traversing unit, which had an accuracy of 0.1 mm, was employed to move the target impingement plate with respect to the jets in order to acquire pressure distributions on the jet impingement side of target surface. To measure surface pressure, a Setra-239 pressure transducer was utilized. Pressure sensors were installed on both the impinging and confining surfaces. The taps were then connected to a scanivalve through PVC tubing with an inner diameter of 1.6 mm and

a length of 600 mm. Sampling at each point was performed for 16 seconds. The signals captured by the transducer were digitally sampled at a rate of 1000 Hz, while being low pass filtered at 300 Hz. Estimates of measurement uncertainty indicated that axial velocity measurements were less than $\pm 3\%$ uncertain, while turbulence velocity measurements in the vertical direction were uncertain by $\pm 4\%$. The experimental outcomes were repeatable within the estimated uncertainty range of $\pm 2\%$ for the pressure measurements conducted on the target impingement plate and confinement surfaces.

Results and Discussions

In order to examine the confined impinging twin jets, numerical and experimental investigations were conducted at Reynolds numbers between 30000-50000, spacings of jet-to-jet (L/D) ranging from 0.5-2, and spacings of nozzle to target impingement plate (H/D) ranging from 0.5-2. Two turbulence models were utilized in the simulations, Standard $k-\omega$ and Realizable $k-\epsilon$, respectively.

Flow Structure

Figure 4 displays flow field images obtained using two turbulence models, while Figure 5 shows flow visualization photographs for H/D values of 1 and 2 at $L/D=1$. Numerical streamline images are obtained at $Re=30000$. Figure 4a shows the streamlines of the calculated velocity fields at $H/D=1$ and $L/D=1$ with Realizable $k-\epsilon$ turbulence model. The impinging jets result in the formation of two wall jets that spread radially at the impingement surface. As a result of the collision between the two jets, a downwash fountain flow is formed between them. Upon exiting the nozzle, each jet creates a negative pressure, which draws fluid from the surroundings and generates a vortex at the periphery of the jet. The peripheral vortices are then compressed between the jets and the downwash fountain flow. Streamlines calculated with Standard $k-\omega$ turbulence model exhibit an alike character with the Realizable $k-\epsilon$ model (Figure 4b). The photograph obtained from flow visualization study performed at $Re=4800$, $H/D=1$ and $L/D=1$ is shown in Figure 4c.

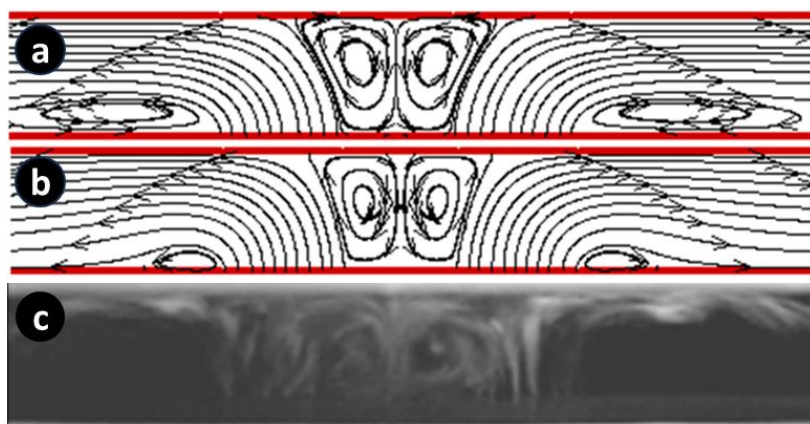


Figure 4. Visuals of the $H/D=1$ and $L/D=1$ confined impinging twin jet configuration. a) Streamline pattern derived using the Realizable $k-\epsilon$ turbulence model for $Re=30000$, b) Streamline pattern derived using the Standard $k-\omega$ turbulence model for $Re=30000$, c) Flow visualization image obtained with smoke-wire technique at $Re=4800$

Despite the difficulty in visualizing flow behavior at high Reynolds numbers, the presence of two counter rotating vortices between the nozzles is clearly evident. The downwash fountain flow interacts with the nozzle mainstream to produce low-pressure recirculation zones.

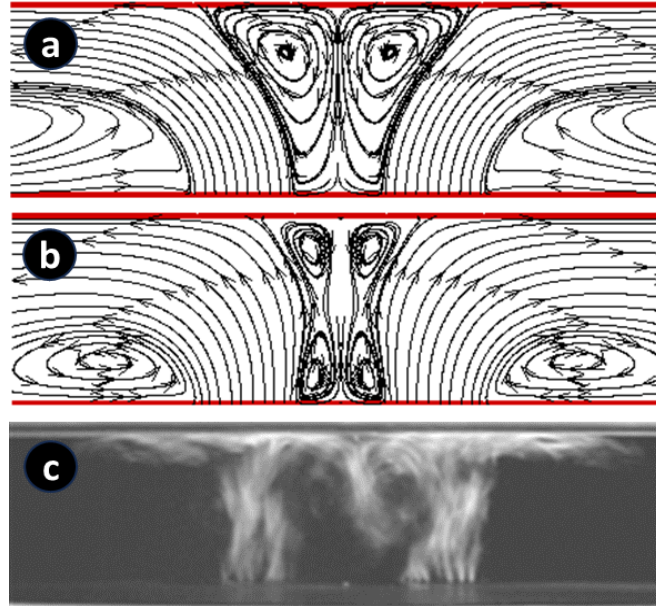


Figure 5. Visuals of the $H/D=2$ and $L/D=1$ confined impinging twin jet configuration. a). Streamline pattern derived using the Realizable $k-\epsilon$ turbulence model for $Re=30000$, b). Streamline pattern derived using the Standard $k-\omega$ turbulence model for $Re=30000$, c). Flow visualization image obtained with smoke-wire technique at $Re=4800$

Streamline plots are given at $H/D=2$ and $L/D=1$ for Realizable $k-\epsilon$ and Standard $k-\omega$ turbulence models in Figures 5a and 5b respectively. The size of the vortices is affected by the H/D ratio. The effect of the confinement plate on the counter rotating vortices close the target impingement plate is less pronounced, as shown in Figure 5c. For lowly spacings of nozzle to target impingement plate, the thickening wall jet pushes the peripheral vortex around each jet towards the confinement plate. The streamlines exhibit a toroidal recirculation zone, which increases in size and distance from the jet axis as H/D increases. The flow images obtained through numerical solutions match well with the flow visualizations captured in photographs. Calculation and measurement of axial velocity profiles and turbulence intensity behavior were conducted throughout the center lines of both jets. The distributions obtained for various nozzle-target impingement plate spacings at Reynolds number of 30000 and L/D ratio of 1 are displayed in Figures 6a and 6b. The turbulence intensity and axial velocity profiles have been normalized with nozzle exit velocity, U_0 and distancing of nozzle to target impingement plate, H , respectively. The results presented are for a single jet as the turbulence intensity and axial velocity profiles for both jets are similar. Figure 6a displays the measured and calculated axial velocity profiles throughout the center line of jet for $Re = 30000$ and $L/D=1$. The flow is decelerated and deflected due to the target impingement plate. The mean velocity in the axial direction decreases quickly after leaving the nozzle. As the distance between nozzle and target impingement plate increases, the effect of the impingement surface on the jet

decreases. The numerical results match the experimental data. The turbulence intensity changes throughout the jet centerline for the same conditions are demonstrated in Figure 6b. As the jet approaches the impingement surface, turbulence levels increase along the centerline. After the flow becomes fully developed, the turbulence intensity close the plate drops rapidly. Experimental data for $H/D=1$ shows higher turbulence intensity than the computed results for the same spacing. The observations made in Figures 4 and 5 are in agreement with these findings.

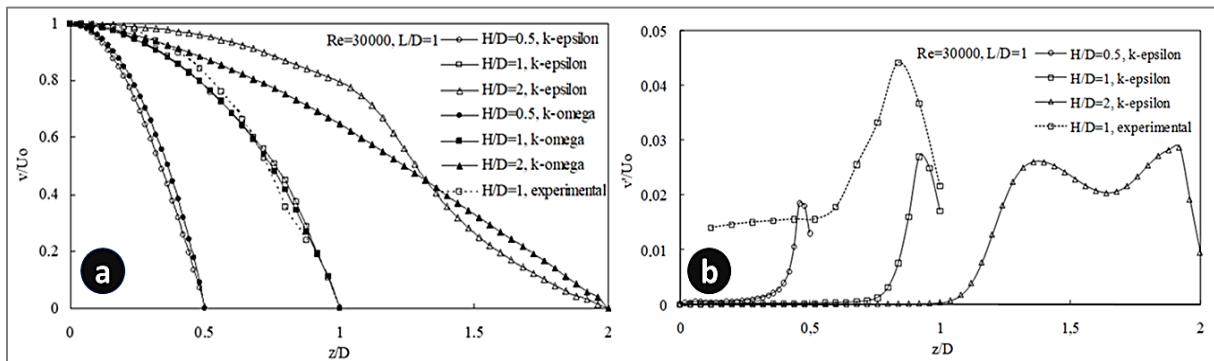


Figure 6. Axial velocity behavior on the jet midline at $Re=30000$ with $L/D=1$. a) average velocity, b) turbulence intensity

Figure 7a and 7b show the impact of nozzle to target impingement plate spacing (H/D) on local pressure distributions at $L/D=1$ and $Re=30000$, as calculated by the Realizable $k-\epsilon$ and Standard $k-\omega$ turbulence models respectively. The pressure distribution along the section between the center point of the jets and one edge of the plates is depicted in the plots. The plots reveal that region of sub-atmospheric pressure exist on the target impingement plate for all spacings of nozzle to target impingement plate examined. The secondary stagnation points, which indicate the midpoint between two jets, occur at $r/D=0$. Local pressure starts to slightly decrease from the secondary stagnation point for $H/D=0.5$ as the radial distance (r/D) increases, reaching a minimum value at $r/D \sim 0.7$, beyond which it starts to decrease again until it reaches the region of sub-atmospheric pressure where it hits a negative minimum value, and then increases towards the atmospheric value. As the distance between the nozzle and target impingement plate increases, the velocity of the fluid decreases as a result of the jet spreading out. Consequently, the point at which the pressure becomes sub-ambient shifts towards a bigger radial distance. As the ratio of H/D increases, the intensity of the sub-ambient region weakens. Additionally, the pressure gradient within this area alternates between negative and positive values (Figure 7a). As was discovered in Obot and Trabold's [47] study of impinging air jets, the flow separates from the surface due to the positive pressure gradient. As the H/D ratio increases, the maximum values at the primary stagnation points shift towards larger radial distances and decrease in magnitude. For instance, for $H/D=1$, the maximum occurs at $r/D \sim 0.9$, while for $H/D=2$, it occurs at $r/D \sim 1.45$. Jet spreading, which results in a decrease in kinetic energy at the jet center, is the cause of this effect as reported by Abdel-Fattah [18]. At $H/D=2$, the minimum values close the secondary stagnation point are no longer present. Figure 7b depicts that the local pressure distributions obtained with the Realizable $k-\epsilon$ model exhibit similar behavior to those

acquired with the Standard $k-\omega$ model for the similar parameters. However, the pressure coefficient values obtained with the Standard $k-\omega$ model are higher.

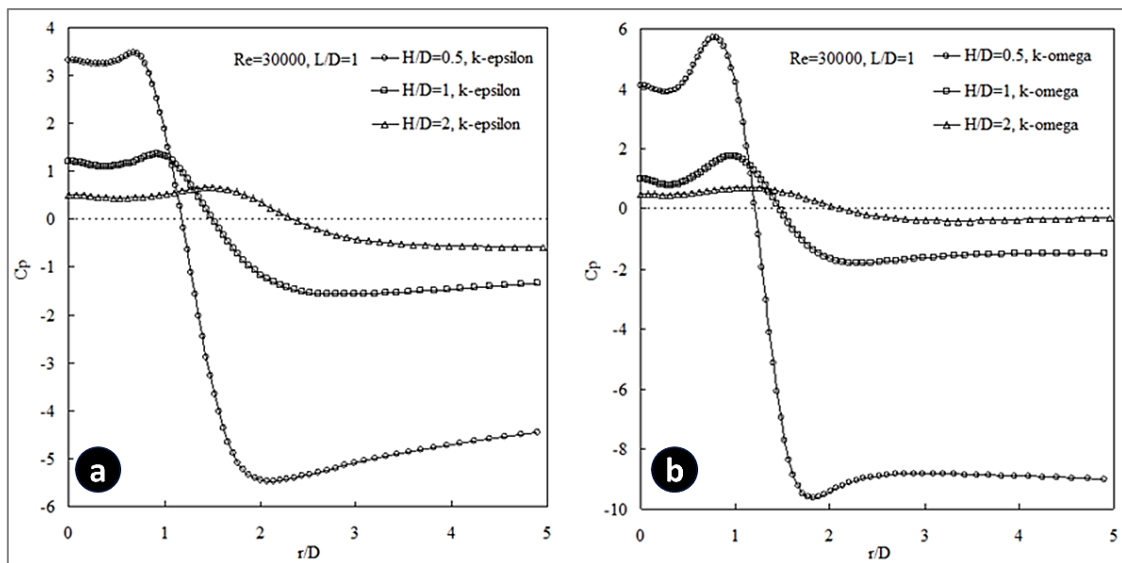


Figure 7. The relationship between nozzle to target impingement plate spacing and pressure distributions for $Re=30000$ at $L/D=1$. a) Realizable $k-\epsilon$ turbulence model b) Standard $k-\omega$ turbulence model

The Realizable $k-\epsilon$ turbulence model was utilized to investigate the effect of distance between two jets (L/D) on the local pressure distributions on the target impingement surface at $Re=30000$ and $H/D=1$, as shown in Figure 8. The figure illustrates that as increases on the spacing of jets, shifting the primary stagnation point to a larger radial distance. This is because the combination of the flow from the two jets occurs later with increasing L/D , resulting in a decrease in flow intensity [18].

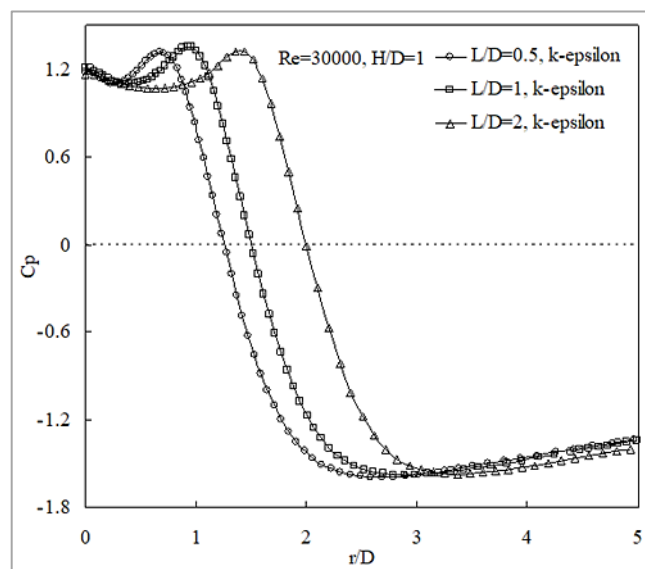


Figure 8. The relationship between jet-to-jet spacing and pressure distributions computed with the Realizable $k-\epsilon$ turbulence model for $Re=30000$ at $H/D=1$

On the target impingement plate, the surface pressure distributions are significantly impressed by the interplay of the two air jets. In other words, the figures show that the pressure coefficients on the

impingement surface are not affected by the Reynolds number, but are mightily dependent on the nozzle to target impingement plate spacings. The impingement surface exhibits a decrease in pressure as the flow accelerates, while the points of maximum pressure align with the stagnation points where the velocity is zero. This behavior is in line with the principles of global continuity. The experimental measurements indicate the existence of a region of sub-atmospheric pressure on the target impingement plate surface for nozzle to target impingement plate spacing up to 1, whereas numerical results reveal its presence for all nozzle to target impingement plate spacings studied. The deductive power of the sub-ambient zones increases as the nozzle to target impingement plate spacing decreases, resulting in a more pronounced effect. The numerically obtained pressure coefficients at the stagnating points are bigger than the experimental results measured at the same points for $H/D=0.5$ and 1 (Figures 9a and b). But for $H/D=2$, experimentally gathered pressure coefficients at the stagnation points are higher than the numerical results (Figure 9c). Compared to the experimentally obtained sub-atmospheric regions, greater sub-atmospheric regions are observed for both turbulence models. The evaluation of performance for both turbulence models indicates that the Realizable $k-\epsilon$ model displays preferable harmony with experimental results for H/D ratios of 0.5 and 1, while the Standard $k-\omega$ model is more successful at H/D ratio of 2.

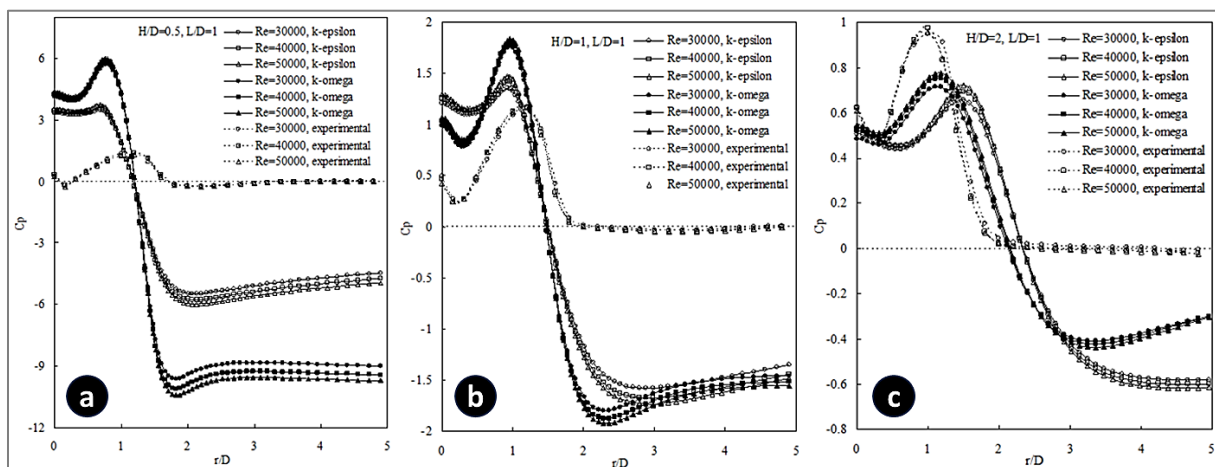


Figure 9. The influence of Reynolds number on the pressure distributions at $L/D=1$. a) $H/D=0.5$, b) $H/D=1$, c) $H/D=2$

It can be figured out from Figures 9a-c that as H/D increases, the closeness between the experimental and numerical outcomes increases as the simulation advances. The statement suggests that there are discrepancies between the computed and measured results, which are caused by the limitations of the turbulence models employed in the study. The models used may not be able to accurately capture the behavior of strongly curved flows. Additionally, the study is limited to 2D calculations, which may not fully reflect the 3D nature of the flow. The possibility of disparities arising between the computed and observed results cannot be ruled out.

Heat Transfer

In order to compare the impact of nozzle to target impingement plate spacing (H/D) on the target impingement plate's Nusselt number distributions at $Re=30000$ and $L/D=1$, we observe Figure 10a and Figure 10b, respectively, for Realizable $k-\varepsilon$ and Standard $k-\omega$ turbulence models. The computation of the local Nusselt number involved the application of the formula $Nu = h \cdot D/k_a$, where $h = q / (T_w - T_j)$ stands for the coefficient of convective heat transfer, and T_j and T_w refer to the jet exit and impingement wall temperatures, respectively. The figures demonstrate that the Nusselt number distributions are extremely impressed by the distance between nozzle and target impingement plate. A decrease in the nozzle to target impingement plate distance causes a rise in both the primary stagnation Nusselt numbers and heat transfer ratios. For nozzle to target impingement plate spacings that are closer, the primary stagnation Nusselt number exhibits a higher rate of change. Aldabbagh and Sezai [14] have also reported similar findings. When the distance between nozzle and target impingement plate is reduced, the interaction zone between the two jets experiences a stronger interference. Nusselt numbers at the midpoint between the two jets exhibit very low values for all studied H/D spacings. Dong et al. [21] attribute this to the fact that the high-temperature reaction zone becomes detached from the target impingement plate. Figure 10a shows that the computed Nusselt profiles using the Realizable $k-\varepsilon$ turbulence model exhibit three peaks. When H/D is equal to 0.5, the first peak appears at $r/D \approx 0.6$, followed by the second peak at $r/D \approx 1.2$ and the third peak at $r/D \approx 2.3$. The observed peaks in the Nusselt number data are associated with the transition of the flow from a laminar to a turbulent state in the wall jet region. This transition leads to an increase in turbulence levels near the wall, which explains the rise in the Nusselt number. Second peak takes higher values than the two other peaks. With an increase in H/D spacings, the figured out Nusselt number peaks on the impingement surface decrease and shift to larger radial distances, occurring every three peaks. The increase in primary vortex size with an increase in H/D , as shown in Figure 5, is the reason behind this phenomenon. The positions of minimum values of Nu move toward the center of target impingement plate as H/D decreases. As the H/D ratio decreases, the primary vortex size also decreases, resulting in steeper slopes of the Nu curves. This is due to the reduction in the size of regions with adverse pressure gradients as H/D decreases. The radial locations of the minimum Nu values between the first and second peaks are similar to the radial locations of the primary stagnation points of the pressure coefficients shown in Figure 7a. Moreover, the regions where the second peaks in Nusselt distributions occur correspond to sub-atmospheric local pressures on the target impingement plate.

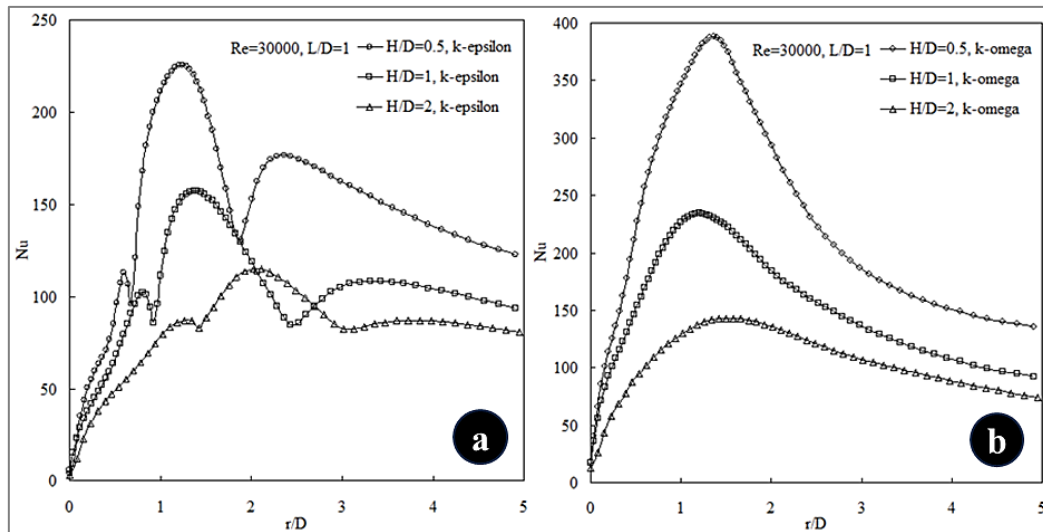


Figure 10. The relationship between nozzle to target impingement plate spacing and local Nusselt number distributions for $Re=30000$ at $L/D=1$. a) Realizable $k-\epsilon$ turbulence model, b) Standard $k-\omega$ turbulence model

For every studied H/D spacing, only one peak in the Nusselt number distribution on the impingement surface is computed by the Standard $k-\omega$ turbulence model (Figure 10b). Dong et al. [21] observed that the heat transfer distributions of twin jets obtained from the Realizable $k-\epsilon$ model are more consistent with experimental data than those obtained from another turbulence model. Figure 11 demonstrates the impact of the distance between twin jets (L/D) on the radial distribution of the local Nusselt number on the target impingement plate at $Re=30000$ and $H/D=1$.

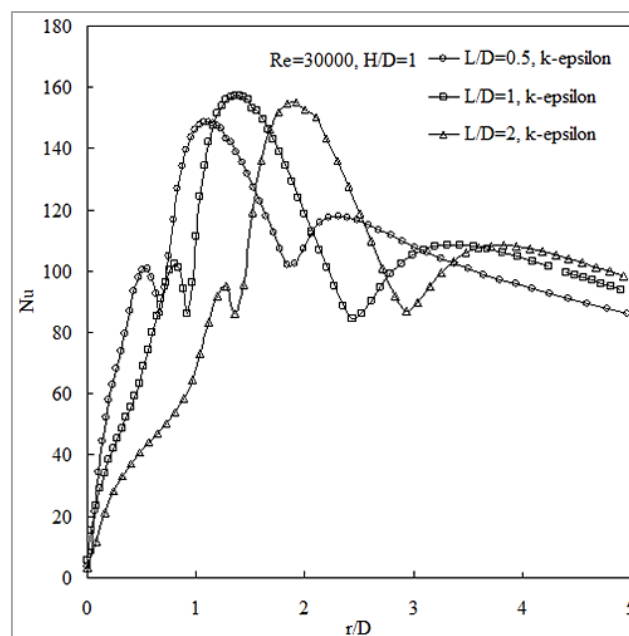


Figure 11. The relationship between jet-to-jet spacing and local Nusselt number distributions for $Re=30000$ at $H/D=1$ using the Realizable $k-\epsilon$ turbulence model.

These results are predicted using the Realizable $k-\epsilon$ turbulence model. Observations show that the magnitude of the Nusselt number is unaffected by the distance between twin jets, but the Nusselt number peaks shift towards the radial direction. Regardless of the L/D value, a region with lower heat transfer

rate occurs at the midpoint between the double jets. This suggests that the heat transfer to the plate is hindered due to the interference between the double jets. Figure 12 illustrates the influence of Reynolds number on the heat transfer distributions at $H/D=1$ and $L/D=1$, as calculated using the Realizable $k-\varepsilon$ and Standard $k-\omega$ turbulence models. The figure presents a comparison of the two turbulence models results under different Reynolds number conditions. The observed increase in local Nusselt numbers with a rise in Reynolds number results in improved convective heat transfer. The effect is attributed to the formation of the downwash fountain, which occurs as a result of the colliding wall jets after impingement. The downwash fountain's presence contributes significantly to the observed phenomenon. The Nusselt profiles exhibit a similar trend for different Reynolds numbers of 30000, 40000, and 50000. Three peaks are evident in the Realizable $k-\varepsilon$ model, with the second peak being the largest of the three. Cooper et al [48] stated that the secondary peak in the Nusselt number is due to an increase in the level of turbulence near the wall. The location of the peak predicted by the Standard $k-\omega$ model differs from the multiple peaks predicted by the Realizable $k-\varepsilon$ model. Radial locations of Nusselt peaks are independent of the Reynolds number. The Realizable $k-\varepsilon$ model predicts local Nusselt number magnitudes that are lower than those predicted by the Standard $k-\omega$ model. The suitability of the Realizable $k-\varepsilon$ model for modeling the flow field with a strong adverse pressure gradient, in contrast to the Standard $k-\omega$ model, is the reason for the observed discrepancy in the predicted Nusselt number peaks.

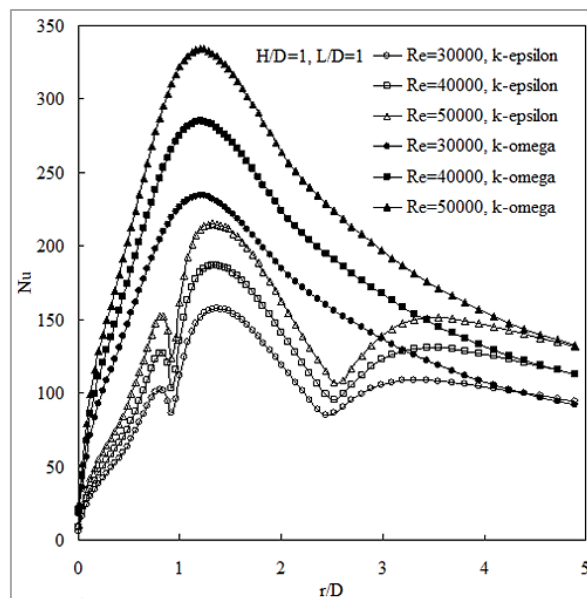


Figure 12. The relationship between Reynolds number and local Nusselt number distributions using Realizable $k-\varepsilon$ and Standard $k-\omega$ turbulence models for $H/D=1$ at $L/D=1$

Conclusion

Experiments and numerical simulations were carried out in present study to investigate the flow structures and fields of the confined twin impinging jet, as well as to determine its heat transfer performance and properties, encompassing Reynolds numbers up to 50000 and different spacings of

nozzle to target impingement plate and jet-to-jet. The collision of the jets close the impingement plate leads to the formation of two counter rotating circular vortices and a downwash fountain flow between the jets. The interplay between the primary jet and the downwash flow creates low-pressure regions, leading to the formation of recirculation zones. These zones are a consequence of the interplay between the two flow components. The flow is decelerated and deflected by the impinging plate. Both numerical and experimental pressure distributions on the impingement surface show a dependence on the distance between nozzle to target impingement plate and twin jets, while being independent of Reynolds number. Additionally, the Standard $k-\omega$ turbulence model exhibits higher pressure coefficients in comparison to the Realizable $k-\varepsilon$ turbulence model. These findings highlight the disparities between the two turbulence models' predictions in terms of pressure coefficients. Regions of sub-atmospheric pressure on the impingement surface for spacing up to 1 are observed at the experimental measurements, while they exist at all studied nozzle to target impingement plate spacings for numerical results. The numerically predicted pressure coefficients are greater than the experimentally obtained pressure coefficients. Nusselt number distributions predicted with two turbulence models depend on Reynolds numbers, distances between twin jets and nozzle to target impingement plate. Nusselt number distributions obtained Realizable $k-\varepsilon$ model have different form from Standard $k-\omega$ model results. While Standard $k-\omega$ model exhibits only one peak, Realizable $k-\varepsilon$ model shows three peaks in the Nusselt profiles. Based on the Realizable $k-\varepsilon$ model, the pressure coefficients on the impingement plate are sub-atmospheric at the radial distances where the second peaks in Nusselt numbers are observed. This relation demonstrates the correlation between sub-atmospheric regions in pressure distribution and heat transfer coefficient peaks on the impingement surfaces. The study's results indicate that the Realizable $k-\varepsilon$ turbulence model is superior to the Standard $k-\omega$ turbulence model in terms of predicting flow fields and structures as well as heat transfer distributions. The inconsistencies in the experimental and numerical findings may stem from the narrow coverage of the turbulence models utilized, in conjunction with a 2D computational domain.

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Authors Contribution Yücel ÖZMEN contributed 70% to the article and performed, analysed and interpreted the experiments. Haluk KELEŞ contributed 30% to the article, prepared the graphs and wrote the article

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Experimental Study on the Pull-Out Capacity of Blind Rivet Nuts (BRNs) Mounted on Cold-Formed Square Hollow Section Members with Different Wall Thickness

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Research Article

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Abstract

In this study, pull-out tests of blind rivet nuts (BRNs) mounted on cold-formed square hollow section (SHS) webs with 100×100 mm nominal cross-section dimensions and different wall thicknesses (2.0 to 5.0 mm) were performed, and the effect of different wall thicknesses and BRN thread sizes on the test results was experimentally investigated. M10 and M12 stainless steel BRNs were mounted on SHSs using a standard riveter tool, and the test elements were prepared for the experiment. Load–displacement curves and the final damage modes were obtained for each test specimen. The results show that the pull-out capacity depends on both the SHS wall thickness and rivet nut thread size. Although the pull-out capacity increased in both thread sizes with the increase in wall thickness parameters, the effect of thread size is negligible in the case of 2.5, 3.0, and 4.0 wall thickness. In addition, when a connection is created using a BRN, the design should consider the stripped thread strength in addition to the pull-out capacity.

Keywords: Blind rivet nut, square hollow section, pull-out capacity

Farklı Et Kalınlıklarına Sahip Soğuk Şekillendirilmiş Kare İçi Boş Kesitli Elemanlara Monte Edilen Kör Perçin Somunlarının (BRN'ler) Çekme Kapasitesi Üzerine Deneysel Çalışma

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Öz

Bu çalışmada, 100x100 mm nominal kesit boyutlarına sahip farklı et kalınlıklarındaki (2.0 ile 5.0 mm) soğuk şekillendirilmiş kare içi boş profil (SHS) gövdelerine monte edilen kör perçin somunlarının (BRN'ler) çekme testleri gerçekleştirilmiş olup farklı duvar kalınlıklarının ve BRN diş boyutunun test sonuçlarına etkisi deneysel olarak araştırılmıştır. M10 ve M12 paslanmaz çelik BRN'ler standart perçinleme aleti kullanılarak SHS'lere monte edilmiş ve deney için test elemanları hazırlanmıştır. Her test numunesi için yük-yer değiştirme eğrileri ve nihai hasar modları elde edilmiştir. Sonuçlar, çekme kapasitesinin hem SHS duvar kalınlığına hem de perçin somunu diş boyutuna bağlı olduğunu göstermektedir. Her iki diş boyutunda da et kalınlığı parametrelerinin artmasıyla çekme kapasitesi artmasına rağmen, 2.5, 3.0 ve 4.0 et kalınlığı durumunda diş boyutunun etkisi ihmal edilebilir düzeydedir. Ayrıca, BRN kullanılarak bir bağlantı oluşturulduğunda, tasarımda çekme kapasitesinin yanı sıra BRN'lerin dişlerinin sıyrılma mukavemeti de dikkate alınmalıdır.

Introduction

Rivet nuts, also known as blind rivet nuts (BRNs), are versatile and easy-to-use connection members used for various materials such as metals, plastics, and composite surfaces. These designs are particularly suitable for applications where access to the rear and inner sides is restricted or impossible because they make it convenient to create threaded holes from only one side of the workpiece. In recent years, the number of studies on BRNs has increased, some of which are described as follows. Heiler [1] explored the benefits and processes of flow drilling technology and thread forming as efficient and secure methods for connecting thin-walled components and hollow sections. This technology, which involves the use of a fast-rotating carbide taper mandrel to create a bush in the material, was presented as an alternative to traditional joining methods such as welding or rivet nuts. The article also detailed the process of flow drilling and its various applications, emphasizing its efficiency and reliability compared with conventional fasteners. The study highlighted the axial forces involved in flow drilling, tool design, and thread formation in sheet metal bushes. The author concluded by asserting that flow drilling technology is an economical alternative for producing sheet metal pull-throughs and subsequent thread formation, particularly for thin-walled components and hollow profiles. Hassanifard et al. [2] investigated the fatigue life of clamped rivet-nut joints under cyclic loading. They used a finite element analysis to account for the residual stress and assessed the local stresses on the joint. The results were then used to predict the fatigue life using damage models. The study also explored the stress distribution in the rivet-nut joints and the influence of the smashing size on the fatigue life of the joints. They further investigated the strain-controlled fatigue behaviors of different materials and numerically predicted the torque-to-turn value of a BRN. The study provides valuable insights into the fatigue behavior of clamped rivet-nut joints and the importance of considering both normal and shear stress components in fatigue life prediction models. Borowiecki et al. [3] conducted numerical and experimental investigations on bolted connections with BRNs. They discussed the classification of screw connections and the associated validation process. They also examined the effect of the strength of the connected elements on the strength of the connection. The study revealed that the strength of the connection is significantly lower than the values declared by a manufacturer of BRNs. Van de Velde et al. (2019) [4] conducted a numerical prediction of the torque-to-turn value of a blind rivet nut using finite element simulations. The study aimed to improve the design of blind rivet nuts by understanding their setting process. This strategy was successfully applied to two blind rivet nuts and the results were validated through experiments. Finite element models were developed to simulate the formation process of the blind rivet nuts. They observed that the strain-hardening behavior of BRNs significantly affected the accuracy of the simulation. A finite element model updating (FEMU) technique was used to optimize the strain-

hardening behavior and torque-to-turn values in the rivet joints. This study also investigated the use of finite element analysis to support the design of BRNs. They observed that the setting process could be accurately simulated, enabling the determination of the optimal setting force, hole clearance, and deformation chamber length. The study concluded that the proposed modeling strategy can predict the forming process and the associated torque-to-turn value; however, the accuracy of the model could be improved. Studziński [5] investigated the application of analytical models to understand the elastic behavior of axially loaded blind rivets in sandwich beams. The models under consideration included the Winkler, Filonenko–Borodich, and Pasternak models. The models were validated using laboratory pull-out tests. They observed that the ultimate capacity of the rivets ranged from 240 to 300 N. While all models accurately depicted the elastic range of the mechanical response, they tended to overestimate the displacement of the face slightly. The study suggested that future research could benefit from a 2D model to better understand the mechanical response of a blind rivet pull-out from a sandwich panel facing. Van de Velde et al. (2022) [6] studied the impact of installing a BRN in a CFRP on the integrity of the plate material. The study used scanning electron microscopy (SEM) to visualize the damage induced by setting a BRN with two different setting forces. The study observed that the quasi-static strength was hardly influenced after installing the BRN when loading the laminate in the “0° orientation” (transverse fibers are dominant). The researchers hypothesized that the through-thickness stress reduces the severity of the local stress state, thus reducing local damage risks and counteracting the possible detrimental effects of damage. However, when loading the laminate in the “90° orientation” (longitudinal fibers are dominant), the quasi-static test indicated that the strength was reduced after installing the BRN. The researchers assumed that the damage to the outer layers, where the fibers were oriented in the loading direction, was responsible for the observed strength reduction. The main objective of a study by Van de Velde et al. (2023) [7] was to investigate the influence of the setting force on the static strength of BRNs embedded in carbon fiber-reinforced plastic (CFRP). The study also investigated the behavior of BRNs in CFRP laminates and the effect of the setting force on the stress state within the laminate and the strength of the joint. The findings of the study revealed that the setting force significantly influences the stress state within the laminate, thereby enhancing its static mechanical strength. The size of the BRN and the setting force are crucial factors affecting the strength of the joint. The study also observed that if no visible damage is observed in the load-carrying layers, the installation of the BRN tends to improve the static performance of the joint. However, if visible damage is induced during the BRN installation, the static strength of the joint is reduced. The push-through resistance is minimally affected by the setting force of the BRN. The study provided valuable insights into the effects of BRN installation on CFRP composites and underscored the importance of optimizing the setting force to improve performance. Kim et al. [8] investigated the impact of the clamping angle on the fastening force in BRN fastening. M6 BRNs were used in the tests. They found that as the clamping angle increases, the fastening force decreases, suggesting a clamping angle of less than 3° is optimal. The

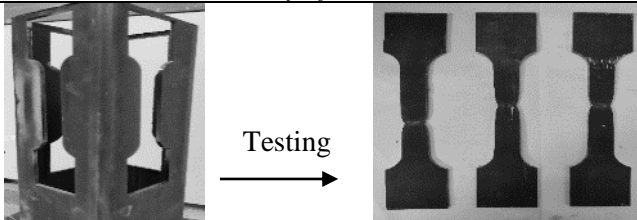
study concluded by emphasizing the need for further research on BRN geometry optimization and the development of jigs for manual fastening. Gu et al. [9] conducted a study on the design optimization of M8 BRN using finite element analysis. The research primarily focused on the impact of the shaft shape of the BRN on the fastening process. The study concluded that shaft thickness and height are the most significant design variables, influencing the gap and load on the plate. The coefficient of friction was found to have a minimal effect on the maximum effective stress and the average plate load. The main objective of this study was to conduct preliminary experimental studies to determine the behavior and pull-out capacity of BRN under load and to investigate the effect of different wall thicknesses of square hollow sections (SHSs) on the behavior and capacity when BRN is used in lightweight and particularly hollow steel structures. Additionally, the effect of BRN sizes (M10 and M12) on pull-out capacity was investigated.

Experimental Study

Tensile Tests

Tensile tests were performed according to ASTM A370-14 [10] to determine the material properties of cold-formed SHSs with five different wall thicknesses considered within the scope of the study. The results are summarized in Table 1.

Table 1. Summary of the tensile test results



Sample	Width (mm)	Nominal thickness (mm)	Measured thickness (mm)	Elastic modulus (GPa)	Nominal yield strength (MPa)	Nominal tensile strength (MPa)
SHS 100x100x5.00	20.00	5.00	4.95	195	280	378
	20.01			200	280	365
	20.02			196	283	375
SHS 100x100x4.00	19.99	4.00	3.85	186	352	412
	19.98			189	350	407
	20.00			193	348	410
SHS 100x100x3.00	14.00	3.00	2.85	-	295	384
	13.98			-	289	379
	13.98			-	296	381
SHS 100x100x2.50	14.00	2.50	2.35	196	308	397
	13.98			-	308	384
	13.99			199	310	398
SHS 100x100x2.00	14.00	2.00	1.95	-	338	462
	13.97			-	335	463
	13.98			-	336	461

Properties of the Test Specimens

Each SHS test specimen was 200 mm in length, and 13 mm and 16 mm holes were drilled in its middle, as specified in the manufacturer's assembly instructions, and mounted. The same settling force was applied as that of the standard riveter tool, regardless of the thickness of the mounted SHS in all test elements. A schematic of the blind-rivet nut installation is shown in Figure 1. The dimensions of the BRNs are listed in Table 2.

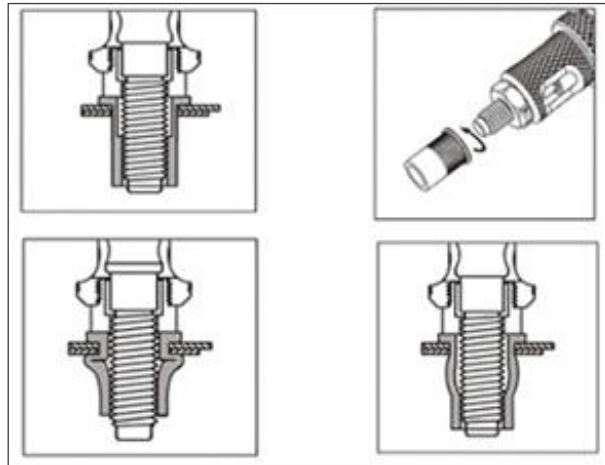
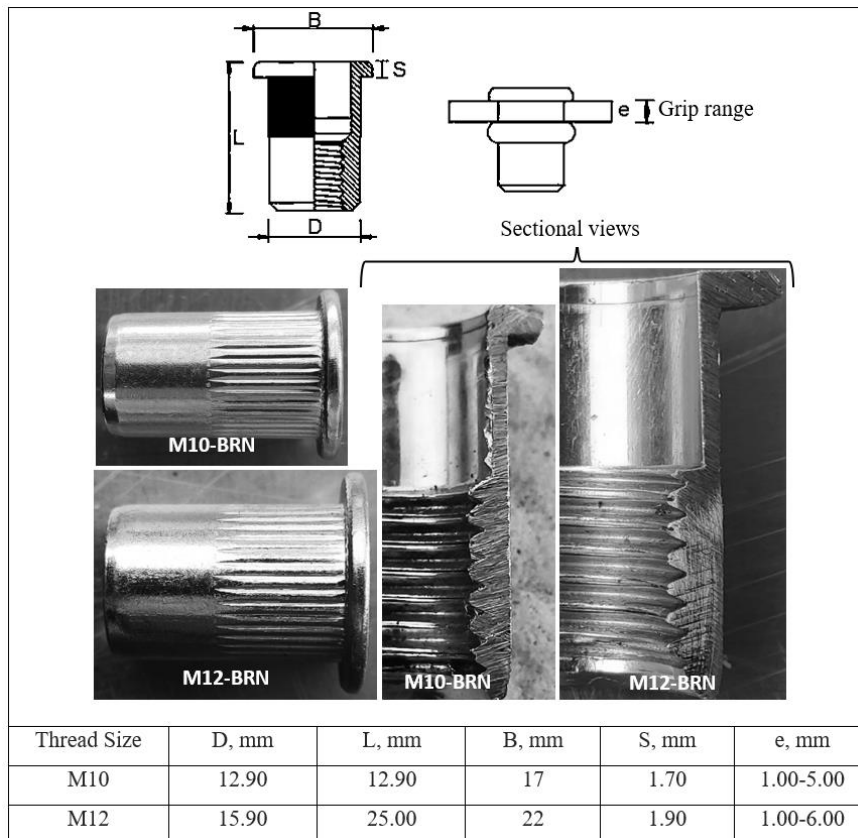


Figure 1. Schematic of the installation stages of a BRN [11]

Table 2. Measured dimensions of the BRNs



Loading Scheme and Measuring Instruments

The specimens were tested using a test setup with two 50-kN hydraulic jacks for monotonic pull loading. Before the loading process was initiated, a test specimen was positioned at the center of the loading setup to ensure concentric axial pulling loading, and the possible rotation of the loading plate was controlled with a digital angle meter placed on the loading plate during the experiment. A consistent loading protocol was applied to all the specimens. The loading continued monotonically until the rivet nut was removed from the mounted SHS. Although the loading rate could not be applied as standard in all experiments, it could be applied approximately between 0.6 and 1.00 mm/sec. A linear variable differential transformer (LVDT) was used to measure the displacement in the loading direction from the loading plate. Data were acquired using a Testbox 1001 data acquisition system (Ankara, Türkiye). A photograph of the test setup is shown in Figure 2.

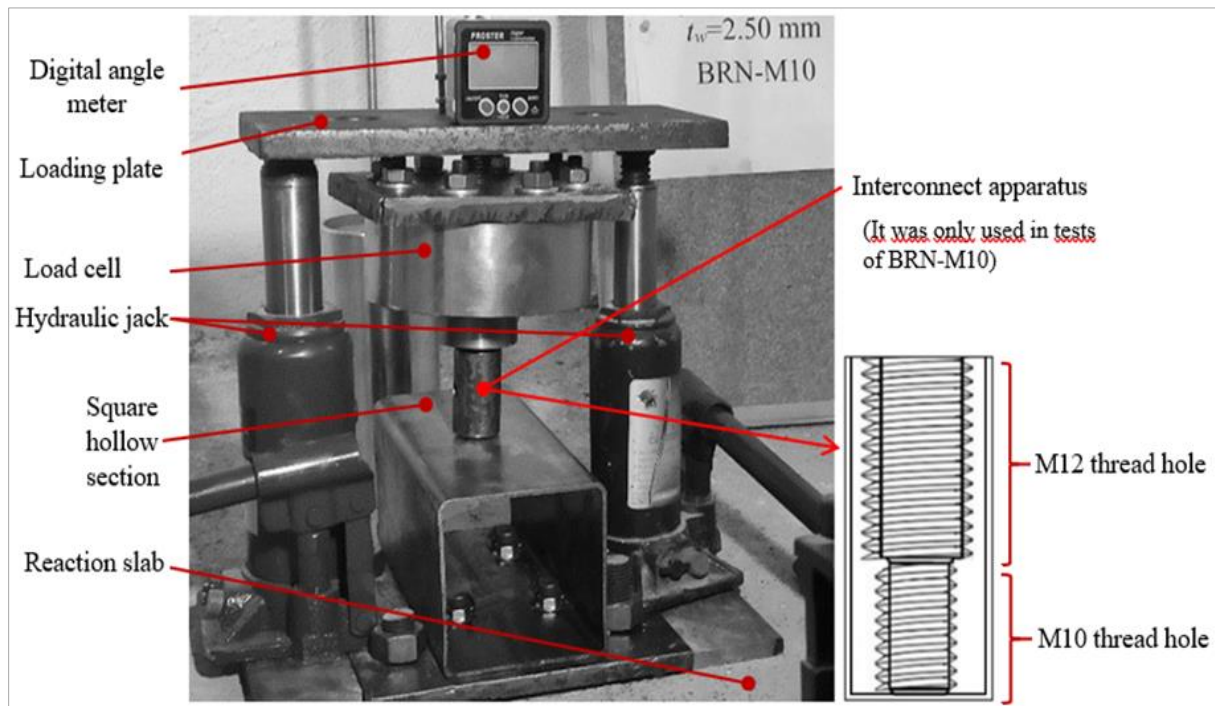


Figure 2. Test setup with instrumentation

Results and Discussions

This study investigated the behavior and ultimate pull-out capacities of single M10 and M12 stainless-steel BRNs mounted on the walls of ten 200 mm-long SHSs with different wall thicknesses under monotonic tensile loading. The summary of the test results and load–displacement curves are presented in Figure 3 and Table 3, respectively. When the initial stiffness was evaluated, the differences in the initial stiffness plots obtained when M10 and M12-sized BRNs mounted on SHSs with different wall thicknesses were tested were negligible (Table 3).

Table 3. Summary of the test results

Specimen ID	Nominal SHS wall thickness, mm	Used BRN	Pull-out capacity, kN	Initial stiffness, kN/mm	Rivet nut hole diameter after test, mm	Global section deformation, mm
S1	2.00	M10	11.37	1.10	16.50	107.30
S2	2.50		14.10	1.25	15.90	101.80
S3	3.00		17.42	1.76	15.80	100.80
S4	4.00		25.40	5.55	13.40	100.00
S5	5.00		30.00	8.38	13.20	100.00
S6	2.00	M12	13.75	1.11	20.30	119.00
S7	2.50		14.15	1.26	19.70	104.50
S8	3.00		17.70	1.80	18.80	101.20
S9	4.00		26.50	5.60	16.80	100.00
S10	5.00		35.84	8.40	16.70	100.00

This is because the behavior of the initial stiffness in the first phase depends on the geometry (wall thickness) and material properties of the SHS wall mounted on it rather than the BRN sizes. Thus, in the experiments in which both BRNs were used, the initial stiffness increased with an increase in the SHS wall thickness.

This is because the behavior of the initial stiffness in the first phase depends on the geometry (wall thickness) and material properties of the SHS wall mounted on it rather than the BRN sizes. Thus, in the experiments in which both BRNs were used, the initial stiffness increased with an increase in the SHS wall thickness. Additionally, as shown in Figure 4, an approximately linear relationship was observed between SHS wall thickness and BRN pull-out capacity for both BRN sizes.

In other words, the grip strength of M12 BRN was approximately 21% more than M10 at a wall thickness of 2.0 mm. The reason for the difference in the pull-out capacities obtained from M10 and M12 BRNs for 5 mm wall thickness was that when M10 was used, capacity loss occurred owing to stripped thread damage of BRN (Figure 7). When M12 was used, the damage was a combination of rupturing of the BRN neck and removal of the BRN from the SHS wall (Figure 8). Before the stripped thread damage to the BRN occurred, the loss of capacity was due to SHS wall deformation. This was because the stripped thread strength was approximately 20% higher in the M12 threads than in the M10 BRN (see [12, 13]). Therefore, when M12 was used, the increase in capacity compared with M10 was approximately 20%.

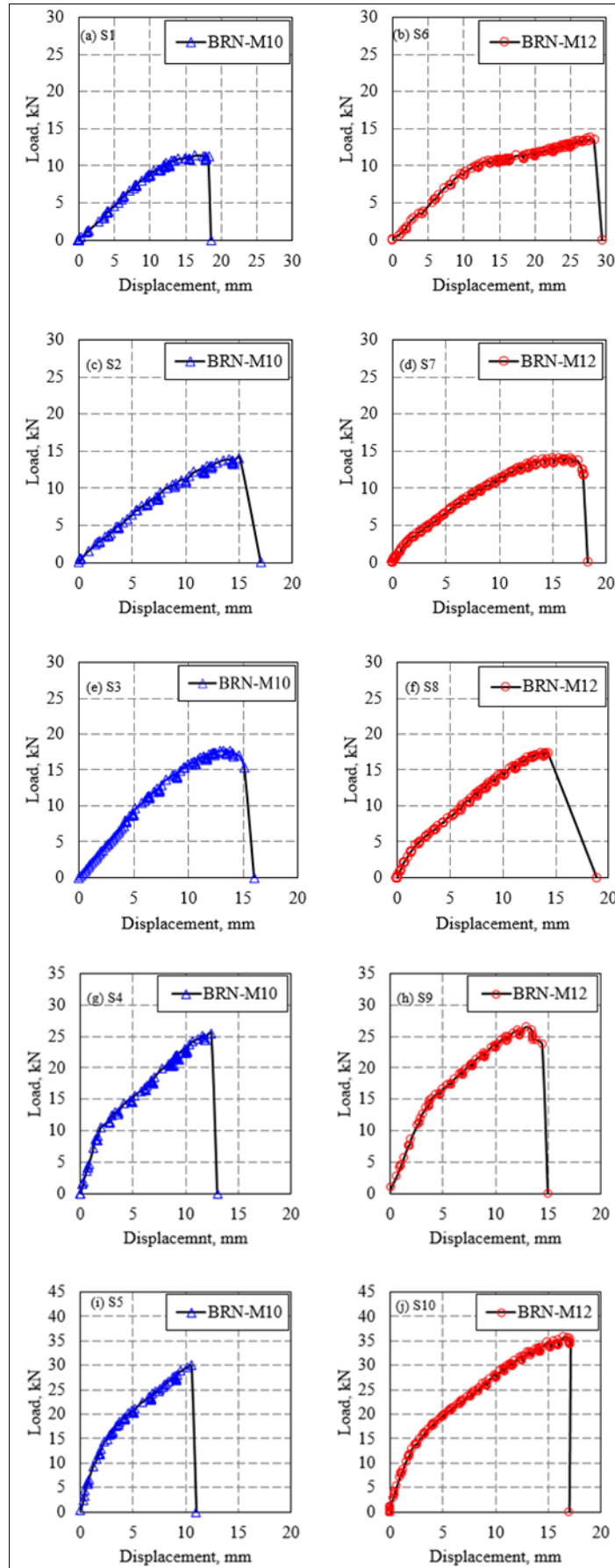


Figure 3. Load–displacement curves

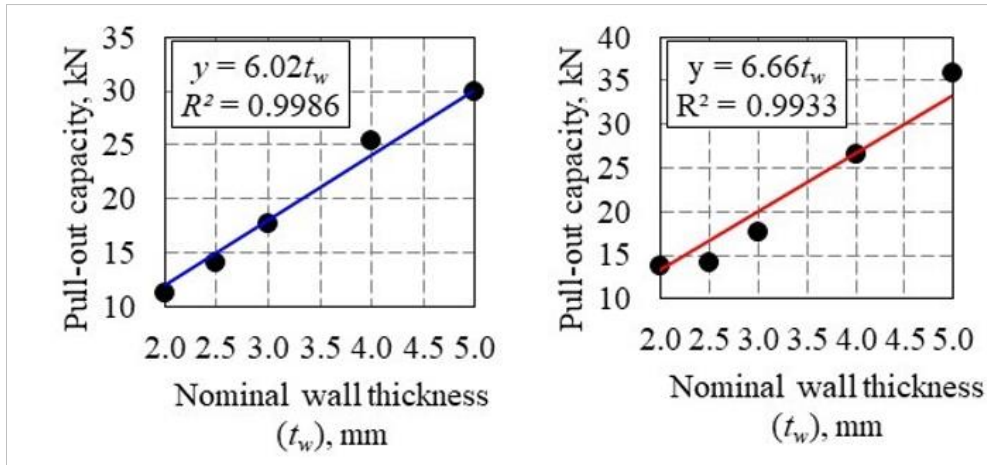


Figure 4. Relationship between wall thicknesses and pull-out capacity

When pull-out capacities were evaluated, in cases in which both M10 and M12 rivet nuts were used, the capacity increased with the increase in the SHS wall thickness, as in the initial stiffness. Additionally, the findings showed that the effect of BRN size was negligible when the wall thickness was 2.50, 3.00, and 4.00 mm (Figure 5).

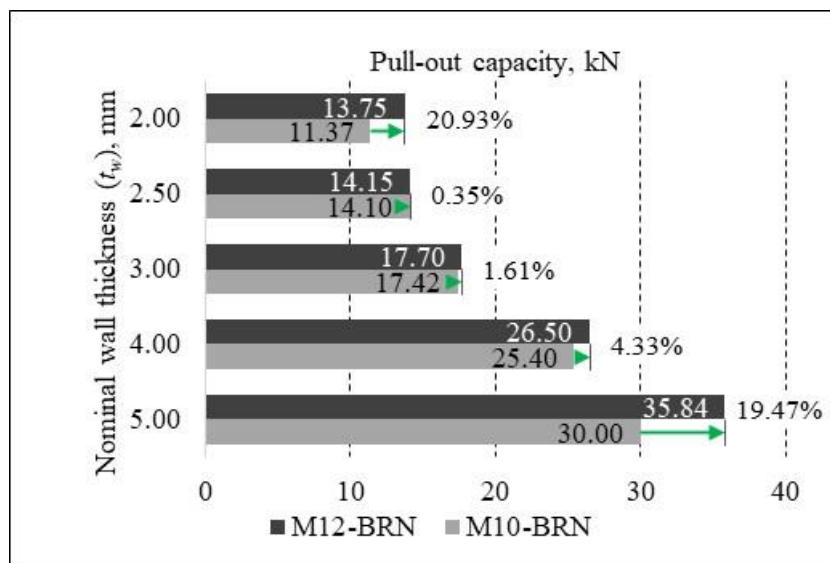


Figure 5. Comparison of pull-out capacities

However, for wall thicknesses of 2.00 and 5.00 mm, the increases in pull-out capacity were 21% and 19.5%, respectively. Unlike at other thicknesses, the effect of the BRN size was more pronounced at these values. The effect of M10 and M12 on the load–displacement relationship was negligible up to a displacement of approximately 18 mm at a wall thickness of 2 mm. However, after this displacement value, when the M12 BRN was used, the final capacity increased as the load was transferred to the SHS wall through the rivet nut. This caused the global deformation in the measured SHS to be greater when the M12 BRN was used than when the M10 SHS was used (Figure 6).

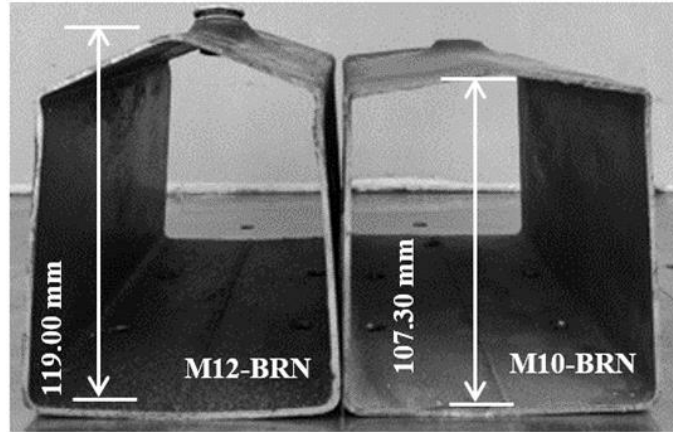


Figure 6. Global deformation of S1(right) and S6 (left)

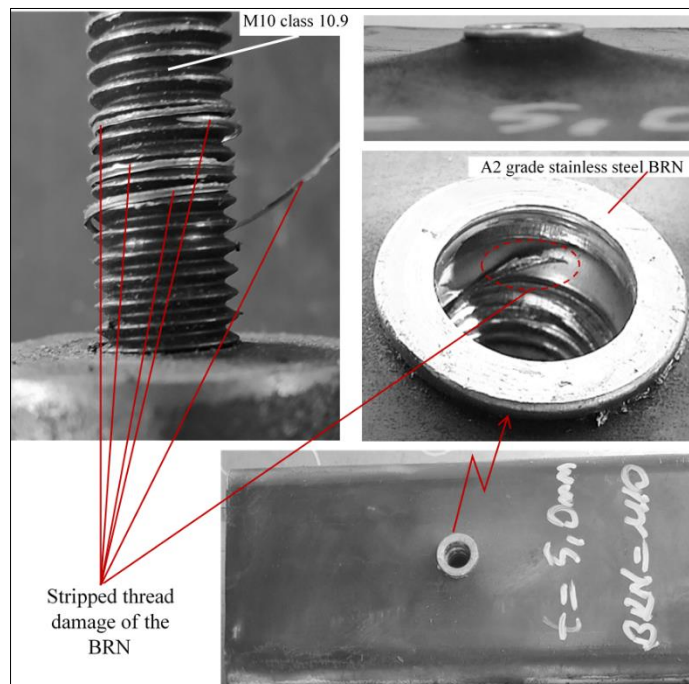


Figure 7. Ultimate damage modes of S5 ($t_w=5.00$ mm and BRN-M10)



Figure 8. Failure mode in the BRN of S10 ($t_w=5.00$ mm and BRN-M12)

Photographs of the damage modes obtained as a result of all tests are presented in Figure 9. When the damage modes were evaluated, as the SHS wall thickness increased at both BRN thread sizes, the damage to the SHS wall transitioned from global sectional and local conical deformation to only local conical damage and excessive BRN damages (Figure 9, Figure 10).

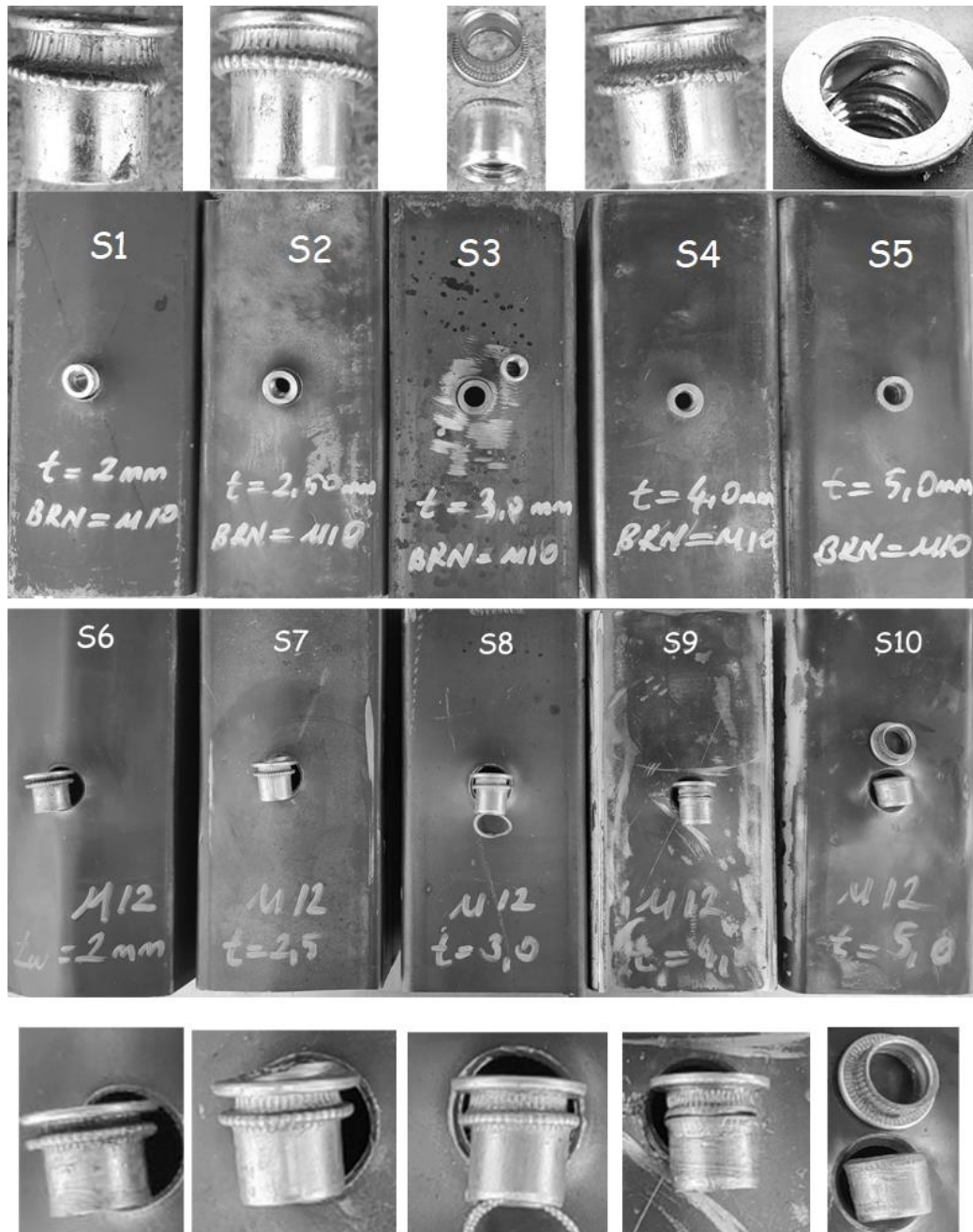


Figure 9. Photographs of final damage modes of all experimental elements

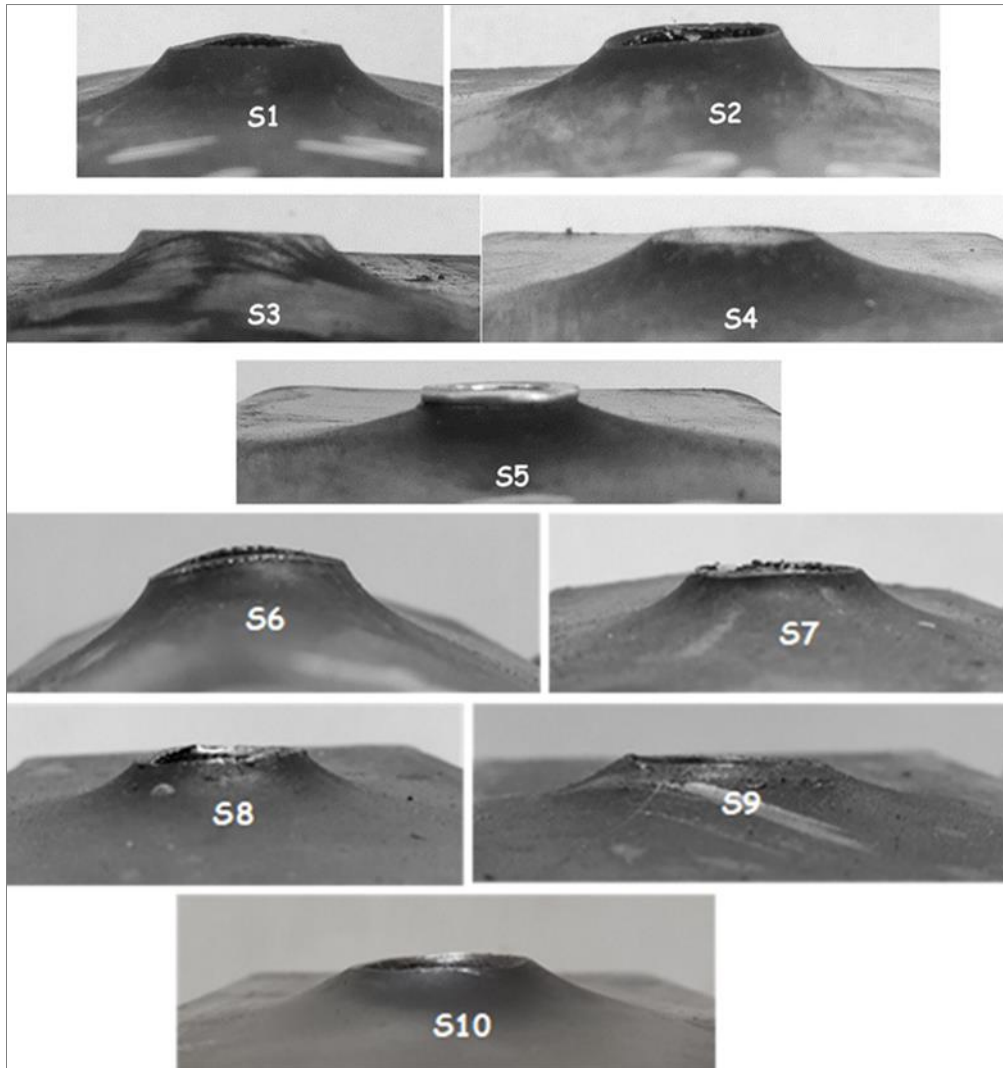


Figure 10. Conical deformation modes of the SHS wall

Conclusions

In this study, pull-out tests of M10 and M12 stainless steel BRNs mounted on cold-formed square hollow section (SHS) bodies with 100×100 mm nominal cross-section dimensions and different wall thicknesses (2.0 to 5.0 mm) were performed, and the effect of different wall thicknesses and BRN thread sizes on the test results was experimentally investigated. The results of the study are summarized as follows:

- The initial stiffness depends largely on the SHS wall properties than on BRN size (M10 or M12).
- Pull-out capacity increases with thicker SHS walls regardless of BRN size.
- BRN size has a minimal impact on pull-out capacity for 2.50, 3.00-, and 4.00-mm walls. For 2.00- and 5.00-mm walls, M12 BRNs offer significantly higher pull-out capacity (21% and 19.5% more) than M10 BRNs.

- The effect of BRN size on the load–displacement relationship is negligible up to an 18-mm displacement for 2.00 mm walls. Beyond 18 mm, M12 BRNs provide approximately 21% higher grip strength than M10 BRNs for 2.00 mm walls.
- The difference in the pull-out capacities for 5-mm walls is due to M10 BRNs undergoing stripped thread damage, whereas M12 BRNs undergo neck rupture and BRN removal.
- M12 BRNs have approximately 20% higher stripped thread strength than M10 BRNs, resulting in increased pull-out capacity.
- When the damage modes were assessed, the damage to the SHS wall changed from global sectional and local conical deformation to only local conical damage and excessive BRN damage as the SHS wall thickness increased at both BRN thread sizes.

This study was conducted considering the limited number of test specimens and the BRN thread sizes. It should be particularly noted that these results are not generalizable, and the investigation scope should be expanded by increasing the number of test specimens to have a deeper insight into the subject.

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Authors Contribution The author read and approved the final manuscript.

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C95200 ve C95300 Al Bronz Alaşımlarının Sertlik, Çekme ve Çentik Darbe Özelliklerinin Karşılaştırılması

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Öz

Bu çalışmanın amacı, yüksek mukavemet, korozyon, aşınma ve yorulma özelliklerini bir araya getiren C95300 ve C95200 alaşımlarının mikroyapı ve mekanik özelliklerini incelemektir. Alüminyum (Al) bronzlarının element miktarları hesaplanıp hazırlandıktan sonra, indüksiyon fırınında eritilmişlerdir. Al bronz standartlarına göre hazırlanan alaşımlar 1150°C'de bir süre bekletildikten sonra 250°C'ye ısıtılmış kalıcı bir kalıba dökülmüştür. Üretilen Al bronz külçelerden numuneler alınmıştır. Optik mikroskop ve SEM (Scanning Electron Microscope) görüntüleme, EDX (Energy Dispersion X-Ray Spectrometer), sertlik, çekme ve darbe testleri de gerçekleştirilmiştir. İncelemeler sonucunda, C95300 alaşımlarında ikincil faz oluşumu gözlenmiş, sertlik ve çekme mukavemeti artmıştır. Çentik darbe testi sonucunda C95300 alaşımı, C95200 alaşımına kıyasla hem darbe enerjisi hem de tokluk için daha düşük değerlere sahiptir.

Anahtar Kelimeler: Alüminyum bronz, mikroyapı, mekanik özellikler

Comparison of the Hardness, Tensile and Notch Impact Properties of C95200 and C95300 Al Bronze Alloys

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Abstract

The aim of this study is to investigate the microstructure and mechanical properties of C95300 and C95200 alloys, which combine high strength, corrosion, wear and fatigue properties. After calculating and preparing the elemental amounts of the aluminium (Al) bronzes, they were melted in an induction furnace. The alloys, prepared to Al bronze standards, were held at 1150°C for some time and then cast in a permanent mould heated to 250°C. Samples were taken from the Al bronze ingots produced. Optical microscope and SEM (Scanning Electron Microscope) imaging, EDX (Energy Dispersion X-Ray Spectrometer), hardness, tensile and impact tests were also carried out. As a result of the investigations, secondary phase formation was observed in the C95300 alloys, increasing hardness and tensile strength. As a result of the notch impact test, the C95300 alloy has lower values for both impact energy and toughness compared to the C95200 alloy.

Keywords: Aluminium bronze, microstructure, mechanical properties

Giriş

Bakırın alüminyum ile yaptığı alaşımlarına (Al) bronzları adı verilir. Yüksek korozyon direncine sahip döküm Al-bronzları mukavemet gerektiren kimya sektöründe, denizcilik ekipmanlarında, pompalarda, valflerde, vinçlerde, dişlilerin gövde ve parçalarında, yataklarda, gemi pervanelerinde, vida dişi ve somun gibi bazı bileşenlerin üretiminde, yaygın olarak kullanılmaktadır [1-3]. Al-bronzları, alüminyuma ek olarak çeşitli miktarlarda demir, manganez, nikel ve silisyum (silikon) içeren bakır bazlı alaşımlardır. Sanayide genellikle en çok %12 sınırına kadar alüminyum içeren Al-bronzları kullanım alanı bulmaktadır. Al-bronzlar içerdikleri ek elementlere göre farklı özellikler gösterirler. Kalay bronzları nispeten daha fazla mukavemete ve sünekliğe sahipken, manganez bronzları basınca karşı iyi direnç gösterir ve mükemmel mekanik özelliklere sahiptir. Kimyasal olarak bileşimdeki element oranlarında bazı değişiklikler yapılarak mekanik özelliklerde olumlu yönde iyileştirmeler gerçekleştirilebilir. Al-bronzlarının güvenilirliği, kimyasal bileşimin ve üretim yönteminin kontrolü ile sağlanabilir [4]. Literatüre göre Al-bronzları %8-14 arasında Al ve yaklaşık %2-4 Mn, Ni ve Fe içermektedir. Ayrıca bu alaşımlar döküm kalıbında büyük yolluk sistemlerine ihtiyaç duyduklarından döküm işlemleri çok kolay yapılamadığı bildirilmiştir. Al-bronzların kimyasal bileşimlerine bağlı olarak mekanik özelliklerinin ısıtma işlemleriyle önemli ölçüde iyileştirilebildiği belirtilmiştir. Örneğin ısıtma işlemi tabii tutulduğunda çekme dayanımı değeri 700 MPa'nın üzerine çıktığı rapor edilmiştir. Öte yandan yaklaşık %8-9.5 oranında Al içeren Al-bronzlarda diğer elementlerin değeri %2'den az olduğunda ısıtma işlemlerinden makul bir sonuç almak mümkün değildir. %9.5-11 Al içeren bronzlar ısıtma işlemlerine tabii tutulabilir ve gerekirse Fe, Ni ve Mg de ilave edilebileceği bildirilmiştir. Literatürde iki farklı kalıpta üretilen alüminyum bronzlarının katılaşma yapısının, çözelti işleminin, temperleme ısıtma işleminin ve kalıp çeşitlerinin mikroyapıya etkileri incelenmiştir. Sonuçlar, ısıtma işlemlerinin numunelerin mekanik özellikleri, mikro yapıları ve faz dönüşüm sıcaklıkları üzerinde bazı ilginç etkilere sahip olduğunu göstermiştir. Hem basınçlı döküme hem de ısıtma işlemlerine bağlı olarak $\alpha+\beta$ ve $\alpha+\beta'$ faz dönüşümlerinin oluştuğu, buna karşılık kum döküm örneğinde $\alpha+\beta$ fazının oluştuğu görülmüştür [3]. %8'den fazla alüminyum içeren ticari alaşımlar, neredeyse her zaman kasıtlı olarak demir ilavelerine sahiptir. Al bronzlarında Fe mekanik özellikleri üzerinde tane inceltici etki gösterir [5]. Literatürde, Cu-14Al-X alaşımı (X eser elementlerdir) çözünürlük sınırının üzerinde eser elementler ve alüminyum eklenerek çekme kalıpları için yeni bir alüminyum kompleks bronz alaşımı olarak geliştirilmiştir. Sertlik, çekme dayanımı ve darbe tokluğu gibi mekanik özellikler deneysel olarak değerlendirilmiştir. Deneysel sonuçlar, geliştirilen alaşımın halihazırda kullanılan Al-bronzlara kıyasla daha yüksek çekme mukavemeti ve sertliğine, daha düşük sürtünme katsayısına ve aşınma oranına sahip olduğunu göstermiştir, bu nedenle çekme kalıplarında yaygın olarak kullanılan geleneksel demir bazlı malzemelerin yerini alması beklenmektedir. Cu-14Al-X alaşımının mükemmel sürtünme önleme özelliği ve yüksek taşıma kapasitesine sahip olduğu rapor edilmiştir [6]. Yapılan bir çalışmada, DIN EN 17 665 tarafından tanımlanan bir bileşime sahip alüminyum bronzundan mikro döküm yöntemiyle elde

edilen küçük parçaların mikro yapısı ve mekanik özellikleri üzerindeki döküm parametrelerinin etkisi incelenmiştir. Farklı numuneler, kalıp sıcaklığı 1000°C'den 700°C'ye düşürüldüğünde mikro-çekme test numunelerinin akma geriliminin ve nihai çekme mukavemetinin mikroyapının incelenmesi ile arttığı bildirilmiştir [7]. Literatürde β -dönüşümlü Cu-Al-X (X = Fe, Ni, Mn, Be, Co, Si ve Sn) alaşım türleri için mikroyapı, soğuma-dönüşüm (CT) diyagramları ve mekanik özelliklere karşılık gelen diyagramlar incelenen çalışmada, su verilmiş ve temperlenmiş Cu-Al-Fe-Ni alaşımlarının dökme halde, hem su verme (900°C) hem de meneviş (600°C) işlemleri yoluyla akma dayanımının önemli ölçüde arttığı rapor edilmiştir [8]. Yapılan literatür araştırmaları sonucunda C95200, C95300 Al bronzları ile ilgili çalışmaların az olduğu görülmüştür. Bu çalışmada C95200 ve C95300 Al bronzlarının mikroyapı özelliklerinin incelenmesi, sertlik, çekme, çentik darbe testleri ile mekanik özelliklerinin araştırılması ve bilimsel açıdan sonuçların belirlenerek yorumlanması, hedeflenmiştir.

Deneylede Kullanılan Materyaller ve Metotlar

Alaşımların üretim aşamasında iç kısmına grafit pota konulmuş indüksiyon ocağı kullanıldı. Ocağın ve potanın içindeki sıcaklık kontrollü termokupl vasıtasıyla takip edildi. Saf bakır elementi grafit pota içerisine yüklendi ve sıcaklık 1155°C civarına kadar çıkartıldı. Ardından talaş halde demir ilavesi yapıldı ve karıştırma işleminden sonra sıcaklık tekrar 1150°C civarına yükseltildi, son olarak alüminyum ilavesi yapılarak karıştırma işlemi gerçekleştirildi ve sıcaklık 1200°C civarına çıkartılıp elde edilen ön alaşım lengo içine döküldü. Elde edilen ön alaşım uniform bir mikroyapı elde edilebilmesi için tekrar grafitten yapılmış pota içerisinde ocağa yüklendi ve 1140°C'ye yakın sıcaklığa kadar ergitilip, karıştırıldı. Sıvı metal ile atmosferin temas etmesini önlemek için florür ve klorür içeren flaks kullanıldı. Hazır hale getirilen alaşım 250°C'ye ısıtılan kokil kalıbın içine dökülerek C95200 ve C95300 Al bronzları üretildi.

Alaşımların Kompozisyonu

Bu çalışmada döküm yöntemiyle elde edilen alaşımların kompozisyonunun belirlenmesi XRF testi kullanılarak belirlenmiştir. Uygunluğu (ASTM B148-78a) ASTM standartları ile kontrol edilmiştir [2, 4, 9, 10].

Mikroyapı İnceleme Metodu

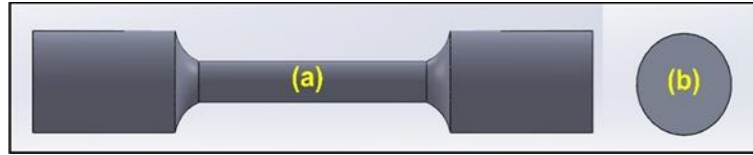
Alaşımların mikroyapılarının incelenmesi için elde edilen Al bronzlarından hazırlanan numuneler 400, 800, 1200, 2000 mesh zımpara ile zımparalandı sonrasında distile su ile temizlendi ve 1 μ m alümina kullanılarak parlatıldı, sonra tekrar distile su, ardından alkol ile temizlendi ve saç kurutma makinesi ile kurutuldu. Ardından nital solüsyonu (%3 nitrik asit, %97 etil alkol) ile dağlandı ve tekrar distile su, ardından alkol ile yıkandı ve kurutma işlemine tabi tutuldu. Mikroyapı görüntüsü alma işlemleri, Nikon optik mikroskop (OM) ile yapıldı. Carl Zeiss Ultra Plus Gemini, tarayıcı elektron mikroskobu ile (SEM) görüntüsü alma işlemleri yapıldı [2].

Sertlik Test Metodu

Deneydeki sertlik ölçümleri Bulut sertlik test cihazı kullanılarak Brinell sertlik ölçme metoduna göre ölçülmüştür. Alaşımların sertlik testleri için numuneler hazırlanmış ve numuneler 2.5 mm çapında bilye ile 10 s süresince 187.5 kg yük uygulanarak 5 farklı noktadan ölçülmüş ve bu rakamların ortalaması alınarak ortalama sertlik değerleri elde edilmiştir [2].

Çekme Testi Metodu

Alaşımlar itina ile tornalanmış ve çekme test numuneleri ASTM E8 M-04'te belirtilen standartlara göre hazırlanmıştır. Çekme test numuneleri Karabük Üniversitesi Teknoloji Fakültesi laboratuvarındaki SHIMADZU çekme testi cihazı ile 0.5 (mm/dk) çekme hızı ile gerçekleştirilmiştir. Her alaşım için 3 adet çekme testi numunesi test edilmiş ve elde edilen değerlerin ortalamaları alınarak sonuca ulaşılmıştır [2]. Çekme testinde kullanılan numune tipinin görüntüsü Şekil 1.'de gösterilmektedir. Şekil 1. ve Şekil 2.'de gösterilen katı modeller Sinop Üniversitesi laboratuvarlarında bulunan lisanslı çizim programında çizilmiştir.



Şekil 1. Çekme testi numunelerinin katı modeli (a) Ön görünüş (b) Yan görünüş

Darbe çentik testi metodu

Alaşımların her birinden 3 adet Charpy çentik darbe test numunesinin hazırlanması için, döküm parçalar freze tezgahında TS 269'a uygun ölçülerde işlenmiştir [9]. Hazırlanan numunelerin tipini göstermek amacıyla hazırlanmış hali Şekil 2.'de verilmiştir.



Şekil 2. Çentik darbe (Charpy) testi numunelerinin katı modeli (a) Ön görünüş (b) Yan görünüş

DeneySEL Sonuçlar ve Tartışma

Alaşımların Kompozisyon Testi Sonucu

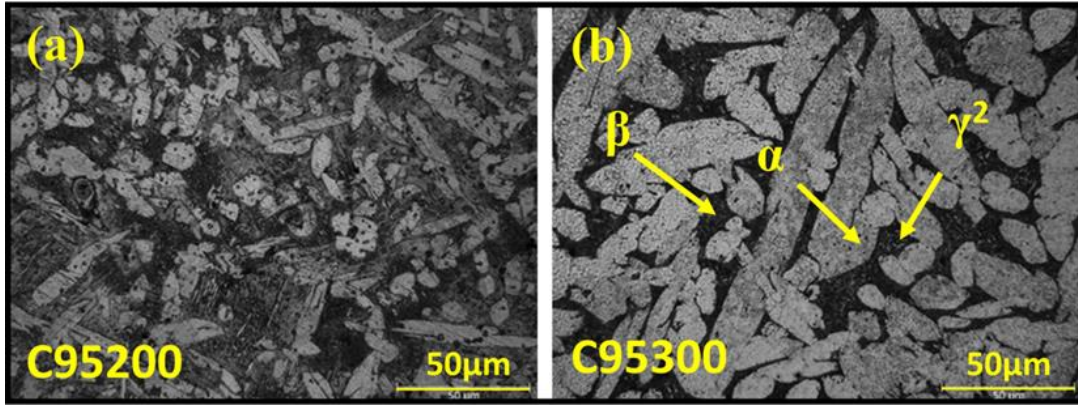
Üretilen alaşımların kompozisyonunun (ASTM B148-78a) ASTM standartları çerçevesinde belirlenen aralığa uygun olduğu tespit edilmiştir. Alaşımlarda bulunan kompozisyon Tablo 1.'de gösterilmektedir.

Tablo 1. Alaşımların kompozisyonu [10]

Alaşım	% Al	% Fe	% Sn	% Ni	% Si	% Pb	% Zn	% Cu
C95200	8.678	2.510	0.043	0.006	0.062	0.016	0.116	Kalan
C95300	10.105	0.983	0.038	0.003	0.073	0.018	0.115	Kalan

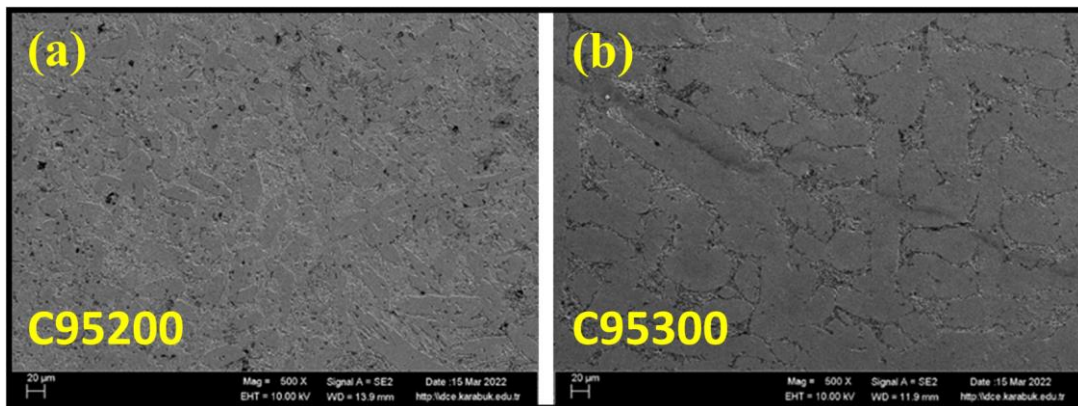
Mikroyapı Testi Sonucu

Döküm sonrası hazırlanan Al bronz numunelerinden alınan optik mikroskop mikroyapı görüntüleri Şekil 3. (a) ve (b)'de gösterilmektedir. C95200 alaşımı Fe bakımından, C95300 alaşımı Al bakımından daha zengindir. Al miktarının artmasıyla yapıda çift fazlı yapı artar ve alaşımın yoğunluğu düşer. Al bronz mikroyapısı içerisinde birtakım fazlar bulunmaktadır. Bu fazlar α , β ve γ^2 olarak sıralanabilir. Bu fazların bulunduğu bölgeler Şekil 3. (b)'de gösterilmektedir.



Şekil 3. (a) C95200 ve (b) C95300 Al bronzlarının mikroyapı görüntüleri

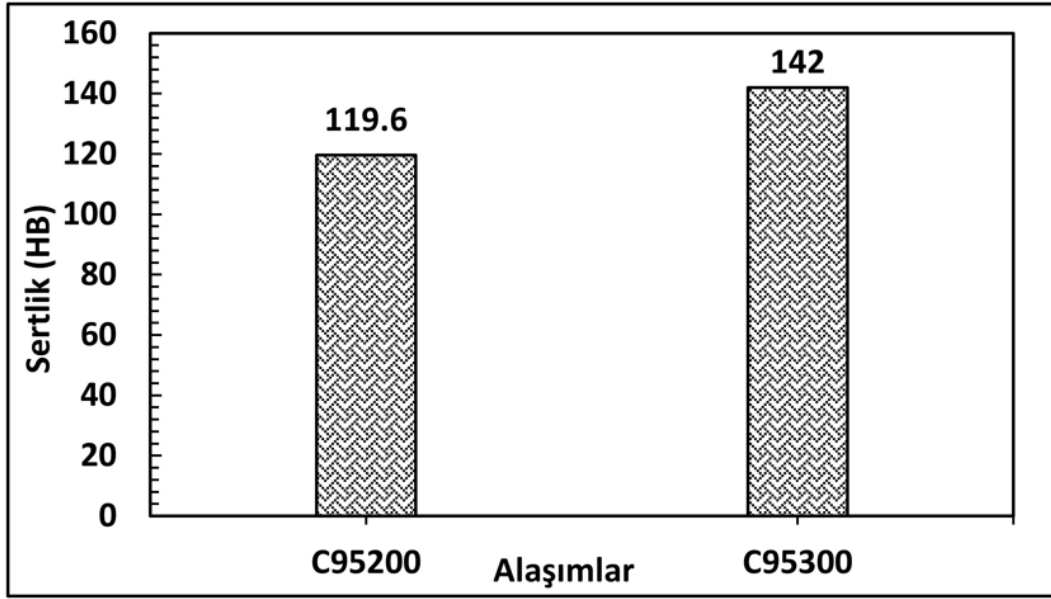
Şekil 4. (a)'da C95200 alaşımı oda sıcaklığında α fazı halindedir. Şekil 4. (b)'de C95300 alaşımında α ve tane sınırlarında ikincil faz β olarak bildirilmiştir. Alüminyum bronz perlit olarak anılan β fazı ($\alpha + \gamma^2$) literatürde açıklanmıştır. Perlitik yapılar çeliklerdeki gibi lamellidir. Oda sıcaklığı koşullarında β yapısına sahip ve çift fazlıdır [2, 10, 11, 12]. Bir diğer çalışmada bulunan mikroyapıda görülen, yüksek sertliğe ve düşük süneklığe sahip olan baskın bir β' matrisinde α çökeltilerinin seyrek dağılımının varlığı bildirilmiştir [13].



Şekil 4. (a) C95200 ve (b) C95300 Al bronzlarının SEM görüntüleri

Sertlik Testi Sonucu

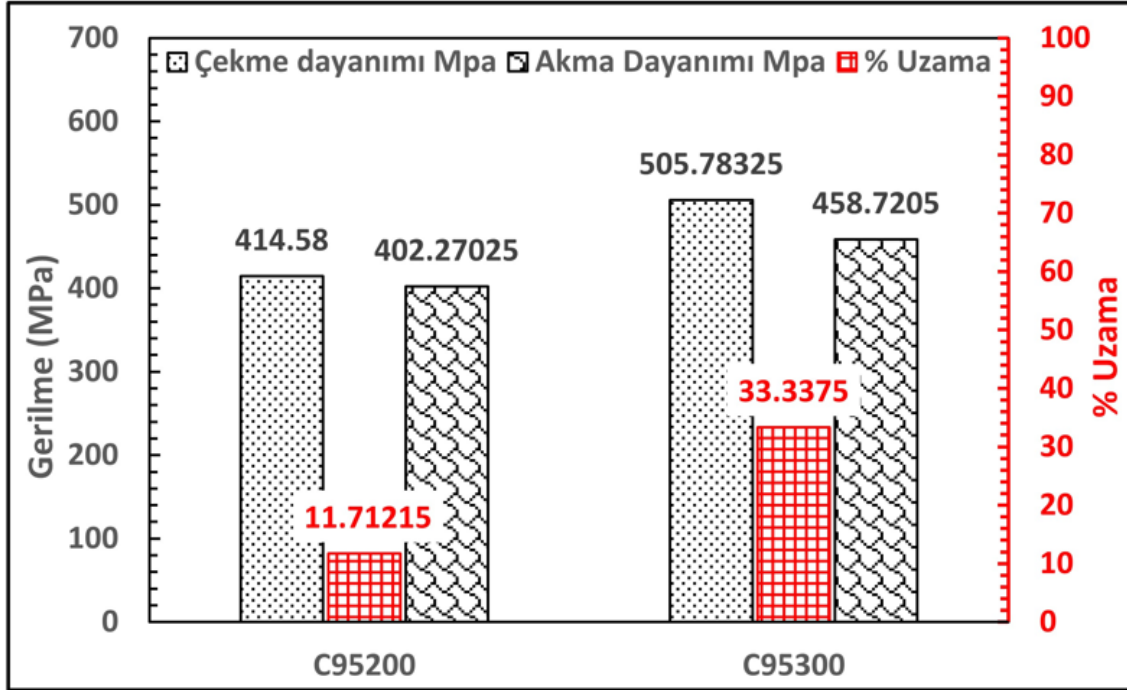
C95200 ve C95300 Al bronzları üzerinden alınan sertlik sonuçlarının ortalamaları Şekil 5.'te verilmiştir. C95300 alaşımının sertliği C95200 alaşımına göre (%18.72) daha yüksek olarak bulunmuştur. C95300 alaşımının sertliğinin mikroyapıda bulunan ve bakır-alüminyum denge diyagramında var olan γ^2 fazı oluşması sonrası daha fazla artış gösterdiği görülmektedir. Mikroyapı içerisindeki β fazı α fazından daha serttir ve matrisin sünekliliğine ve korozyon direncine katkı sunmaktadır [2, 14].



Şekil 5. C95200 ve C95300 Al bronzlarının sertlik sonuçları

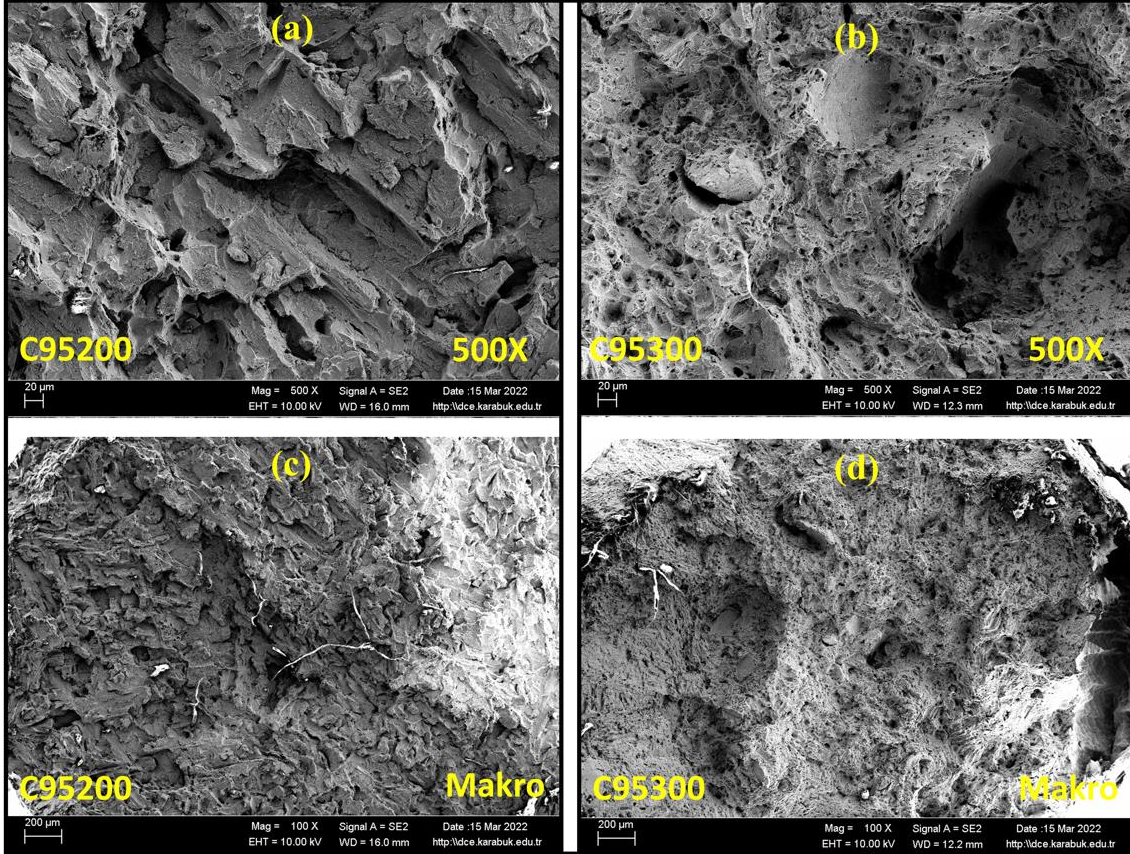
Çekme Testi Sonucu

Literatürde geleneksel olarak kullanılan yapısal alaşımlara göre alüminyum bronzunun daha iyi mekanik özelliklere ve mikro yapıya sahip alaşımlar olarak üretilebildiği rapor edilmiştir. Özenle seçilmiş (%11) Al içerikli çift fazlı alüminyum bronzun üretiminde kum dökümün, düşük maliyet, kullanım kolaylığı ve esnek avantajları nedeniyle etkili bulunduğu belirtilmiştir. (%11) Al içeren çift fazlı alüminyum bronzu üzerinde yapılan çalışmada, soğuk deformasyon sonrası uygulanan ısı işlemlerle mekanik özelliklerin optimum noktalara geldiği bildirilmiştir [13]. Bakır alüminyum alaşımına silikon ilavesi ile oluşan ikincil faz parçacıklarının çekme ile akma mukavemetini ve sertliği arttırdığı belirtilmiştir [15]. Bu çalışmada Şekil 6. incelendiğinde C95300 alaşımında oluşan ikincil faz, mukavemet değerlerini arttırmıştır. Böylece çekme gerilmesi (%21.99), akma gerilmesi (%14.03), % uzama değerleri (%184.62) oranında C95200 alaşımına göre daha yüksek bulunmuştur.



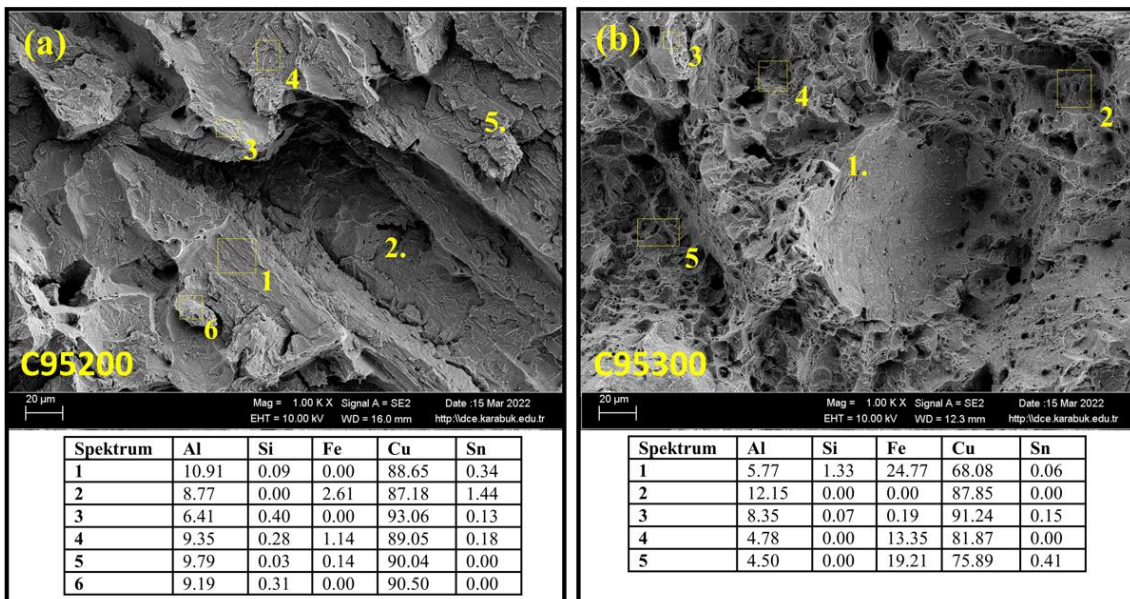
Şekil 6. C95200 ve C95300 Al bronzlarının çekme testi sonuçları

Şekil 7.'de C95200 ve C95300 Al bronzlarının çekme testi sonrası kırık yüzey görüntüleri görülmektedir. Şekil 7. (a) ve (b) alaşımlarının SEM görüntülerini, Şekil 7. (c) ve (d) alaşımların makro SEM görüntülerini göstermektedir. Al bronzlarındaki mekanik özellikler ilave edilen elementlerin miktarı ile değişiklik gösterir. En önemli element alüminyum olarak göze çarpmaktadır. C95300 alaşımında Al miktarının artmasıyla oluşan β fazı ile çift fazlı bir mikroyapı meydana gelmiştir. Böylece C95300 alaşımı daha sert ve daha düşük yoğunluğa sahip olmuştur. C95200 alaşımında yaklaşık (%2.5) demir, (%8.7) Al içerirken, C95300 alaşımı yaklaşık (%1) demir, (%10) Al içermektedir [2, 10, 13] Şekil 7. (a) ve (b)'deki çekme sonrası oluşan kırık yüzey görüntüleri incelendiğinde oluşan β fazından dolayı C95300 alaşımının daha sık yüzey kopuşları yaşadığı görülmektedir.



Şekil 7. C95200 ve C95300 Al bronzlarının çekme testi sonrası kırık yüzey SEM resimleri

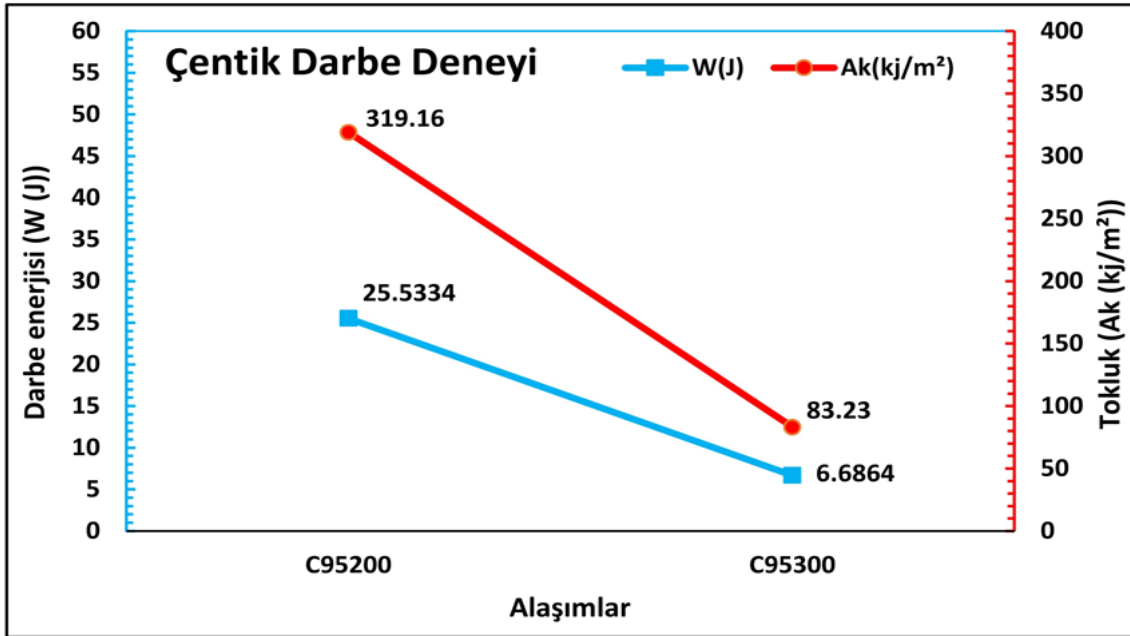
Şekil 8.'de C95200 ve C95300 Al bronzlarının çekme testi sonrası kırık yüzey EDX analiz sonuçları görülmektedir. Literatürdeki bir çalışmada kalıcı kalıp içine döküm yapılan alüminyum bronzu incelenmiştir. Mikroyapıda demir ile alüminyum içeren intermetalik bileşikler ($Al_{13}Fe_4$, Fe_3Al ve Al_3Fe_2) tespit edilmiştir. Bunun yanında küresel biçimde demir parçacıklarının bulunduğu ve bu parçacıkların alüminyum ile reaksiyona girmediği rapor edilmiştir [16].



Şekil 8. C95200 ve C95300 Al bronzlarının çekme testi sonrası kırık yüzey EDX analizi sonuçları

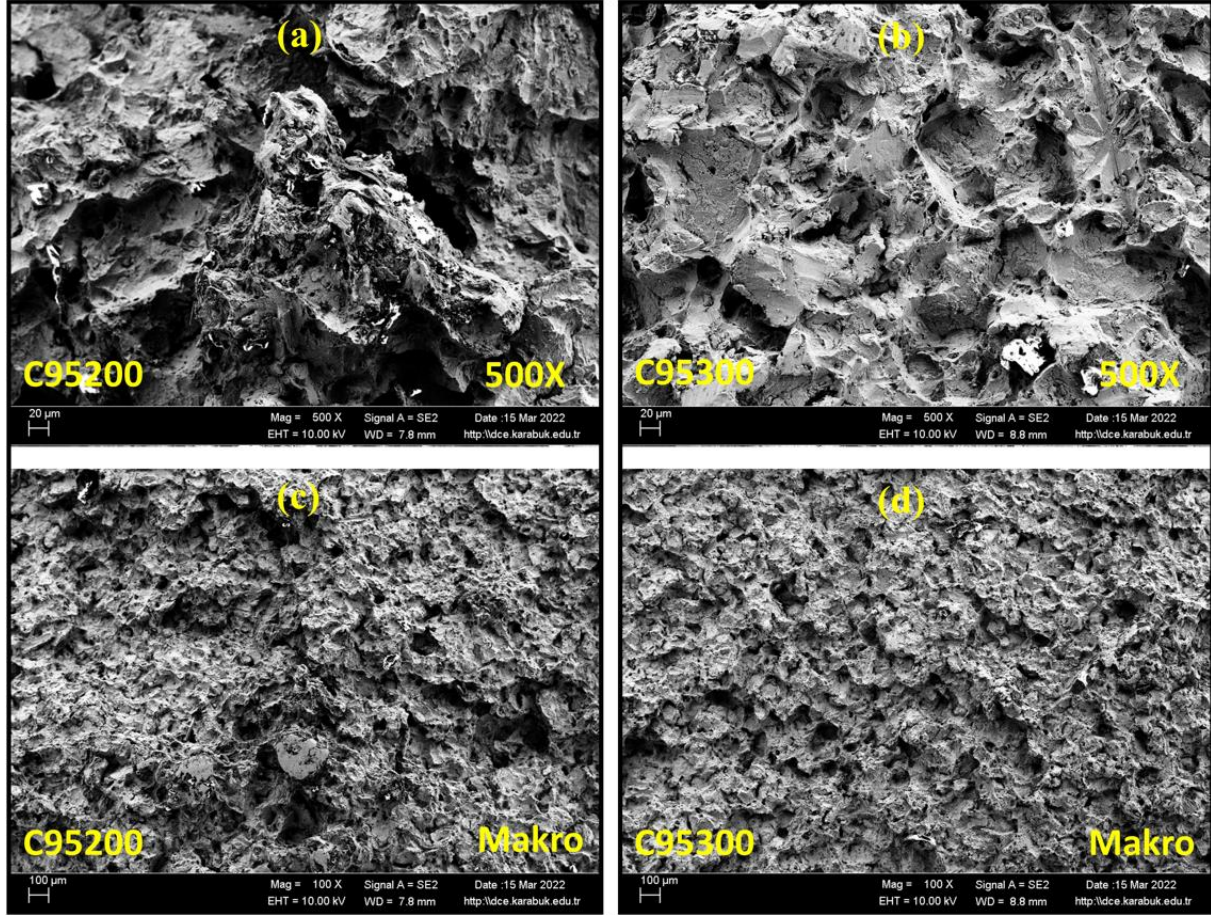
Çentik Darbe Testi Sonucu

Şekil 9.'da Al bronzlarının çentik darbe testi test sonuçları verilmiştir. Çentik darbe testinde darbe enerjisi joule (j) olarak, tokluk ise (kj/m²) olarak gösterilmiştir. C95300 alaşımının darbe direnci C95200 alaşımına göre daha düşüktür. Bu durum C95300'ün C95200'e göre (%18.72) daha sert olması ile açıklanabilir. Literatürde çift fazlı CuAl₉Fe₄ Al bronzlarının deniz suyu dahil sulu ortamlarda iyi bir mukavemete, yüksek yorulma direncine, aşınma, sürtünme ve korozyon direncine sahip olduğu belirtilmektedir. Bu özelliklere sahip CuAl₉Fe₄ Al bronzları agresif ortamlarda artan darbeler, değişen yükler altında çalışan kaymalı yatak burçlarının yapımında kullanılır. Al bronzlarından üretilmiş makina bileşenlerinin aşınma direnci büyük ölçüde yüzey bütünlüğüne bağlıdır. Belirlenmesi önemli bir mühendislik görevi olan çentik darbe konusunda bu alaşım özelinde az sayıda çalışma yapılmıştır [17].



Şekil 9. C95200 ve C95300 Al bronzlarının çentik darbe testi sonuçları

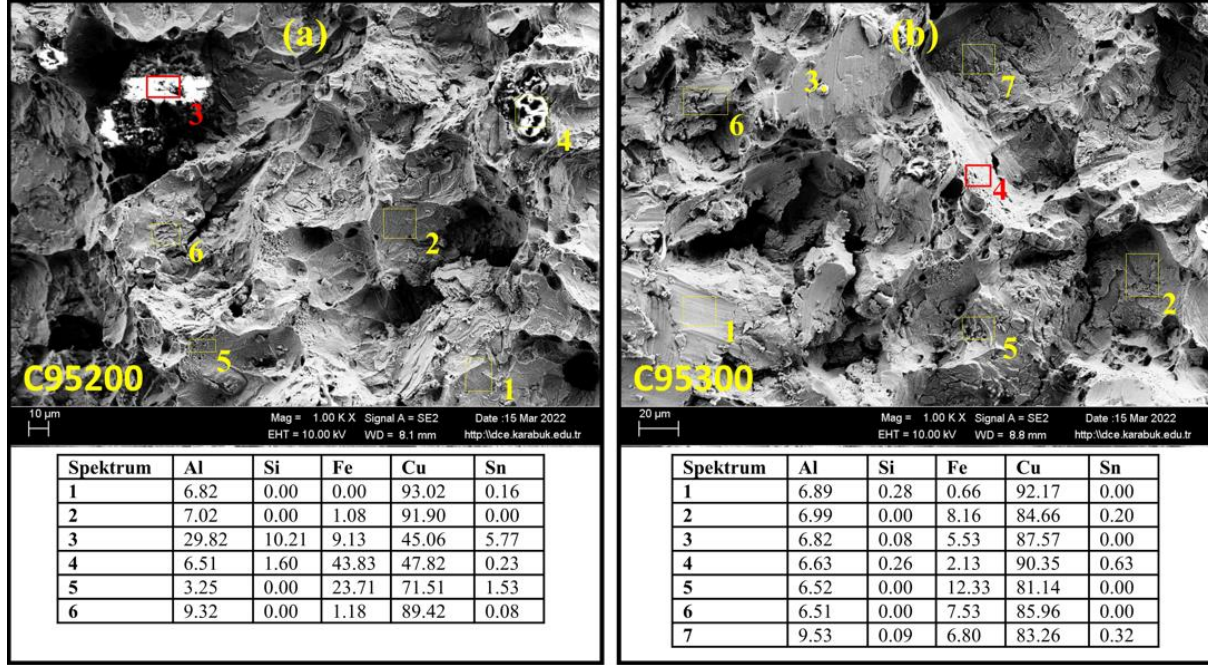
Şekil 10.'da C95200 ve C95300 Al bronzlarının çentik darbe testinde kırık yüzeyin SEM görüntüleri görülmektedir. Şekil 10 (a) ve (b)'de Al bronzlarının 500 X büyütülmüş görüntüsü, Şekil 10 (c) ve (d)'de Al bronzlarının makro görüntüleri sergilenmiştir.



Şekil 10. C95200 ve C95300 Al bronzlarının çentik darbe testi sonrası SEM görüntüleri

Literatürde CuAl_8Fe_3 bronzunun yüzey bütünlüğü açısından kayma ve aşınmaya karşı gösterdiği direncin, yüzey katmanında bulunan iki özellik grubuna bağlı olduğu belirtilmiştir. Bu özelliklerin geometrik olarak yüzey dokusu ve fiziksel-mekanik olarak mikro sertlik ve mikroyapı olduğu rapor edilmiştir [18]. Şekil 11.'de C95200 ve C95300 Al bronzlarının çentik darbe testinde kırık yüzeyin EDX analiz sonuçları görülmektedir. Malzeme yüzeyinde çentik darbe deneyi sonrasında gamze benzeri irili ufaklı çukurlar oluşmuştur. C95200 Alaşımının yüzeyinde oluşan çukurlar daha küçük olduğu görülmektedir. Yüzeyde oluşan çukurlar Al miktarı daha yüksek olan çift fazlı C95300 alaşımında daha büyük ölçekte oluşmuştur. Dökme nikel-alüminyum-bronz (NAB) UNS C95800 bronzu üzerinde yapılan incelemelerde standart Charpy numunesinde 27 Joule ile kırılmanın gerçekleştiği rapor edilmiştir. SEM görüntülerinde bu gevrek kırılma sonucunda farklı boyutlarda çukurların oluştuğu gözlemlenmiştir. Daha büyük çukurların MnS kalıntılarında çekirdeklendiği yani büyük çukurların çoğu manganez sülfür (MnS) olarak tanımlanan metalik olmayan kalıntılar içinde çekirdeklendiği görülmüştür. Çok küçük mikro çukur grubunun ise malzemenin kırılma dayanıklılığıyla ilişkilendirilebileceği bulunmuştur. Ayrıca malzeme, zararlı β' fazını ortadan kaldırmak için ısıtılma tabii tutulmuştur. Ayrıca hacimsel faz yüzdeleri hesapladıklarında (%7.4) Fe_3Al fazının varlığını rapor etmişlerdir [18]. Bu çalışmada alaşım kompozisyonunda Mn bulunmamaktadır fakat çukurların benzer şekilde meydana geldiği görülmüştür.

Tavares ve ark. [19]'daki çalışmalarında benzer şekilde makroskopik kırılğan görünüme rağmen, çekme numunesinin kırılmasının, taramalı elektron mikroskobu (SEM) incelemelerinde mikro çukurlar ile karakterize edildiğini bildirmişlerdir.



Şekil 11. C95200 ve C95300 Al bronzlarının çentik darbe testi sonuçları

Sonuçlar

Bu çalışmada C95200 ve C95300 Al bronzlarının döküm işlemi sonrasında alınan numunelerden elde edilen optik mikroskop, SEM ve EDX görüntüleri, mekanik özelliklerini belirlemede yardımcı olabilecek sertlik, çekme, çentik darbe testleri kapsamlı bir şekilde incelenmiştir. Bu testlerin sonuçları aşağıda değerlendirilmiştir.

Tane boyutu Fe % miktarı daha yüksek olan C95200'de, C95300 alaşımına göre daha küçüktür. Fe miktarı daha az fakat alüminyum miktarı daha fazla olan C95300 alaşımında tane sınırlarında ikincil faz (β) miktarı artmıştır. Ayrıca tane boyutu daha kaba hale gelmiştir. Sertlik sonuçları incelendiğinde C95300 alaşımının sertlik değeri çift fazlı yapıdan dolayı C95200 alaşımının sertliğine göre (%18.72) daha fazla olarak belirlenmiştir. Çekme testi sonuçlarında ikincil fazın etkisi ile C95300 alaşımının C95200 alaşımına göre çekme gerilmesinde (%21.99), akma gerilmesinde (%14.03), % uzama değerlerinde (%184.62) yükseklik gözlemlenmiştir. Çekme sonrası kırık yüzey SEM görüntüleri incelendiğinde C95300 alaşımının daha sık yüzeye sahip olduğu ve bölgesel gamzeli çukurlardan oluştuğu gözlemlenmiştir. Çentik darbe testi sonuçları incelendiğinde, C95200 alaşımının C95300 alaşımından darbe enerjisi bakımından (%383.46), tokluk açısından (%381.87) daha yüksek değere sahip olduğu bulunmuştur. C95300 alaşımının darbe direnci C95200'e göre daha azdır. C95200

alaşımına göre C95300 alaşımında Al miktarının arttığı, Fe miktarının azaldığı, ikincil fazdan dolayı sertliğinin arttığı ve yoğunluğunun düştüğü belirlenmiştir.

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Algebraic Solution of Gaunt Coefficients via the Angular Momentum Ladder Operators

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Research Article

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Abstract

In this study, Gaunt coefficients, frequently encountered in quantum mechanical calculations of atomic and molecular structures, have been algebraically derived. Firstly, the Gaunt coefficient, equal to the integral over the solid angle of the product of three spherical harmonics, is written in terms of angular momentum ladder operators. Subsequently, raising or lowering operators are applied to spherical harmonics, and the obtained integrals are solved using the recurrence and orthogonality relations of spherical harmonics. As a result, algebraic expressions for Gaunt coefficients are obtained in terms of quantum numbers.

Keywords: Gaunt coefficients, ladder operators, spherical harmonics

Açısal Momentum Merdiven İşlecileri ile Gaunt Katsayılarının Cebirsel Çözümü

Sinop University, Faculty of
Education, Department of Science
Education, Sinop, Türkiye

Öz

Bu çalışmada, atomik ve moleküler yapıların kuantum mekaniksel hesaplamalarında sıklıkla karşılaşılan Gaunt katsayıları cebirsel olarak türetilmiştir. İlk olarak, üç küresel harmoniğin çarpımının katı açılı üzerinden integraline eşit olan Gaunt katsayısı, açısal momentum merdiven işlemcileri cinsinden yazılır. Daha sonra, yükseltme veya alçaltma işlemcileri küresel harmoniklere uygulanır ve elde edilen integralleri çözmek için küresel harmoniklerin tekrarlar ve diklik bağıntıları kullanılır. Sonuç olarak, Gaunt katsayıları için cebirsel ifadeler, kuantum sayıları cinsinden elde edilir.

Anahtar Kelimeler: Gaunt katsayıları, merdiven işlemcileri, küresel harmonikler

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Introduction

In quantum mechanics, two formulations are used: matrix mechanics and wave mechanics. In matrix mechanics, developed by Heisenberg in 1925, dynamical quantities such as position, energy, momentum, and angular momentum are expressed in terms of matrices defined using algebraic equations and commutation relations. Well-known applications of matrix mechanics in quantum

mechanics include the harmonic oscillator and angular momentum [1, 2]. Wave mechanics, which describes the dynamics of microscopic systems using the Schrödinger wave equation, was developed by Schrödinger in 1926. This method requires solving the Schrödinger wave equation, formulated as a second-order linear differential equation. For different potentials, power series, boundary conditions, and separation of variables methods are used for the analytical solution of the Schrödinger equation. Still, it cannot be solved exactly except for some simple systems, such as the hydrogen atom and the harmonic oscillator, and approximate methods are employed. The algebraic method, which depends on raising and lowering operators, is very useful for systems with a finite-dimensional matrix, such as angular momentum. This is because while the orbital angular momentum quantum number l has a certain value, the magnetic quantum number m takes a value of $2l + 1$, and the angular momentum is represented by $2l + 1$ dimensional matrices. In the case of a spherically symmetric potential, the Hamiltonian operator exhibits commutation with both the squared angular momentum operator and its z-component. As a consequence of this commutative behavior, these operators share identical eigenfunctions. These eigenfunctions are precisely the spherical harmonics derived as solutions to the angular part of the Laplace equation in spherical coordinates. The angular momentum operator algebra is one of the most commonly used methods for deriving spherical harmonics. In this method, raising and lowering operators of angular momentum, also known as ladder operators, are applied to a state of spherical harmonics to obtain spherical harmonics corresponding to different states. Many textbooks and articles in the literature use this method [3-7]. In atomic and molecular systems, particles have spin angular and orbital angular momentum. While the orbital and spin angular momentums are not conserved separately, the total angular momentum equal to their vector sum is conserved. In this case, the linear combination coefficients connecting the reducible and irreducible representations are called Clebsch-Gordan coefficients. According to this, Clebsch-Gordan coefficients are the most general coefficients related to angular momentum. Other coefficients related to angular momentum, such as Gaunt, Wigner $3j$, and $6j$, are written in terms of Clebsch-Gordan coefficients. Clebsch-Gordan coefficients can be calculated by different methods, either analytically or using recurrence relations [8-19]. Based on the variational principle, the Hartree Fock Roothaan (HFR) method is a widely used approximate technique for calculating atoms or molecules' physical and chemical properties in multi-electron systems. When employing this method to determine any physical property, we encounter Gaunt coefficients, which represent the integral of the product of three spherical harmonics over solid angles [20]. Due to the vast number of Gaunt coefficients that need to be computed (often in the hundreds of thousands), it is crucial to calculate these coefficients accurately and efficiently. In the literature, Gaunt coefficients are usually expressed as the product of two Clebsch-Gordan coefficients or $3j$ symbols. Calculations for Gaunt coefficients are performed using the explicit expressions of these coefficients in terms of different functions or recurrence relations [16, 21-25]. Other approaches used in calculating Gaunt coefficients can be found in Refs. [26-30]. First, this paper introduces the angular momentum

ladder operators in the spherical coordinates and recurrence relations of spherical harmonics. Then, using these operators, the Gaunt coefficients, defined by integrating the tri-product of spherical harmonics, are calculated algebraically. Gaunt coefficients are given as master formulae based only on quantum numbers.

Angular Momentum Ladder Operators in the Spherical Coordinates

Since angular momentum has rotational symmetry, it is convenient to express the angular momentum operator $\hat{\mathbf{L}}$, which is defined by its three components \hat{L}_x , \hat{L}_y , and \hat{L}_z , in terms of spherical coordinates. In this case, the components of the angular momentum operator are expressed as [8-10].

$$\hat{L}_x = i\hbar \left(\sin\phi \frac{\partial}{\partial\theta} + \cot\theta \cos\phi \frac{\partial}{\partial\phi} \right) \quad (1)$$

$$\hat{L}_y = i\hbar \left(-\cos\phi \frac{\partial}{\partial\theta} + \cot\theta \sin\phi \frac{\partial}{\partial\phi} \right) \quad (2)$$

$$\hat{L}_z = -i\hbar \frac{\partial}{\partial\phi} \quad (3)$$

Using these equations, the operator \hat{L}^2 , which consists of the sum of the squares of its components, is obtained as follows.

$$\hat{L}^2 = -\hbar^2 \left[\frac{1}{\sin\theta} \frac{\partial}{\partial\theta} \left(\sin\theta \frac{\partial}{\partial\theta} \right) + \frac{1}{\sin^2\theta} \frac{\partial^2}{\partial\phi^2} \right] \quad (4)$$

Since the differential form of angular momentum operators depends only on the θ and ϕ angles, their eigenfunctions are the spherical harmonics $Y_l^m(\theta, \phi)$. Accordingly, well-known eigenvalue equations of \hat{L}^2 and \hat{L}_z operators are given below.

$$\begin{aligned} \hat{L}^2 Y_l^m(\theta, \phi) &= l(l+1) \hbar^2 Y_l^m(\theta, \phi) \\ \hat{L}_z Y_l^m(\theta, \phi) &= m\hbar Y_l^m(\theta, \phi) \end{aligned} \quad (5)$$

When performing analytical operations on angular momentum, it is necessary to solve the differential equation of the associated Legendre functions $P_l^m(\cos\theta)$ given below.

$$\frac{1}{\sin\theta} \frac{d}{d\theta} \left(\sin\theta \frac{dP_l^m(\cos\theta)}{d\theta} \right) + \left\{ l(l+1) - \frac{m^2}{\sin^2\theta} \right\} P_l^m(\cos\theta) = 0 \quad (6)$$

For algebraic operations involving angular momentum, ladder operators need to be used. The angular momentum ladder operators, \hat{L}_+ and \hat{L}_- , are introduced as follows.

$$\hat{L}_{\pm} = \hat{L}_x \pm i\hat{L}_y = \pm\hbar e^{\pm i\phi} \left[\frac{\partial}{\partial\theta} \pm i\cot\theta \frac{\partial}{\partial\phi} \right] \quad (7)$$

Here \hat{L}_+ and \hat{L}_- are called raising (or creation) and lowering (or annihilation) operator, respectively. The following equation gives the action of angular momentum ladder operators on spherical harmonics:

$$\hat{L}_{\pm} Y_l^m(\theta, \phi) = \hbar [l(l+1) - m(m \pm 1)]^{1/2} Y_l^{m \pm 1}(\theta, \phi) \quad (8)$$

According to this equation, while the angular momentum quantum number l remains unchanged, the magnetic quantum number m increases or decreases by one.

Recurrence Relations for Spherical Harmonics

In quantum mechanics, the spherical harmonics, $Y_l^m(\theta, \phi)$, that constitute the angular part of the wave function are also eigenfunctions of the orbital angular momentum operators \hat{L}^2 , \hat{L}_z and \hat{L}_\pm . $Y_l^m(\theta, \phi)$ is defined as below for non-negative values of m magnetic quantum number [31].

$$Y_l^m(\theta, \phi) = (-1)^m \sqrt{\frac{2l+1}{4\pi} \frac{(l-m)!}{(l+m)!}} P_l^m(\cos\theta) e^{im\phi} \quad (9)$$

Where $P_l^m(\cos\theta)$ is represented as the associated Legendre polynomial. Also, for negative values of m we have

$$Y_l^{-m}(\theta, \phi) = (-1)^m Y_l^{m*}(\theta, \phi) \quad (10)$$

Spherical harmonics are orthogonal functions and orthogonality relation is given by

$$\int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} Y_{l_1}^{m_1*}(\theta, \phi) Y_{l_2}^{m_2}(\theta, \phi) \sin\theta d\theta d\phi = \delta_{l_1, l_2} \delta_{m_1, m_2} \quad (11)$$

Using the recurrence relations of the associated Legendre polynomials, recurrence relations can be written for spherical harmonics. Some of these relations, which are very useful in solving integrals consisting of the product of trigonometric functions and spherical harmonics, are given below [11, 31].

$$\cos\theta Y_l^m(\theta, \phi) = \sqrt{\frac{(l-m+1)(l+m+1)}{(2l+1)(2l+3)}} Y_{l+1}^m(\theta, \phi) + \sqrt{\frac{(l-m)(l+m)}{(2l-1)(2l+1)}} Y_{l-1}^m(\theta, \phi) \quad (12)$$

$$e^{i\phi} \sin\theta Y_l^m(\theta, \phi) =$$

$$-\sqrt{\frac{(l+m+1)(l+m+2)}{(2l+1)(2l+3)}} Y_{l+1}^{m+1}(\theta, \phi) + \sqrt{\frac{(l-m-1)(l-m)}{(2l-1)(2l+1)}} Y_{l-1}^{m+1}(\theta, \phi) \quad (13)$$

$$e^{-i\phi} \sin\theta Y_l^m(\theta, \phi) =$$

$$\sqrt{\frac{(l-m+1)(l-m+2)}{(2l+1)(2l+3)}} Y_{l+1}^{m-1}(\theta, \phi) - \sqrt{\frac{(l+m-1)(l+m)}{(2l-1)(2l+1)}} Y_{l-1}^{m-1}(\theta, \phi) \quad (14)$$

$$(2l-1)(2l+3) \cos^2\theta Y_l^m(\theta, \phi) =$$

$$(2l-1) \sqrt{\frac{((l+1)^2 - m^2)((l+2)^2 - m^2)}{(2l+1)(2l+5)}} Y_{l+2}^m(\theta, \phi)$$

$$\begin{aligned}
& +(2l(l+1) - 2m^2 - 1) Y_l^m(\theta, \phi) \\
& +(2l+3) \sqrt{\frac{(l^2 - m^2)((l-1)^2 - m^2)}{(2l+1)(2l-3)}} Y_{l-2}^m(\theta, \phi) \quad (15)
\end{aligned}$$

$$\begin{aligned}
(2l-1)(2l+3) \sin\theta \cos\theta e^{i\phi} Y_l^m(\theta, \phi) = \\
& -(2l-1) \sqrt{\frac{((l+1)^2 - m^2)(l+m+2)(l+m+3)}{(2l+1)(2l+5)}} Y_{l+2}^{m+1}(\theta, \phi) \\
& -(2m+1) \sqrt{(l-m)(l+m+1)} Y_l^{m+1}(\theta, \phi) \\
& +(2l+3) \sqrt{\frac{(l^2 - m^2)(l-m-1)(l-m-2)}{(2l+1)(2l-3)}} Y_{l-2}^{m+1}(\theta, \phi) \quad (16)
\end{aligned}$$

$$\begin{aligned}
(2l-1)(2l+3) \sin\theta \cos\theta e^{-i\phi} Y_l^m(\theta, \phi) = \\
& (2l-1) \sqrt{\frac{((l+1)^2 - m^2)(l-m+2)(l-m+3)}{(2l+1)(2l+5)}} Y_{l+2}^{m-1}(\theta, \phi) \\
& -(2m-1) \sqrt{(l+m)(l-m+1)} Y_l^{m-1}(\theta, \phi) \\
& -(2l+3) \sqrt{\frac{(l^2 - m^2)(l+m-1)(l+m-2)}{(2l+1)(2l-3)}} Y_{l-2}^{m-1}(\theta, \phi) \quad (17)
\end{aligned}$$

$$\begin{aligned}
(2l-1)(2l+3) \sin^2\theta e^{2i\phi} Y_l^m(\theta, \phi) = & \frac{(2l-1)}{\sqrt{(2l+1)(2l+5)}} \sqrt{\frac{(l+m+4)!}{(l+m)!}} Y_{l+2}^{m+2}(\theta, \phi) \\
& -2 \sqrt{\frac{(l+m+2)!(l-m)!}{(l-m-2)!(l+m)!}} Y_l^{m+2}(\theta, \phi) \\
& + \frac{(2l+3)}{\sqrt{(2l+1)(2l-3)}} \sqrt{\frac{(l-m)!}{(l-m-4)!}} Y_{l-2}^{m+2}(\theta, \phi) \quad (18)
\end{aligned}$$

$$\begin{aligned}
(2l-1)(2l+3) \sin^2 \theta e^{-2i\phi} Y_l^m(\theta, \phi) &= \frac{(2l-1)}{\sqrt{(2l+1)(2l+5)}} \sqrt{\frac{(l-m+4)!}{(l-m)!}} Y_{l+2}^{m-2}(\theta, \phi) \\
&\quad - 2 \sqrt{\frac{(l-m+2)!(l+m)!}{(l+m-2)!(l-m)!}} Y_l^{m-2}(\theta, \phi) \\
&\quad + \frac{(2l+3)}{\sqrt{(2l+1)(2l-3)}} \sqrt{\frac{(l+m)!}{(l+m-4)!}} Y_{l-2}^{m-2}(\theta, \phi) \quad (19)
\end{aligned}$$

Algebraic Derivation of Gaunt Coefficients

The Gaunt coefficients are defined by the integral of the product of three spherical harmonics, $Y_l^m(\theta, \phi)$, or associated Legendre functions over solid angles by Gaunt [20].

$$Y_{l_1 m_1, l_2 m_2}^l = \int_0^{2\pi} \int_0^\pi Y_{l_1}^{m_1*}(\theta, \phi) Y_{l_2}^{m_2}(\theta, \phi) Y_l^m(\theta, \phi) \sin\theta d\theta d\phi \quad (20)$$

Where selection rules are $m = m_1 - m_2$ and $|l_1 - l_2| \leq l \leq l_1 + l_2$.

The Gaunt coefficients can be expressed using the lowering and raising operators given in Eq. (8).

$$\begin{aligned}
Y_{l_1 m_1, l_2 m_2}^l &= \frac{1}{\hbar \sqrt{l_2(l_2+1) - m_2(m_2-1)}} \\
&\quad \int_0^{2\pi} \int_0^\pi Y_{l_1}^{m_1*}(\theta, \phi) (\hat{L}_+ Y_{l_2}^{m_2-1}(\theta, \phi)) Y_l^m(\theta, \phi) \sin\theta d\theta d\phi \quad (21)
\end{aligned}$$

$$\begin{aligned}
&= \frac{1}{\hbar \sqrt{l_2(l_2+1) - m_2(m_2+1)}} \\
&\quad \int_0^{2\pi} \int_0^\pi Y_{l_1}^{m_1*}(\theta, \phi) (\hat{L}_- Y_{l_2}^{m_2+1}(\theta, \phi)) Y_l^m(\theta, \phi) \sin\theta d\theta d\phi \quad (22)
\end{aligned}$$

In Eq. (20), if we use $Y_{l_2}^{m_2}(\theta, \phi) = Y_0^0(\theta, \phi) = 1/\sqrt{4\pi}$ and the orthogonality relation of spherical harmonics for $l_2 = 0$ and $m_2 = 0$ the Gaunt coefficient is obtained easily as:

$$Y_{l_1 m_1, 00}^l = \frac{1}{\sqrt{4\pi}} \delta_{l_1, l} \delta_{m_1, m} \quad (23)$$

For $l_2 = 1$, m_2 takes the values $-1, 0$ and 1 . To find the algebraic expressions of $Y_{l_1 m_1, 1 m_2}^l$ Gaunt coefficients we start $m_2 = 0$ value. For these values inserting $Y_{l_2}^{m_2}(\theta, \phi) = Y_1^0(\theta, \phi) = \sqrt{3/4\pi} \cos\theta$ relation into Eq. (20) the Gaunt coefficient can be written as below

$$Y_{l_1 m_1, 10}^{l m} = \sqrt{\frac{3}{4\pi}} \int_0^{2\pi} \int_0^\pi Y_{l_1}^{m_1*}(\theta, \phi) (\cos\theta Y_l^m(\theta, \phi)) \sin\theta d\theta d\phi \quad (24)$$

For the product of trigonometric function and spherical harmonic, we insert the recurrence relation of spherical harmonics given by Eq. (12) into Eq. (24). Then, using the orthogonality relation of spherical harmonics, for the values of $l_2 = 1$ and $m_2 = 0$ we obtain the Gaunt coefficient algebraically.

$$Y_{l_1 m_1, 10}^{l m} = \sqrt{\frac{3}{4\pi}} \left\{ \left\{ \frac{(l-m+1)(l+m+1)}{(2l+1)(2l+3)} \right\}^{1/2} \delta_{l_1, l+1} \delta_{m_1, m} + \left\{ \frac{(l-m)(l+m)}{(2l-1)(2l+1)} \right\}^{1/2} \delta_{l_1, l-1} \delta_{m_1, m} \right\} \quad (25)$$

To obtain the expression of $Y_{l_1 m_1, 11}^{l m}$ Gaunt coefficient from the $Y_{l_1 m_1, 10}^{l m}$, we use the definition of Gaunt coefficients given by the Eq. (21). Therefore, we apply the raising operator of angular momentum \hat{L}_+ to $Y_1^0(\theta, \phi)$ substituted in Eq. (21).

$$Y_{l_1 m_1, 11}^{l m} = \frac{1}{\sqrt{2}} \int_0^{2\pi} \int_0^\pi Y_{l_1}^{m_1*}(\theta, \phi) \left(\hat{L}_+(\sqrt{3/4\pi} \cos\theta) \right) Y_l^m(\theta, \phi) \sin\theta d\theta d\phi \quad (26)$$

Using the differential form of \hat{L}_+ operator given by Eq. (7) we have

$$Y_{l_1 m_1, 11}^{l m} = -\sqrt{\frac{3}{8\pi}} \int_0^{2\pi} \int_0^\pi Y_{l_1}^{m_1*}(\theta, \phi) (e^{i\phi} \sin\theta Y_l^m(\theta, \phi)) \sin\theta d\theta d\phi \quad (27)$$

Finally, when the recurrence relation given by Eq. (13) and orthogonality relation of spherical harmonics are used respectively in Eq. (27), for $l_2 = 1$ and $m_2 = 1$, the Gaunt coefficient $Y_{l_1 m_1, 11}^{l m}$ is algebraically obtained as follows.

$$Y_{l_1 m_1, 11}^{LM} = \sqrt{\frac{3}{8\pi}} \left\{ \left\{ \frac{(l+m+1)(l+m+2)}{(2l+1)(2l+3)} \right\}^{1/2} \delta_{l_1, l+1} \delta_{m_1, m+1} - \left\{ \frac{(l-m)(l-m-1)}{(2l-1)(2l+1)} \right\}^{1/2} \delta_{l_1, l-1} \delta_{m_1, m+1} \right\} \quad (28)$$

Since atomic units are used in these calculations, the Planck's constant \hbar is taken as 1.

For the values $l_2 = 1$ and $m_2 = -1$, when obtaining the expression of $Y_{l_1 m_1, 1-1}^{l m}$ Gaunt coefficient from $Y_{l_1 m_1, 10}^{l m}$, we use the definition of Gaunt coefficients given by the Eq. (22). To do this, we must apply the lowering operator of angular momentum \hat{L}_- to $Y_1^0(\theta, \phi)$ substituted in Eq. (22)

$$Y_{l_1 m_1, 1-1}^{l m} = \frac{1}{\sqrt{2}} \int_0^{2\pi} \int_0^\pi Y_{l_1}^{m_1*}(\theta, \phi) \left(\hat{L}_-(\sqrt{3/4\pi} \cos\theta) \right) Y_l^m(\theta, \phi) \sin\theta d\theta d\phi \quad (29)$$

and then we use the differential form of \hat{L}_- operator given by Eq. (7) in Eq. (29):

$$Y_{l_1 m_1, 1-1}^{l m} = -\sqrt{\frac{3}{8\pi}} \int_0^{2\pi} \int_0^\pi Y_{l_1}^{m_1*}(\theta, \phi) (e^{-i\phi} \sin\theta Y_l^m(\theta, \phi)) \sin\theta d\theta d\phi \quad (30)$$

Substitution of Eq. (14) into Eq. (30) and using orthogonality relation of spherical harmonics gives the algebraical expression of Gaunt coefficient for $l_2 = 1$ and $m_2 = -1$ as follows.

$$Y_{l_1 m_1, 1-1}^{l m} = \sqrt{\frac{3}{8\pi}} \left\{ \left\{ \frac{(l-m+1)(l-m+2)}{(2l+1)(2l+3)} \right\}^{1/2} \delta_{l_1, l+1} \delta_{m_1, m-1} - \left\{ \frac{(l+m)(l+m-1)}{(2l-1)(2l+1)} \right\}^{1/2} \delta_{l_1, l-1} \delta_{m_1, m-1} \right\} \quad (31)$$

In order to get algebraically the Gaunt coefficients with the value $l_2 = 2$ we start the value of $m_2 = 0$. To do this, $Y_{l_2}^{m_2}(\theta, \phi) = Y_2^0(\theta, \phi) = \sqrt{(5/16\pi)}(3\cos^2\theta - 1)$ is written in definition of the Gaunt coefficient $Y_{l_1 m_1, 2 0}^{LM}$ in Eq. (20).

$$Y_{l_1 m_1, 2 0}^{l m} = \sqrt{\frac{5}{16\pi}} \int_0^{2\pi} \int_0^\pi Y_{l_1}^{m_1*}(\theta, \phi) (3\cos^2\theta - 1) Y_l^m(\theta, \phi) \sin\theta d\theta d\phi \quad (32)$$

If we use Eq. (15) and the orthogonality relation of spherical harmonics, the algebraical expression of the $Y_{l_1 m_1, 2 0}^{LM}$ Gaunt coefficients is obtained easily in terms of Kronecker delta functions as follows.

$$Y_{l_1 m_1, 2 0}^{l m} = \sqrt{\frac{5}{16\pi}} \left\{ \frac{3}{(2l+3)} \left\{ \frac{((l+1)^2 - m^2)((l+2)^2 - m^2)}{(2l+1)(2l+5)} \right\}^{1/2} \delta_{l_1, l+2} \delta_{m_1, m} + \frac{(2l(l+1) - 6m^2)}{(2l-1)(2l+3)} \delta_{l_1, l} \delta_{m_1, m} + \frac{3}{(2l-1)} \left\{ \frac{(l^2 - m^2)((l-1)^2 - m^2)}{(2l+1)(2l-3)} \right\}^{1/2} \delta_{l_1, l-2} \delta_{m_1, m} \right\} \quad (33)$$

According to the Eq. (21), if the raising operator of angular momentum \hat{L}_+ is applied one time on $Y_{l_1 m_1, 2 0}^{lm}$, we obtain $Y_{l_1 m_1, 2 1}^{lm}$, if it is applied two times we obtain $Y_{l_1 m_1, 2 2}^{lm}$.

$$Y_{l_1 m_1, 2 1}^{l m} = \frac{3}{2} \sqrt{\frac{5}{6\pi}} \left\{ \frac{1}{(2l+3)} \left\{ \frac{((l+1)^2 - m^2)(l+m+2)(l+m+3)}{(2l+1)(2l+5)} \right\}^{1/2} \delta_{l_1, l+2} \delta_{m_1, m+1} + \frac{(2m+1)\sqrt{(l-m)(l+m+1)}}{(2l-1)(2l+3)} \delta_{l_1, l} \delta_{m_1, m+1} \right\}$$

$$-\frac{1}{(2l-1)} \left\{ \frac{(l^2 - m^2)(l-m-1)(l-m-2)}{(2l+1)(2l-3)} \right\}^{1/2} \delta_{l_1, l-2} \delta_{m_1, m+1} \quad (34)$$

$$Y_{l_1 m_1, 22}^{lm} = \frac{3}{4} \sqrt{\frac{5}{6\pi}} \left\{ \frac{1}{(2l+3)\sqrt{(2l+1)(2l+5)}} \sqrt{\frac{(l+m+4)!}{(l+m)!}} \delta_{l_1, l+2} \delta_{m_1, m+2} \right. \\ \left. + \frac{1}{(2l-1)\sqrt{(2l+1)(2l-3)}} \sqrt{\frac{(l-m)!}{(l-m-4)!}} \delta_{l_1, l-2} \delta_{m_1, m+2} \right. \\ \left. - \frac{2}{(2l-1)(2l+3)} \sqrt{\frac{(l+m+2)!(l-m)!}{(l-m-2)!(l+m)!}} \delta_{l_1, l} \delta_{m_1, m+2} \right\} \quad (35)$$

Similarly, to calculate $Y_{l_1 m_1, 2-1}^{lm}$ we must apply one time the lowering operator of angular momentum \hat{L}_- on $Y_{l_1 m_1, 20}^{lm}$.

$$Y_{l_1 m_1, 2-1}^{lm} = \frac{3}{2} \sqrt{\frac{5}{6\pi}} \left\{ \frac{1}{(2l+3)} \left\{ \frac{((l+1)^2 - m^2)(l-m+2)(l-m+3)}{(2l+1)(2l+5)} \right\}^{1/2} \delta_{l_1, l+2} \delta_{m_1, m-1} \right. \\ \left. - \frac{(2m-1)\sqrt{(l+m)(l-m+1)}}{(2l-1)(2l+3)} \delta_{l_1, l} \delta_{m_1, m-1} \right. \\ \left. - \frac{1}{(2l-1)} \left\{ \frac{(l^2 - m^2)(l+m-1)(l+m-2)}{(2l+1)(2l-3)} \right\}^{1/2} \delta_{l_1, l-2} \delta_{m_1, m-1} \right\} \quad (36)$$

If we apply two time the lowering operator of angular momentum \hat{L}_- on $Y_{l_1 m_1, 20}^{lm}$, we find that

$$Y_{l_1 m_1, 2-2}^{lm} = \frac{3}{4} \sqrt{\frac{5}{6\pi}} \left\{ \frac{1}{(2l+3)\sqrt{(2l+1)(2l+5)}} \sqrt{\frac{(l-m+4)!}{(l-m)!}} \delta_{l_1, l+2} \delta_{m_1, m-2} \right. \\ \left. + \frac{1}{(2l-1)\sqrt{(2l+1)(2l-3)}} \sqrt{\frac{(l+m)!}{(l+m-4)!}} \delta_{l_1, l-2} \delta_{m_1, m-2} \right. \\ \left. - \frac{2}{(2l-1)(2l+3)} \sqrt{\frac{(l-m+2)!(l+m)!}{(l+m-2)!(l-m)!}} \delta_{l_1, l} \delta_{m_1, m-2} \right\} \quad (37)$$

Results

Spherical harmonics are orthogonal functions that depend on polar (θ) and azimuth (ϕ) angles. Using ladder operators when numerically calculating the Gaunt coefficients obtained from the integral of the product of three spherical harmonics as given Eq. (20), since the integral over azimuth angles have the following value.

$$\int_0^{2\pi} e^{i(-m_1+m_2+m)\phi} d\phi = 2\pi\delta_{-m_1+m_2+m,0} \quad (38)$$

According to this result, the selection rule based on magnetic quantum numbers must satisfy the $-m_1 + m_2 + m = 0$ condition for the Gaunt coefficients to be different from zero. The remaining integral over polar angles consists of the product of three associated Legendre polynomials. In some special cases, this integral takes the following form.

$$\int_0^\pi P_{l_1}^{m_1}(\cos\theta) f(\theta) P_l^m(\cos\theta) \sin\theta d\theta \quad (39)$$

Here, $f(\theta)$ is a function depending on trigonometric functions. Using the recurrence relation of associated Legendre polynomials, the product $f(\theta)P_l^m(\cos\theta)$ is written as the sum of associated Legendre polynomials of different degrees. After this process is performed, the integral over polar angles becomes the integral of the product of two associated Legendre polynomials. This gives the orthogonality relation for associated Legendre polynomials given below.

$$\int_0^\pi P_{l_1}^m(\cos\theta) P_l^m(\cos\theta) \sin\theta d\theta = \frac{2}{2l+1} \frac{(l+m)!}{(l-m)!} \delta_{l_1,l} \quad (40)$$

This result demonstrates that the selection rules depending on the orbital angular momentum quantum number are $l_1 + l_2 + l = 2n$. Here n is an integer. In solutions using algebraic methods, the encountered integrals can be easily solved using the functions' orthogonality relations and recurrence relations without the need to solve integral and differential equations. Whichever method is used, analytic or algebraic, the physical results are the same, even if the obtained mathematical expressions differ. In this paper, the Gaunt coefficients are derived algebraically using the definition given in Eq. (20). To do this, angular momentum ladder operators, which are frequently used in the derivation of spherical harmonics in quantum mechanics, are applied to $Y_{l_2}^{m_2}(\theta, \phi)$ in Eq. (20). We start with the case $m_2 = 0$, which corresponds a given value of l_2 . As given in Eq. (21) and Eq. (22), applying the raising operator \hat{L}_+ we get the cases $m_2 > 0$ and applying the lowering operator \hat{L}_- we get the cases $m_2 < 0$. This algebraic operation is performed for all physical values of the m_2 magnetic quantum number, corresponding to the constant values $l_2 = 0, 1, 2$. As can be seen from the derived algebraic expressions in Eqs. (23, 25, 28, 31, 33, 34, 35, 36, 37), the values of the l_1 and m_1 are determined by the values of l and m quantum numbers. Accordingly, the algebraic formulae given for Gaunt coefficients in the 5th column of Table

1 are expressed solely in the l and m quantum numbers. Gaunt coefficients can be easily computed by substituting the desired physical values into the l and m quantum numbers, as indicated in Table 1.

Table 1. Algebraic expressions of Gaunt coefficients for $l_2 = 0, 1, 2$ values

l_1	m_1	l_2	m_2	$Y_{l_1 m_1 l_2 m_2}^{l m}$
l	m	0	0	$1/\sqrt{4\pi}$
$l+1$	m	1	0	$\sqrt{\frac{3(l-m+1)(l+m+1)}{4\pi(2l+1)(2l+3)}}$
$l-1$	m	1	0	$\sqrt{\frac{3(l-m)(l+m)}{4\pi(2l-1)(2l+1)}}$
$l+1$	$m+1$	1	1	$\sqrt{\frac{3(l+m+1)(l+m+2)}{8\pi(2l+1)(2l+3)}}$
$l-1$	$m+1$	1	1	$-\sqrt{\frac{3(l-m)(l-m-1)}{8\pi(2l-1)(2l+1)}}$
$l+1$	$m-1$	1	-1	$\sqrt{\frac{3(l-m+1)(l-m+2)}{8\pi(2l+1)(2l+3)}}$
$l-1$	$m-1$	1	-1	$-\sqrt{\frac{3(l+m)(l+m-1)}{8\pi(2l-1)(2l+1)}}$
$l+2$	m	2	0	$\frac{3}{(2l+3)}\sqrt{\frac{5((l+1)^2-m^2)((l+2)^2-m^2)}{16\pi(2l+1)(2l+5)}}$
l	m	2	0	$\sqrt{\frac{5(2l(l+1)-6m^2)}{16\pi(2l-1)(2l+3)}}$
$l-2$	m	2	0	$\frac{3}{(2l-1)}\sqrt{\frac{5(l^2-m^2)((l-1)^2-m^2)}{16\pi(2l+1)(2l-3)}}$
$l+2$	$m+1$	2	1	$\frac{3}{(2l+3)}\sqrt{\frac{5((l+1)^2-m^2)(l+m+2)(l+m+3)}{24\pi(2l+1)(2l+5)}}$
l	$m+1$	2	1	$\frac{3(2m+1)}{(2l-1)(2l+3)}\sqrt{\frac{5(l-m)(l+m+1)}{24\pi}}$
$l-2$	$m+1$	2	1	$-\frac{3}{(2l-1)}\sqrt{\frac{5(l^2-m^2)(l-m-1)(l-m-2)}{24\pi(2l+1)(2l-3)}}$
$l+2$	$m+2$	2	2	$\frac{3}{(2l+3)\sqrt{(2l+1)(2l+5)}}\sqrt{\frac{5(l+m+4)!}{96\pi(l+m)!}}$
l	$m+2$	2	2	$-\frac{6}{(2l-1)(2l+3)}\sqrt{\frac{5(l+m+2)!(l-m)!}{96\pi(l-m-2)!(l+m)!}}$
$l-2$	$m+2$	2	2	$\frac{3}{(2l-1)\sqrt{(2l+1)(2l-3)}}\sqrt{\frac{5(l-m)!}{96\pi(l-m-4)!}}$
$l+2$	$m-1$	2	-1	$\frac{3}{(2l+3)}\sqrt{\frac{5((l+1)^2-m^2)(l-m+2)(l-m+3)}{24\pi(2l+1)(2l+5)}}$

Table 1. ...continued

l	$m - 1$	2	-1	$-\frac{3(2m - 1)}{(2l - 1)(2l + 3)} \sqrt{\frac{5(l + m)(l - m + 1)}{24\pi}}$
$l - 2$	$m - 1$	2	-1	$-\frac{3}{(2l - 1)} \sqrt{\frac{5(l^2 - m^2)(l + m - 1)(l + m - 2)}{24\pi(2l + 1)(2l - 3)}}$
$l + 2$	$m - 2$	2	-2	$\frac{3}{(2l + 3)\sqrt{(2l + 1)(2l + 5)}} \sqrt{\frac{5(l - m + 4)!}{96\pi(l - m)!}}$
l	$m - 2$	2	-2	$-\frac{6}{(2l - 1)(2l + 3)} \sqrt{\frac{5(l - m + 2)!(l + m)!}{96\pi(l + m - 2)!(l - m)!}}$
$l - 2$	$m - 2$	2	-2	$\frac{3}{(2l - 1)\sqrt{(2l + 1)(2l - 3)}} \sqrt{\frac{5(l + m)!}{96\pi(l + m - 4)!}}$

In the Mathematica programming language, the Gaunt coefficients, defined by integral representation in Eq. (20), are calculated numerically using the integral command below.

$$\begin{aligned} & \text{Integrate}[\text{Conjugate}[\text{spherical}[l_1, m_1, \theta, \phi]] * \text{spherical}[l_2, m_2, \theta, \phi] \\ & * \text{spherical}[l, m, \theta, \phi] * \text{Sin}[\theta], \{\phi, 0, 2 * \text{Pi}\}, \{\theta, 0, \text{Pi}\}] \end{aligned} \tag{41}$$

The spherical harmonics employed in Eq. (41) are derived using angular momentum lowering and raising operators, and the program utilized for this purpose is detailed in the appendix. The Gaunt coefficients are calculated numerically for the chosen quantum sets using the Mathematica program provided in the appendix for Eq. (41) and the algebraic expressions presented in Table 1. The numerical results obtained are in complete agreement and are shown in the 6th column of Table 2.

Table 2. Numerical values and CPU times of Gaunt coefficients for some quantum sets

l_1	m_1	l_2	m_2	l	$Y_{l_1 m_1, l_2 m_2}^{l m}$	CPU times (seconds)	
						Algebraic expressions in Table 1	Eq. (41)
1	0	1	0	2	0.252313252202016	0.	0.125000
3	0	1	1	4	-0.194663900273006	0.	0.421875
5	-2	1	-1	6	-0.129207486045503	0.	0.828125
8	3	2	1	8	0.110108998314263	0.	1.046875
10	4	2	-1	12	-0.247740673270131	0.	5.734375
12	-5	2	-2	14	0.047285232345527	0.	129.812500
20	5	2	2	18	0.140116470887863	0.	221.296875

Additionally, CPU times are computed and presented in the 7th and 8th columns of Table 2. When the obtained CPU times are compared, it is seen that the use of algebraic expressions in calculating the Gaunt coefficients is more efficient. The programs are executed on an Intel(R) Core (TM) i7-6500U CPU @ 2.50 GHz computer.

Appendix. Mathematica code

The Mathematica program presented in this section calculates the Gaunt coefficients and CPU times using the integral definition consisting of the product of three spherical harmonics shown in Eq. (41). The spherical harmonics employed within the program are derived using lowering and raising angular momentum operators.

Program:

```
In[1]:= ClearAll["Global`*"];

carpp[pl_,pm_]:= Sqrt[pl*(pl+1)-pm*(pm+1)];
carpm[ml_,mm_]:= Sqrt[ml*(ml+1)-mm*(mm-1)];
plusop[pt_,pf_,khf_]:= Exp[I*pf]*(D[khf,pt]+I*Cot[pt]*D[khf,pf]);
minop[mt_,mf_,khf_]:= -Exp[-I*mf]*(D[khf,mt]-I*Cot[mt]*D[khf,mf]);

spherical[sl_,sm_,θ_,φ_]:= Block[{sphr=0},
  mek=0;
  fonkpl= SphericalHarmonicY[sl,mek,θ,φ];
  If[sm > 0,
    For[i=1,i<=sm,i++,
      kat= carpp[sl,mek];
      fonkp= plusop[θ,φ,fonkpl];
      fonkpl= fonkp/kat;
      mek= mek+1],
    If[sm < 0,
      For[i=-1,i>=sm,i=i-1,
        kat= carpm[sl,mek];
        fonkm= minop[θ,φ,fonkpl];
        fonkpl= fonkm/kat;
```

mek= mek-1]]];

sphr= fonkpl];

l1=3; m1=0;

l2=1; m2=1;

l=4; m= m1-m2;

f1=spherical[l1,m1,θ,φ];

f2=spherical[l2,m2,θ,φ];

f3=spherical[l,m,θ,φ];

Timing[N[Integrate[Conjugate[f1]*f2*f3*Sin[θ],{φ,0,2*Pi},{θ,0,Pi}],15]]

Out[1]= {0.421875,-0.194663900273006}

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**Hakkâri İlinde Üretilen Kabakgillerde Hıyar Mozaik Virüsü'nün DAS-ELISA Yöntemi ile Tespiti****Mehmet AKTAŞ¹ ve Nevin AKDURA²**

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Öz

Bu çalışmada; Hakkâri ilinde yetiştirilen kabakgil çeşitlerinde zararlı ve ekonomik kayıplara neden olan viral etmenlerden Hıyar mozaik virüsü (Cucumber mosaic virus; CMV), DAS-ELISA (Double Antibody Sandwich Enzyme-Linked Immunosorbent Assay) yöntemi ile serolojik olarak araştırılmıştır. Bu viral etmenin dünya genelinde ciddi ekonomik kayıplara sebep olduğu yapılan çalışmalar ile bildirilmiştir. Bu çalışmada kullanılan yaprak örnekleri, Hakkâri ilinde kabakgil üretiminin yapıldığı Kırıkdağ, Otluca ve Merzan alanlarından virüs hastalığı açısından şüpheli bulunan yapraklarda sararma, nekroz, mozaik ve şekil bozukluğu semptomları sergileyen kabakgillerden toplanmıştır. Viral belirti gösteren 7 adet karpuz (*Citrullus lanatus* L.), 5 adet kavun (*Cucumis melo* L.), 38 adet hıyar (*Cucumis sativus* L.), 15 adet kabak (*Cucurbita* sp.), 20 adet bal kabağı (*Cucurbita pepo*) ve 7 adet acur (*Cucumis melo* var. *flexuosus*) olmak üzere toplam 92 adet yaprak örneği Eylül 2022'de toplanmış ve örneklerle CMV enfeksiyonunun tanılanması amacı ile DAS-ELISA testi uygulanmıştır. DAS-ELISA testi ile 92 örneğin 29'unda CMV tespit edilmiştir. CMV enfekteli örnek sayısı ile en fazla %31.52 oranında Otluca'da tespit edilmiştir. Kabakgil çeşitlerinde ise test edilen 7 örneğin 6'sında %85.71 ile acurda tespit edilmiştir.

Anahtar Kelimeler: Kabakgil, CMV, DAS-ELISA, Hakkâri

Detection of Cucumber Mosaic Virus Method in Cucurbits Produced in Hakkâri Using DAS-ELISA Method

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Abstract

In the presence of the viral agent Cucumber mosaic virus (CMV), known to cause detrimental effects and economic losses in various types of squash cultivated in Hakkâri, was investigated through serological analysis using the DAS-ELISA (Double Antibody Sandwich Enzyme-Linked Immunosorbent Assay) method in this study. It has been reported by studies that this viral agent causes serious economic losses worldwide. The leaf samples used in the present study were collected from cucurbits, which exhibit yellowing, necrosis, mosaic, and deformity symptoms on leaves suspected of virus disease from Kırıkdağ, Otluca, and Merzan areas where cucurbit production is carried out in Hakkâri. A total of 92 leaf samples showing viral symptoms, comprising 7 watermelons (*Citrullus lanatus* L.), 5 melons (*Cucumis melo* L.), 38 cucumbers (*Cucumis sativus* L.), 15 zucchinis (*Cucurbita pepo*), 20 pumpkins (*Cucurbita moschata*) and 7 acrids (*Cucumis melo* var. *flexuosus*) were collected in September 2022, and DAS-ELISA test was applied to the samples for the purpose of

Giriş

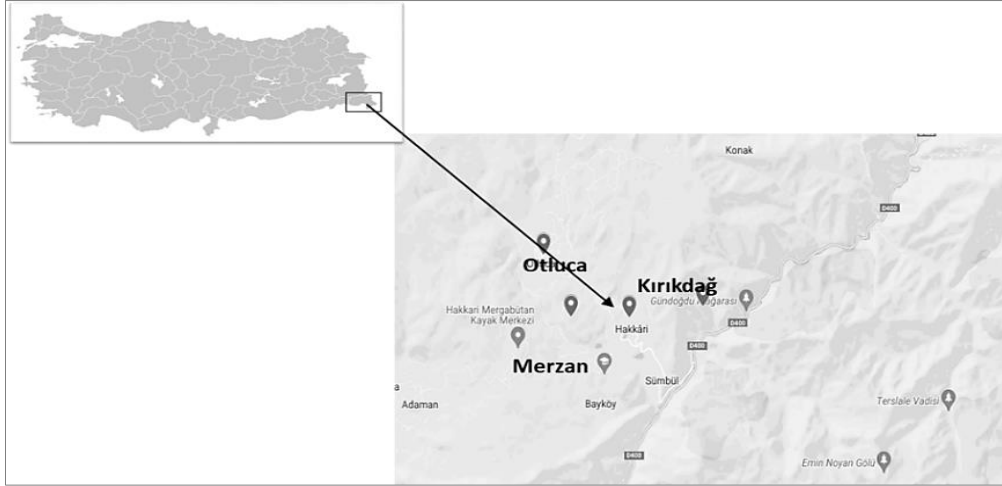
Dünya genelinde olduğu gibi ülkemizde de sebze üretimi oldukça önemlidir. Kabakgiller en eski kültüre alınan ve meyvesi yenen sebzeler arasında olup Cucurbitaceae familyası içinde yer alan bitkilerdir [1, 2]. İnsan besini olarak kullanılan bitki türlerinin çoğu bu familyada yer almaktadır ve dünya çapında gelişmiş ülkelerde, bu familya içinde yer alan hıyar (*Cucumis sativus* L.), kavun (*Cucumis melo* L.), karpuz (*Citrullus lanatus* L.), sakız kabağı (*Cucurbita pepo* L.), bal kabağı (*Cucurbita moschata* L.), kestane kabağı (*Cucurbita maxima* L.) insan beslenmesinde önemli ve en çok bilinen kültür bitkileridir [3-5]. Dünyanın tropik ve ılıman iklim bölgelerine yayılmış olarak bu familyanın yaklaşık 125 cins ve 960 türü bulunmaktadır. Kabakgiller arasında dünyada en popüler olan karpuzdur. Dünyada üretimde daha sonra hıyar, kavun, kabak ve balkabağı gelmektedir. 2020 yılı verilerine göre dünya genelinde kabakgil üretiminde ülkemiz 580.624 ton ile 8. sırada yer almıştır [6]. Ülkemizin ekolojik koşulları birçok tarım bitkisinin üretimi için oldukça uygundur. Ülkemizde 2022 yılı TUIK verilerine göre yaklaşık 3.417.963 ton karpuz, 1.942.836 ton hıyar, 1.600.167 ton kavun, 608.092 ton sakız kabağı, 94.177 ton bal kabağı ve 40.859 ton acur üretimi gerçekleştirilmiştir ve karpuz ülkemizde de en fazla yetiştirilen kabakgil çeşidi olmuştur [7]. Kabakgiller değişen farklı tarımsal ekosistemlerde yetiştirilebilmektedir ancak kabakgil yetiştiriciliğinde üretimi sınırlandıran biyotik etmenler bulunmaktadır. Bu etmenlerden funguslar, bakteriler, virüsler ve virüs benzeri organizmalar önemlidir. Viral etmenler, kabakgil üretimini büyük oranda etkilemektedir ve kabakgil yetiştiriciliğini tehdit etmektedir. Ayrıca virüsler diğer hastalık etmenlerinden farklı olarak kimyasal mücadelelerinin bulunmaması sebebi ile de önemlidirler [8]. Yapılan çalışmalar ile kabakgillerde hastalık yapan yaklaşık 60 virüs ve virüs benzeri hastalık etmeninin bulunduğu bildirilmiştir. Ülkemizde görülen özellikle Tütün mozaik virüsü (Tobacco mosaic virus; TMV), Kabak sarı mozaik virüsü (Zucchini yellow mosaic virus; ZYMV) ve Hıyar mozaik virüsü (Cucumber mosaic virus; CMV) daha sonra Kabakgil afitle taşınan sarılık virüsü (Cucurbit aphid-borne yellows virus; CABYV), Kabak mozaik virüsü (Squash mosaic virus; SqMV), Karpuz mozaik virüsü-1 (Watermelon mosaic-1; WMV-1), Karpuz mozaik virüsü-2 (Watermelon mosaic-2; WMV-2) ve Papaya halkalı leke virüsü (Papaya ringspot virus; PRSV) kabakgillere zarar veren önemli virüslerden birkaçı olup ZYMV, CMV, WMV ve CABYV viral etmenleri Akdeniz ülkelerinde de yaygın olarak rapor edilmişlerdir. Bu virüsler bitkilerin gelişmesini olumsuz etkilemekte ve meyve oluşumunu tamamen engelleyebilmektedirler [9-11]. CMV; kabakgiller dışında odunsu, yarı odunsu, tek çenekli, çift çenekli olmak üzere yetiştirilen tüm ürünlerde hastalığa ve zarara sebep olan bir etmen olup 85 familyaya ait yaklaşık 1000 çeşit bitki türünü olumsuz etkileyebilmektedir [12-16]. 1916 yılında ilk olarak hıyar ve diğer kabakgillerde tanımlanmış ve Price

tarafından, 1934'te Amerika Birleşik Devletleri'nde ilk defa izole edilmiştir [12]. CMV *Bromoviridae* familyası, Cucumovirus cinsinde yer almaktadır. Küresel şekilli, pozitif polariteli tek iplikli RNA (Single strand RNA; ssRNA)'dan oluşan üç parçalı genoma sahiptir. En büyük genom parçası RNA 1 olup bunu RNA 2 ve RNA 3 takip etmektedir [12, 15, 17]. Bu virüs yaprak bitleri, tohum ve mekanik yolla taşınabilmektedir. CMV bitkilerde meyve ve yapraklarında şekil bozukluğu ve ölümlerine sebep olabilmektedir. Bazı bitkilerde sistematik enfeksiyonlara sebep olurken, bazı türlerde hiç belirtiyeye sebep olmamaktadır. CMV enfeksiyonunun belirtileri bitkinin yaşı ve bitkiyi enfekte ettiği döneme göre değişebilmektedir [18, 19]. Bitki virüslerinin tespitinde değişik test yöntemleri kullanılmaktadır. Viral etmenlerin teşhisinde kullanılan serolojik, biyolojik ve moleküler teknikler farklı açılardan incelendiğinde birtakım avantaj ve dezavantajlara sahip oldukları görülmektedir. Serolojik yöntemler, bitkilerde hastalık meydana getiren viral etmenlerin karakterize edilmesinde ve teşhisinde yaygın olarak kullanılmaktadır. Biyolojik indeks testi ile moleküler yöntemlerde olduğu gibi, serolojik teşhis metotları da birçok avantaj ve dezavantajlara sahiptir. Serolojik teşhis yöntemlerinden biri olan ELISA testi, 10 yıldan daha fazla bir süredir bitki virüs hastalıklarının tanısı için yaygın kullanım alanına sahip bir metot haline gelmiştir. Belli bir virüse spesifik olan serolojik reaksiyonlarda, sadece küçük miktarlarda viral materyal kullanılarak birkaç gün içerisinde sonuç almak mümkündür. Ayrıca geniş ölçekli rutin testlemelerde faydalı olabilen serolojik yöntemlerde uygun antiserumun önceden temini durumunda, testlerin uygulanabilirliği önem kazanmaktadır [20]. Bu çalışma ile kabakgil yetiştiriciliğinin yapıldığı Hakkâri ilinde CMV etmeninin DAS-ELISA testi ile serolojik olarak tanılması yapılmıştır. Örneklerin toplandığı Kırıkdağ, Merzan ve Otluca alanlarında bu viral etmenlerin yaygınlıkları ile hastalık oranları belirlenmiştir.

Materyal ve Metot

Arazi Çalışmaları

2022 yılında, Ağustos-Eylül aylarında çalışmada kullanılmak üzere Hakkâri Merkezde kabakgil yetiştiriciliğinin yapıldığı Kırıkdağ, Otluca ve Merzan alanlarında survey çalışması yapılarak hıyar (*Cucumis sativus* L.) kabak (*Cucurbita pepo* L.), karpuz (*Citrullus lanatus* L.), kavun (*Cucumis melo* L.), bal kabağı (*Cucurbita moschata* Butternut) ve acur (*Cucumis melo* var. *flexuosus*)' dan yaprak örnekleri toplanmıştır (Şekil 1).



Şekil 1. Hakkâri ilinde kabakgil örneklerinin toplandığı alanlar

Bitki Materyalinin Temini

Çalışmada kullanılmak üzere CMV ile bulaşık olduğu şüphelenilen bitki materyalleri toplanmıştır. Kabakgillerdeki sararma, mozaik, şekil bozukluğu ve bodurluk gibi semptomları sergileyen ve bitki virüslerinin sebep olduğu genel belirtileri de gösteren kabakgil bitkilerinden yaprak örnekleri alınmıştır. Kabakgillerin tümü şayet aynı alanda yetiştirildiyse aynı anda ve herbir izolat için 3'er örnek toplanmıştır. Daha sonra örnekler arazi bölgesi bilgilerini içeren etiketler hazırlanarak polietilen poşetlere konulup -20°C 'de muhafaza edilmiştir.

Örneklerin Toplandığı Alanlara ve Kabakgil Çeşitlerine Göre Dağılımı

Ağustos-Eylül 2022'de gerçekleştirilen survey çalışması ile Hakkâri ili kabakgil üretim alanlarından 15 bahçeden 92 örnek toplanarak bu çalışmada kullanılmak seçilmiştir (Tablo 1).

Tablo 1. Hakkari ilinden toplanarak seçilen kabakgillerin alanlar ve türlerine göre dağılımı

Alan	Karpuz	Kavun	Hıyar	Kabak	Bal Kabağı	Acur	Toplam
Kırıkdağ	3	2	14	7	9	1	36
Otluca	-	1	8	-	4	3	16
Merzan	4	2	16	8	7	3	40
Toplam	7	5	38	15	20	7	92

Serolojik Test Yöntemi (DAS-ELISA)

Survey çalışmasında arazi çıkışlarında semptomatolojik olarak şüphe duyulan bitki örneklerinde CMV etmeninin varlığının ortaya konulması için DAS-ELISA yöntemi uygulanmıştır. Poliklonal antiserumlar, pozitif ve negatif kontroller BIOREBA-AG firmasından temin edilmiştir (İsviçre). DAS-ELISA yöntemi [21] üretici firmaların önerdiği şekilde yürütülmüştür.

DAS-ELISA Testinin Uygulama Aşamaları:

-Virüslere spesifik antiserum kaplama tamponunda belli oranda sulandırılarak plakanın her bir gözüne konularak 37°C’ de 2 saat inkübe edilmiş, inkübasyonu takiben gözlerdeki içerik ters çevrilerek boşaltılıp ve 3 kez yıkama tamponu ile yıkanmıştır.

-Ekstraksiyon tampon solüsyonunda hazırlanmış bitki ekstraktı pleytin her bir gözüne konulmuş ve bir gece +4°C’de bekletilip, tekrar yıkama tamponu ile 3 kez yıkanmıştır.

-Konjugat tamponu içerisinde sulandırılmış alkalın fosfataz enzimi ile etiketli konjugat pleytlerin her bir gözüne konulup 37°C’de 4 saat bekletilmiş ve yıkama işlemi tekrarlanmıştır.

-Pleytlerin her bir gözüne substrat çözeltisi konulmuş ve oda sıcaklığında 2 saat bekletilmiştir. Sonuçlar 405 nm ELISA okuyucusunda değerlendirilmiştir.

-Absorbans değerine göre sağlıklı kontrol değerinin en az iki katı ve daha yukarı okuma değeri verenler pozitif olarak kabul edilmiştir [22].

Bulgular

Arazi Çalışmaları

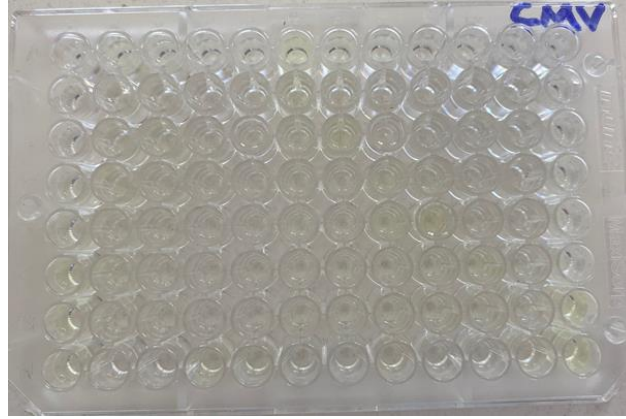
Hakkâri ilinin Merzan, Otluca ve Kırıkdağ alanları kabakgil yetiştiriciliğinin yapıldığı alanlarda gerçekleştirilen survey çalışmalarında sararma, mozaik, şekil bozukluğu, yapraklarda kıvrılma ile küçülme ve nekrotik lekeler gibi genel viral belirtileri gözlenmiştir (Şekil 2).



Şekil 2. a) Kırıkdağ alanında hıyar bitkilerinde mozaik ve renk açılması belirtileri, b) Kırıkdağ alanı karpuz bitkilerinde mozaik ve yapraklarda küçülme belirtileri

DAS-ELISA Testi Bulguları

Hakkâri ilinde yetiştirilen kabak, hıyar, kavun, karpuz, bal kabağı, su kabağı ve acur kabakgil bitkilerinden toplanan 92 yaprak örneği DAS-ELISA testine tabi tutulmuştur. Test edilen pleytlerin görüntüleri Şekil 3’de verilmiştir.



Şekil 3. CMV için test edilen örneklerin ELISA okuyucusu öncesindeki görüntüleri

Negatif kontrol absorbans değeri 0.1366-0.1149 olarak değerlendirilmiş olup 0.24’den büyük değerler pozitif olarak alınmıştır. 92 adet yaprak örneğinin 29 adedinin CMV ile enfekteli olduğu tespit edilmiştir. Kabakgil çeşitlerinden toplanan örnek sayısı Tablo 2’de verilmiştir. Buna göre 7 adet karpuz, 5 adet kavun, 38 adet hıyar, 15 adet kabak, 20 adet bal kabağı ve 7 adet acur örneği test edilmiştir. Örneklerde karpuzda 2, kavunda 2, hıyarda 11, kabakta 1, bal kabağında 7, acurda 6 örnek CMV ile tespit edilmiştir. Enfeksiyon oranları incelendiğinde %28.57, %40, %28.94, %6.66, %35 ve %85.71 olarak saptanmıştır.

Tablo 2. DAS-ELISA testinde kabakgil çeşitlerinde test edilen bitkiler ve CMV enfeksiyon oranları

Kabakgil türü	Test edilen bitki sayısı	CMV ile enfekteli örnek sayısı	Enfeksiyon oranı (%)
Karpuz	7	2	28.57
Kavun	5	2	40
Hıyar	38	11	28.94
Kabak	15	1	6.66
Bal Kabağı	20	7	35
Acur	7	6	85.71
Toplam	92	29	31.52

Tablo 3’te DAS-ELISA test sonuçlarına göre Hakkâri merkez Otluca, Kırıkdağ, Merzan alanlarından toplanan 92 adet örneğin 36’sı Kırıkdağ’dan, 16’sı Otluca’dan ve 40’ı Merzan alanlarından toplanarak enfeksiyon oranları sırası ile %36.11, 62.5 ve 15 olarak saptanmıştır. Genel olarak test edilen tüm örneklerde %31.52 oranında CMV tespit edilmiştir.

Tablo 3. Hakkâri ili kabakgil alanlarından toplanan yaprak örneklerinde DAS -ELISA testi sonuçları

Alan	Örnek sayısı	CMV ile enfekteli örnek sayısı	Enfeksiyon Oranı %
Kırıkdağ	36	13	36.11
Otluca	16	10	62.5
Merzan	40	6	15
Toplam	92	29	31.52

Tartışma ve Sonuç

Bu çalışmada, Hakkâri ilindeki kabakgil üretiminin yapıldığı Kırıkdağ, Merzan ve Otluca alanlarından viral hastalık belirtileri gözlenen hıyar, kavun, karpuz, kabak, su kabağı, bal kabağı ve acur bitki örneklerinin toplanması ile yapılan viral olarak enfekteli olduğu düşünülen bitki örnekleri DAS-ELISA testi yöntemi ile serolojik olarak test edilmiş ve CMV'nin yaygınlığı araştırılmıştır. Survey çalışması yapılan alanlardan semptomolojik olarak CMV enfekteli olduğu düşünülen 92 adet kabakgil bitkisinden 29 adedinde %31.52 oranında CMV enfeksiyonu tespit edilmiştir. Toplanan alanlar değerlendirildiğinde kabakgillerde 13 örneğin CMV enfeksiyonlu tespit edilmesi ile %36.11 ile Kırıkdağ alanı en yüksek CMV görülen alan olmuştur. En düşük ise %15 ile Merzan alanı tespit edilmiştir. Kabakgil bitki çeşitlerine göre de CMV toplanan 7 örneğin 6'sında tespit edilmesinden dolayı %85.71 ile acurda, en düşük ise %6.66 ile kabakta görülmüştür. DAS-ELISA test sonuçları değerlendirildiğinde Otluca alanından toplanan 16 yaprak örneğinden 10 adedinin, Kırıkdağ alanından toplanan 36 yaprak örneğinden 13 adedinin, Merzan alanından toplanan 40 yaprak örneğinden 6 adedinin CMV ile enfekteli olduğu saptanmıştır. CMV bulunma oranları da sırası ile %36.11, %62.5 ve %15 oranlarında tespit edilmiştir. Özellikle karpuzza zarar veren önemli virüsler arasında CMV gelmektedir [23] ve yaptığımız bu çalışmada da karpuz için test edilen örneklerde %28.57 oranında CMV tespit edilmiştir. Ertunç [24], kabakgillere ait 40 tohum örneğinde DAS-ELISA ile CMV'yi tespit etmek amacı ile çalışma yapmış ve test ettiği örneklerin 9'unda CMV'yi tespit etmiştir. Bu çalışma tohumda CMV'nin tespiti açısından önem taşımaktadır. Tohumda CMV'nin araştırılmasına yönelik yapabileceğimiz çalışmalara olanak sağlamıştır. Bostan ve ark. [25] kabakgillerdeki viral etmenleri belirlemek amacı ile Erzurum, Erzincan ve Artvin illerinde virüslere özgü genel belirtilere sahip bitkilerden 90 adet yaprak örneği toplamıştır. Daha sonra yaprak örneklerini CMV ve ZYMV'ye spesifik DAS-ELISA kitleri ile test etmiştir. Örneklerin hiçbirinde CMV tespit edilmemiştir. Farklı illerden örnekler toplanarak yapılan bu çalışmada CMV etmeninin hiçbir örnekte tespit edilememesine sebep olarak farklı bitki virüslerinin aynı bitkide bulunması durumunda birbirlerini olumsuz etkileyerek tespit edilememeleri olabileceğini düşündürmektedir. Bu çalışmada bitkilerde ZYMV'de araştırıldığı için ZYMV'nin aynı bitkide tek başına tespiti gerçekleşmiş olabilir. Nadir olarak bu şekilde çalışma örnekleri görülebilmektedir. Şevik ve Arlı-Sökmen [26] 165 kabakgil örneğini survey çalışmaları ile toplayarak WMV, ZYMV ve CMV'nin örneklerde bulunma durumunu ELISA ile test etmiştir. Çalışma sonucunda %53.9 oranında WMV, %38.8 oranında ZYMV ve %20.6 oranında CMV yaygın olarak

tespit edilmiştir. CMV'nin test edilen karpuz ve balkabağında bulunmadığı sonucuna varılmıştır. Dursunoğlu [27], 2002 yılı Temmuz-Ağustos-Eylül aylarında Ankara ili ve çevresinde yetiştirilen kabakgil ekim alanlarından topladıkları 230 bitki örneğini mekanik olarak aşılama ve serolojik olarak da DAS-ELISA yöntemi ile test etmiştir. Araştırma sonucunda toplanan örneklerin 7 tanesini CMV alt grup-I olarak tespit etmişlerdir. Gümüş ve ark. [28], çeşitli tohum firmalarından temin ettikleri hıyar, kavun ve kabak tohum örneklerinde bulunması olası viral etmenlerin varlığını ELISA yöntemi ile araştırmıştır. CMV'yi, %36.8 oranında hıyar tohum ve %18.5 oranında kabak ve kavun tohum örneklerinde tespit etmişlerdir. Köklü ve Yılmaz [29], Trakya'da test ettikleri karpuz örneklerinin %19.9 oranında CMV ile enfekteli olduklarını tespit etmiştir. Yaptığımız çalışmada da karpuzda CMV oranı yakın tespit edilmiştir. Karakurt [30] 2014 yılında İstanbul ilinde karpuz üretim alanlarındaki viral etmenleri belirlemek amacı ile survey çalışmaları gerçekleştirmiş ve 344 adet yaprak örneği toplamıştır. Örneklerde CMV ve ZYMV etmenleri araştırılmıştır. Bunun için DAS ELISA testi ile 13 örnekte CMV ve 20 örnekte ZYMV etmenleri tespit edilmiştir. 2 örnek de CMV ve ZYMV ile enfekteli tespit edilerek toplam 35 bitki örneğinde tekli ve çoklu virüs enfeksiyonları belirlenmiştir. Test edilen bitkilerin genelinde %4.3 CMV ve %6.9 oranlarında ZYMV bulunmuştur. Survey çalışması ile fazla sayıda karpuz yaprak örneği toplanarak gerçekleştirilen bu çalışmada CMV tespit oranı oldukça düşüktür. Yaptığımız çalışmada ise örnek toplanılan bahçelerde karpuz, kavun ve hıyar bitkileri genellikle bir arada yetiştirildiği için CMV tespit oranı değişkenlik göstermiştir. Topkaya [31], 2015 yılında Kastamonu ili ve çevresinde kabakgil yetiştiriciliği yapılan alanlarda viral etmenleri belirlemek amacı ile 25 bahçeden virüs benzeri belirti gösteren ve göstermeyen hıyar, sakız kabağı, kavun, karpuz ve bal kabağı bitkilerinden 99 örnek toplamıştır. Toplanan bitkiler, CMV'yi de tespit etmek amacı ile DAS-ELISA yöntemi ile test edilmiştir. Buna göre CMV %3.96 oranında tespit edilmiştir. Yardımcı ve ark. [32] Göller Bölgesinde yaptıkları çalışmada 2011-2012 yetiştirme sezonunda yapılan araştırmalarda tarlada yetişen kabak bitkilerinde mozaik, klorotik beneklenme, damar şeritlenmesi, kabarma ve yaprak şekil bozukluğu belirtileri gözlemlenmiştir. Türkiye kabakgil üretiminde önemli bir bölge olan bu bölgedeki çeşitli lokasyonlardan 268 kabak örneği toplayarak ELISA ve çift sarmallı RNA (dsRNA) analizi ve RT-PCR yöntemleri kullanılarak CMV'yi tespit etmiştir. ELISA testleri, test edilen 268 saha örneğinden 54'ünün CMV ile enfekte olduğunu göstermiştir. ELISA ile negatif numuneler CMV için RT-PCR ile test edildiğinde pozitif olarak tespit edilmiştir. dsRNA analizi sonucunda da spesifik 3 CMV RNA profili elde edilmiştir. Çat ve ark. [33] 2014-2015 yılları arasında Antalya ili ve ilçelerinde örtüaltı hıyar ve kabak üretim alanlarında ZYMV, PRSV, SqMV ve CMV'nin varlığının, serolojik ve biyolojik yöntemlerle saptanması ve toplanan örneklerdeki yaygınlığının ortaya konulması amacı ile örtüaltı hıyar ve kabak üretim alanlarından viral belirtilere sahip 455 yaprak ve meyve örneğini DAS-ELISA ile testlemiştir. Testlenen 455 örneğin 346 adedinin (%76) bir ve daha fazla virüs ile enfekteli olduğu belirlenmiştir. ELISA testleri sonucunda pozitif reaksiyon veren bitkilerden alınan dokular mekanik inokulasyon çalışmalarında kullanılmıştır. İndikatör bitkiler üzerinde 15-30 gün gibi bir sürede belirti

gözlenmiştir. Bu çalışmada örnekler örtü altı hıyar ve kabak üretim alanlarından seçilmiştir. Örtü altı üretimlerde özellikle viral etmenler vektörler ile daha kolay taşınabilmekte ve ekonomik zarara neden olmaktadır. Hakkâri ilinde örtü altı sebze üretimi yaygın olarak yapılmamaktadır. Bu durumda da viral etmenlerin tespit oranları değişkenlik gösterebilmektedir. Daha hızlı ve ekonomik olması sebebi ile yaptığımız çalışmada örneklere ELISA testi uygulanmıştır ancak son yıllarda CMV etmeninin moleküler tespiti yaygın olarak gerçekleştirilmektedir. Güller ve Usta [34], 2019 yılında Bingöl ilinde karpuz yetiştiriciliği yapılan alanlarda gerçekleştirdikleri surveyler ile 12 viral şüpheli yaprak örneğini CMV ve WMV etmenleri için RT-PCR ile test etmiştir. Sonuçlara göre 657 ve 822 bp DNA fragmentleri agaroz jelde tespit edilmiştir [34]. Karanfil ve Korkmaz [35] Güney Marmara Bölgesi Çanakkale, Balıkesir ve Bursa illerinde CMV enfeksiyonunun tespiti için kabakgil üretim alanlarından 72 bitki örneği olarak DAS-ELISA yöntemi ile 10 örnekte CMV enfeksiyonu belirlemiştir. Elde edilen CMV izolatlarının moleküler karakterizasyonunu gerçekleştirmek amacı ile örneklerden 3 tanesi elde edildikleri coğrafik orijine göre seçilmiş, RT-PCR ile kılıf protein genlerinin tamamı çoğaltılarak klonlanmış ve sekanslanmıştır. Gerçekleştirilen sekans analizleri sonucunda Güney Marmara Bölgesi CMV izolatları birbirleri ile nükleotit düzeyinde %93.15-99,70 oranında, amino asit düzeyinde ise bu izolatların %97.71-100 oranında benzerlik gösterdiği belirlenmiştir. Dünya izolatları ile gerçekleştirilen karşılaştırmalar sonucunda ise bu izolatların nükleotit ve aminoasit düzeyinde %76-100 benzerlikler gösterdiği tespit edilmiştir. Gerçekleştirilen filogenetik analizler sonucunda CMV izolatlarının ikisinin altgrup IA, birinin ise altgrup IB'de olduğu belirlenmiştir. Grafton-Cardwell ve ark. [36], 1988-1989 yıllarında Kaliforniya'da gerçekleştirdikleri surveyler ile yaptıkları çalışmada CMV'nin yaygınlığını %20 olarak saptamıştır. Bashir ve ark. [37], İran'ın Kuzey-Batısında genel viral belirtilerden bir veya birkaçını birden gösteren kabakgil bitkilerinden 123 adet toplayarak DAS-ELISA testi ile 13 örnekte CMV etmenini tespit etmiştir. Yaptığımız çalışmada da benzer sonuçlar elde edilmiştir. Ayo-John ve ark. [38], Nijerya'da kabakgil ve yabancı otlardan topladıkları 90 yaprak örneğini DAS-ELISA testi ile CMV bakımından da test etmiştir. CMV'yi kabakgillerde ve yabancı otlarda belirlemiştir. Bu çalışma CMV'nin hem kabakgiller hem de yabancı otlarda yaygın bir virüs olduğunu ortaya koymuştur. Yabancı otlarda da CMV etmeninin tespit edilmesi yapılacak diğer çalışmalar için fikir vermektedir. Yaptığımız çalışmada da test edilen örnekler genellikle aynı bahçede yetiştirilen farklı kabakgil çeşitleri olmuştur. CMV'nin yaygınlığının bu durumdan kaynaklanabileceği düşünülmüştür. Constable ve ark. [39] üç önemli kabakgil türünün (hıyar, kavun ve kabak) tohumları temin edilerek biyogüvenlik ve agronomik kaygı taşıyan seçilmiş virüsler için test etmiştir. Test edilen 31 tohumunun 23'ünde hedeflenen virüslerden biri veya daha fazlası tespit edilmiştir. CMV tespit edilmiştir ve böcek ile bitki çöpü kontaminasyonu vakaları da gözlemlenmiştir. Milojević ve ark. [40] Sırbistan'da yaptıkları çalışmada karpuzda ELISA ve PCR testleri ile %40 oranında CMV'yi tespit etmiştir. Bitki virüs hastalıklarının teşhisinde PCR yöntemi artık en güvenilir ve net sonucu veren yöntemlerden birisidir. ELISA yöntemi her ne kadar hastalıkların teşhisinde halen kullanılsa da ELISA testinde negatif olan sonuçlar PCR ile

pozitif sonuca dönüşebilmektedir. Yapılan çalışmada da %40 oranında CMV tespitinin yüksek olması bu durumu desteklemektedir. Viral hastalık etmenleri ile mücadelede üretimde kullanılan ilaç bulunmamaktadır ve dolaylı mücadele yöntemleri önemlidir. Virüsten ari sertifikalı fide, tohum, fidan, yumru ve soğan gibi bitkisel üretim materyallerinin kullanılmasının yaygınlaştırılması gerekmektedir. Viral patojenin teşhis ve tanılamasının yapılması da bitki virüsleri ile mücadelede en önemli adımlardan biridir. Bitki zararlısı böcekler viral enfeksiyonlarda önemli bir vektör kaynağıdır. Bu nedenle viral etmenin vektörünün biyolojisinin, beslendiği bitki profilinin, viral etmeni ne kadar sürede ve ne düzeyde bulaştırma yeteneğinde olduğunun araştırılması virüslerin üretim alanlarında yaygınlıklarının azaltılmasında etkili olmaktadır. Üretim alanlarından enfekteli bitkilerin toplanması veya hasat sonrası bitki artıklarının yakılarak imha edilmesi ile viral etmenlerin yayılımları engellenebilmektedir [41]. Viral etmenlerin varlıklarını, tarlaların etrafında virüs kaynağı olabilecek diğer bitkilerin mevcut olup olmaması veya vektörler etkilemektedir. CMV kabakgillerde tohumla taşınabildiği için sertifikalı tohum veya aşılı fide kullanımı sanitasyon önlemlerinin başlangıcını oluşturmaktadır [42]. CMV etmeni kabakgilleri genel olarak enfekte edebilme özelliğine sahiptir. Ekonomik öneme sahip bu etmen ile mücadele de vektörlerin belirlenerek mücadelelerinin yapılması ön koşullardan biridir. Yapılan bu çalışma ile CMV etmeni DAS-ELISA yöntemi ile Hakkâri ilinde kabakgillerde ilk defa tespit edilmiştir.

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Kamusal Sanat Yoluyla Koruma Bilincine Katkı: Mersin Balığı Örneği

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Öz

Geçmişten günümüze kamusal mekânlarda özel bir yeri olan görsel sanat eserleri, çağdaş kamusal alanların estetik yüzleri olmanın yanı sıra topluma verilmek istenen çeşitli mesajlara da aracılık ederler. Bu mesajlar tarihsel, kültürel ve siyasi içerikli olabilir. Ayrıca bu eserler, günümüz sorunlarına değinerek topluma bilgi vermek, yaygın eğitime katkıda bulunmak ve bilinçlendirmek gibi amaçlar da taşıyabilir. Dünya çapında nesli tehlikede olan mersin balıkları da kamusal sanat yoluyla tanıtılabilir ve koruma bilinci geliştirilebilir. Bu çalışmada, mersin balıklarının dünyada ve ülkemizde geçmişten günümüze kamusal alanlarda görsel sanat objesi olarak kullanımları değerlendirilmekte ve koruma bilincinin geliştirilmesine katkı sağlayabilecek bazı öneriler sunulmaktadır.

Anahtar Kelimeler: Mersin balıkları, koruma bilinci oluşturma, kamusal sanat, görsel sanatlar

A Contribution to Awareness of Conservation by the Help of Public Art: Sturgeon Case

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Abstract

Visual art objects, which have a special place in public spaces from the past to the present, not only serve as the aesthetic faces of contemporary public spaces, but also mediate the various messages to be given to society. These messages can be historical, cultural and political content. Additionally, these art objects can also serve purposes such as providing information to society by addressing contemporary issues, contributing to non-formal education and raising awareness. The endangered sturgeons around the world can also be promoted through public art and awareness of conservation can be developed. In this study, from the past to the present the use of sturgeons as visual art objects in public spaces is being evaluated worldwide and, in our country, and some recommendations are being presented that can contribute to the development of conservation awareness.

Keywords: Sturgeons, creating conservation awareness, public art, visual arts

Giriş

Dünya tarihinde yeni bir dönemi başlatan endüstri devrimi, toprağa bağlı üretim-tüketim ilişkileri temelinde örgütlenen feodal toplumları dönüştürmüş [1], bu dönüşümün sancıları tüm toplumsal kurumları temelden sarsmıştır. Endüstri toplumu, kendi dinamiklerinin biçimlendirdiği sanat

anlayışını 19. yüzyılda ortaya koyarken, özellikle bu yüzyılın ikinci yarısında aydınlar hem toplumu hem de sanatı sorgulamaya başlamıştır. Toplumun ve buna bağlı olarak sanatın dönüşümünün temel nedeni olan üretim-tüketim süreçlerinde görülen köklü değişiklikler, doğa üzerindeki etkisini kısa zamanda göstermiştir. Endüstri toplumları, üretim-tüketim süreçlerindeki değişikliklerle eş zamanlı olarak doğayı denetim altına alma çabalarını ve doğal kaynakları kullanmayı hızlandırarak, karasal ve sucul ekosistemlerde tarihin önceki dönemleriyle karşılaştırılamayacak yıkımlara yol açan süreci de başlatmıştır. Habitatların ve türlerin kaybı ve diğer ekolojik sorunlarla etkilerini gösteren, özellikle 20. yüzyılın ikinci yarısında kronikleşmeye başlayan bu çevresel yıkım, doğal alanları ve türleri koruma güdüsü taşıyan toplumsal hareketleri ortaya çıkartırken devletleri bu konuda önlemler almaya yöneltmiştir. Endüstrileşmenin toplumsal ve çevresel etkisini gösterdiği dünyada, kendine özgü dilini ve kamusal alanla ilişkisini geliştiren sanat, bu sürecin taraflarından biri haline gelmiştir. Başta edebiyat olmak üzere, aralarında resim ve heykel gibi görsel sanatların da bulunduğu sanat dallarında toplumsal dönüşüm, çevresel yıkım ve türlerin yok oluşu işlenmeye başlanmıştır. Sanatın 19. yüzyılda başlayıp 20. yüzyılda güçlenen bu yönelimi, bir yandan doğal yaşamı tehdit eden uygulamalara karşıt görüşleri savunan bir manifesto niteliği taşıırken, diğer yandan yitirilen çevre değerleri hakkında farkındalık yaratmaya hizmet etmiştir. Özellikle kamusal alanlarda yer verilen sanat eserleri bu işlevleriyle öne çıkmaktadır. Teknolojik gelişmelerin ve endüstriyel düzenin katılaştırdığı yaşamın insanileştirilmesinde sanatın önemine vurgu yapan Sargın [2], insanın doğanın bir parçası olma bilincine sahip olarak tüm canlı türlerinin yaşama hakkına saygı duymasının, yaşam alanlarında sanat ürünlerine yer verilmesiyle pekiştirileceğine dikkat çekmektedir. Caddeler, sokaklar, meydanlar, parklar gibi insanların ortak kullanımına açık alanlar olan kamusal dış mekânlar, Carr ve ark. [3] tarafından bir sahneye benzetilmektedir. Yaşama ve çalışma alanları dışında kalan bu mekânlar, insanların kendini gösterdiği bir sahne olmanın yanında, kamusal iletişimin ve eğitimin aracı olan mekânlardır. Kamusal alanlarda sergilenen sanat eserleri ise Tırl ve ark. tarafından, sanat dünyasının topluma açılan pencereleri olarak nitelendirilmektedir [4]. İnsanın duygu ve düşünce dünyasında; yaşamı, evreni, doğayı anlama ve algılama sürecinde kıvılcım yaratma özelliğine sahip olan sanat eserleri, kamusal alanlarda etki alanını genişletmektedir. Sanatın insanların günlük yaşamlarına sokulmasıyla etki alanını genişlettiğinin farkında olan toplumlar, yaşam alanlarını sanatın bütün dallarına açmaktadır. Kamusal alanlarda toplumla buluşan sanat, kapalı mekânlardaki sanata göre daha geniş bir kitleye hitap etmektedir [2]. Kamusal alanlar konusunda ürettiği düşüncelerle bilinen Habermas'ın kullandığı “*evin eşliğinden kamunun ışığına*” deyişi, uygarlığın tarihsel bir dönemini işaret etmekle birlikte, özel alandan herkesin kullanımına açık olan kamusal alana çıkan günümüz insanına da uyarlanabilir [5]. “*Evin eşliğinden kamunun ışığına*” geçmekle başlayan kamusallaşmanın eğitim boyutu, özellikle son yüzyılda sanatla tamamlanmaktadır. Sanatın kamusal eğitimle ilişkisi son yüzyılda ağırlık kazansa da bu ilişki tarihsel bir derinliğe sahiptir. Sanat eserlerinin kamusal dış mekânlarda yer alması insanlığın en eski dönemlerine kadar gitmektedir. Ancak bu eserler varoluşlarından beri bir amaca yönelik olarak

üretimiştir. İnsanlık tarihinin çeşitli dönemlerinden kalan ve bugün sanat eseri olarak görülen eserlerin bir gereksinimi gidermek amacıyla üretildiklerini belirten Gombrich [6], bu eserlerin yapımında önceliğin kendilerinden beklenen işlevi en iyi biçimde yerine getirmeleri olduğuna işaret etmektedir. Bununla birlikte, üretenlerin estetik beğenileri sayesinde işlevsel olan bu ürünler sanat eseri olarak görülmektedir. Bu eserlerin sanat eserine dönüşmesinde esas olan, işlevlerini en iyi şekilde yerine getirmeleri yanında duyularda oluşturdukları etkilerdir. Sanat, üretilenin duyularda yarattığı güzellik algısına bağlı bir kavramdır. Sanatçının eseri ile yarattığı algı, bir anlamda kendi algılarının yansımasıdır. Çevresel algıların bir yansıması olan sanat başlangıçta doğanın ve evrenin yansıması olarak ortaya çıkmıştır. Sanatın algılanması, insanda uyandırdığı güzel duygulara işaret eden “estetik” sözcüğünün kökeninde de bulunmaktadır. Yazının icadından önce insanın kendini ifade etmekte kullandığı ve günümüze ulaşabilen en güçlü araç olan görsel sanat, ister resim ister heykel ve heykelciklerle ifade edilsin, insanların çevrelerini algılamalarının yansımasıdır. Barnard [7], modern Batı dillerinde kullanılan estetik sözcüğünün, eski Yunancada “algı” anlamındaki bir kelimedenden türetildiğini; estetiğin güzel olanın algısını da içerdiğini belirtmektedir. İnsanın doğa ve evren algısının yansıması olan sanat, insanlık tarihi boyunca özellikle görsellik üzerinden insanları etkilemiştir. Habermas [8], aydınlanma çağını yaşayan 17. yüzyıl Fransa’sında “kamu” kavramının, “devlet” anlamının ötesine geçerek sanat ve edebiyatı izleyenleri, tüketenleri ve eleştirenleri içeren bir anlam kazandığını belirtmektedir. Kamusal bilincin gelişmesinde kamusal sanatın yerinin tarihin her döneminde önem kazandığı görülmekle birlikte, endüstrileşme ile yeni bir boyut kazanan kentlerde ağırlığının arttığı söylenebilir. Sanat, görsel imgeler üzerinden kamusal bir etki oluşturma gücünü her zaman kullanmıştır. Bu etki, kamusal alanlarda geniş kitlelerde algı oluşturmada kullanılmıştır. Januchta-Szostak [9], kamusal sanatı, fiziksel ve kamusal alanda sergilenen veya sahnelenen ve erişilebilir olan sanat olarak tanımlamaktadır. Siyasal ve dinsel temeli bin yıllar öncesi giden kamusal sanatın modern çağdaki yönelimlerinden biri de çağın sorunlarını işlemesidir. Bu bağlamda, özellikle 20. yüzyılın ikinci yarısında çevre ile ilgili konular kamusal sanatın önemli konuları arasına girmiştir. Kamusal sanat, daha çok seçkinlere hitap ettiği düşünülen galeri sanatına alternatif olarak ve kentsel mekânları canlandırmak amacıyla 1960’lı yıllarda yaygınlaşmış ve kısa zamanda güncel sorunların ifade edildiği bir içerik kazanmıştır. Kamusal sanata ev sahipliği yapan kentsel mekânların toplumun bulunduğu ve iletişim kurduğu alanlar olması, bu eserler aracılığıyla iletilen mesajların geniş bir kitleye ulaşmasını sağlamaktadır [9]. Resim, heykel, seramik, mozaik gibi sanatları içeren görsel sanatlar göze hitap eden sanatlardır; insan beynine gönderdikleri mesajlar göz aracılığıyla iletilir. Sennett [10], görülen şeye önem vermenin insanda bir şey yapma arzusu uyandırdığını belirtmektedir. Gözün algıladığı görüntünün insana vereceği mesaj ve uyandıracığı merak, bu amaca yönelik üretilmiş görsel sanat eserlerinin kullanılmasıyla tehdit altındaki yaşam ortamlarına ve türlere dikkat çekerek koruma bilinci uyandırılmasını sağlayabilir. Barnard, Debord’un, modern toplumun gerçek hayattan ve gerçek ihtiyaçlarından kopuk imgeler, görüntüler ve seyirlik nesnelere önem verdiğini, Foucault’nun ise insanın görsel olana önem verdiğini 1970’li yıllarda

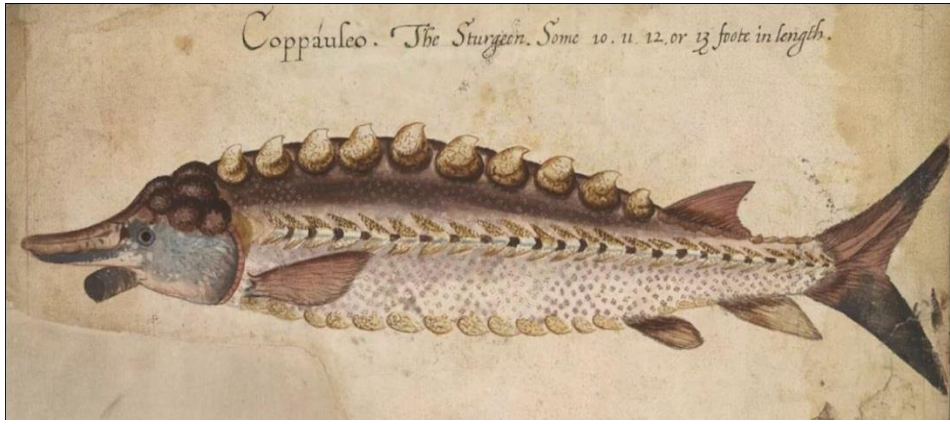
belirttiğini aktarmaktadır [7]. Bu görsel uyarıcılar içinde yer alan kamusal sanat insana mesaj veren, dikkatini çeken, düşünmesini ve bilinçlenmesini sağlayan önemli bir unsurdur. Collingwood [11] tarafından da ifade edildiği gibi, sanatta her zaman bir özne ve bir nesne, yani düşünen biri ile düşünülen bir “şey” vardır. Sanatsal bir içerik taşıyan nesne, izleyen öznedeki, yani insanda uyandıracığı imgelem ve oluşturacağı bilinçle düşünsel bağlamda besleyici bir rol oynar. Kamusal sanat eserleriyle kurulan görsel ilişkinin toplumda farkındalık yaratma özelliği nedeniyle bu tür sanat eserlerine kamusal alanlarda her geçen gün daha çok yer verilmektedir. Mekânda üç boyutlu yer kaplayan sanat eserlerinin etkisi iki boyutlu eserlerden daha güçlüdür [12]. Üç boyutlu plastik sanatlar kentsel mekânlarda genellikle heykellerle temsil edilmektedir. Kentsel alanlarda mekâna ve kentsel yaşama anlam katan estetik öğeler olan heykeller, toplumla ilişki kuran ve günlük yaşamın ayrılmaz bir parçası haline gelen eserlerdir. Günümüzde kenti süsleyen bir unsur olmanın ötesinde sosyal ve kültürel yapının ifadesi olan heykeller, diğer sanat ürünleri gibi, görünürde ifade ettiklerinden başka anlamları çağrıştırmaya, içermeye ve uyandırma gücüne sahiptir. Bu geniş anlamlandırma olanağı, sanat eserini sosyal ve kültürel değerleri değiştirip dönüştürme ya da yapılandırıp güçlendirme konusunda etkili bir araç haline getirmektedir. Kamusal mekânlardaki heykeller, bir olay ya da olgu hakkında bilinç uyandırma ve toplumsal farkındalığın artırılmasında önemli rol oynar [13]. Mağaraların duvarlarına ve tavanlarına yapılan ilk resimler çoğunlukla insanın yakın çevresindeki hayvanların tasvirleridir. Böylece erken dönemde fauna öğeleri sanatın ilk tasvirleri olarak karşımıza çıkmaktadır. Binyıllar öncesinin korkuya dayalı sanatsal hayvan betimlemeleri, günümüzde içerik ve anlam değiştirerek sanata konu olmayı sürdürmektedir. 19. yüzyıl sonlarında insanlığın dikkatini çeken habitat ve tür kaybı, doğal yaşamın ve yaban hayvanlarının 20. yüzyıl sanatında farklı amaçlarla yer almasına neden olmuştur. 20. yüzyılda önem kazanan doğa koruma bilinci ve onun uzantısı olan çevre eğitimi, kamusal alanlarda görsel sanatları yoğun olarak kullanmaya başlamıştır. Krasny [14] tarafından da belirtildiği gibi, 1900’lerin başında kent parklarında başlayan ve gelişerek günümüze ulaşan çevre eğitiminde, başta heykel olmak üzere kamusal alanlarda sergilenen sanat ürünlerinin önemli bir rolü vardır. Sabour ve ark. [15], kentsel mekânlardaki heykel türleri arasında belirli bir bölgedeki doğal hayatı ya da yabani hayvanları temsil eden doğal ve ekolojik temalı heykellerin de yer aldığını belirtmektedir. Modern kentler, uzak düştükleri doğal unsurları kamusal sanatla simgesel olarak tekrar kente dâhil etmektedir. Mekânsal ve felsefi düzlemde doğadan ayrı düşen modern kent insanına doğal süreçlerin yıkımını ve türlerin yok oluşunu anımsatarak korumacı bir tutum kazandırmak amacıyla kamusal alanlarda sanat eserlerinin kullanılması sürecinde dünyada ve ülkemizde özellikle fauna öğelerinden yararlanılmaktadır. Buradan hareketle, dünya genelinde mersin balıklarının yaygın olarak yaşadığı coğrafyalarda bu türlerin kamuoyuna görsel sanatlar yoluyla varlıklarının ve yok olma tehlikesi altında olduklarının gösterilmesini, tanıtılmasını ve koruma duyarlılığı geliştirilmesini örnekleyen eserler ele alınarak, benzer bir yaklaşımın ülkemizde de geliştirilmesi gerektiği vurgulanmaktadır. Ülkemizde yaygın oldukları coğrafyalarda bile kamuoyunca yeterince tanınmayan ve sularımızdaki biyolojik çeşitlilik açısından önemi yeterince anlaşılabilen bu

değerli balıkların yok olma tehlikesiyle karşı karşıya olduklarına vurgu yapmak amacıyla kamusal sanatın ne şekilde kullanılabileceği bu makalenin temel çıkış noktasıdır.

Mersin Balıklarının Koruma Faaliyetlerinin Kamusal Sanata Yansıması

Yaklaşık 200 milyon yıldır var olan mersin balıkları, çok değerli havyarı ve etiyle insanlık tarihi boyunca her zaman büyük önem taşımıştır. Bu nedenle yoğun bir av baskısı altında kalan mersin balıkları, 1980’li yıllara kadar dünya çapında doğal olarak buldukları tüm sularda bol miktarda avlanmakla birlikte hiçbir yerde sürdürülebilir avcılığı sağlanamamıştır. Aşırı avcılık yanı sıra, akarsular üzerine inşa edilen barajlar, HES’ler, taşkın önleme yapıları ve kum-çakıl alma faaliyetleri ve kirlilik, üreme alanlarını oldukça tahrip etmiş; üreme, popülasyon devamlılığını sağlayacak yeterlilikte gerçekleşmemiş ve bu değerli balıkların nesilleri yok olma tehlikesine girmiştir. Günümüzde 27 mersin balığı türünden 25’inin nesli ciddi oranda tehlikede olup IUCN Red List (Kırmızı Liste)’de yer almaktadır. Bir taraftan mersin balıklarının 1980’li yıllara kadar dünya çapında av miktarı gittikçe azalırken diğer taraftan bu değerli balıklar hem stok takviyesi amacıyla hem de havyar ve et üretimi bakımından yetiştiricilik sektöründe önem kazanmıştır. 1980’li yıllardan itibaren stok takviyesi dışında havyar ve et üretimine yönelik olarak ortaya çıkan yetiştiricilik faaliyetleri günümüze kadar artarak devam etmiştir. Bu bağlamda mersin balıklarının dünya çapındaki ticaretini kontrol etme zorunluluğu nedeniyle 1 Nisan 1998 tarihinden itibaren, mersin balığından elde edilen havyar, et, deri, canlı balık, yumurta gibi ürünlerin ticareti, ülkemizin de 1996 yılında taraf olduğu sözleşme olan CITES (Nesli Tehlikede Olan Yabani Hayvan ve Bitki Türlerinin Uluslararası Ticaretine İlişkin Sözleşme) kapsamına alınmıştır. Halihazırda ülkemiz sularında mersin balığı avcılığı yasak olup korunması ve nesillerinin devamının sağlanması yönünde hem resmi kurum ve kuruluşlarca hem de sivil toplum örgütlerince çeşitli faaliyetler yürütülmektedir. Genel anlamda değerlendirildiğinde, endüstri çağının çevresel yıkıcılığı ve birçok hayvan ve bitki türünün kaybı; peyzaj ekolojisi, sucul ekoloji ve koruma biyolojisi gibi habitat ve tür koruma odaklı disiplinlerin uygulamalı çalışmalarını artırmıştır. Korumaya yönelik bilimsel çalışmalar yanında bu çalışmaların hukuksal ve toplumsal ayaklarını oluşturacak çalışmalar da yapılmıştır. Bu süreçte topluma ulaşmayı sağlayan araçlardan biri de kamusal sanattır. Korumaya yönelik bilimsel çalışmaların kamuoyuna yansıtılmasında ve bilinç oluşturulmasında önemli bir unsur olarak karşımıza çıkan kamusal sanat eserleri sadece kentsel mekânlarda değil, nesli tehlike altında olan türlerin yaşadığı koruma alanlarında da yerlerini almaya başlamıştır. Dünyanın çeşitli ülkelerindeki tekil örnekler yanında, özellikle hayvanat bahçelerinde ve Batı ülkelerinde çok sayıda sanat eserini içeren açık hava müzesi niteliğindeki doğal alanlarda da koruma altındaki türleri ele alan sanat eserlerine rastlanılmaktadır. Gerek endüstri devrimi öncesinde gerek sonrasında doğal veya evcil hayvan tasvirleri hemen hemen her kültürün sanatında yer almış, birçok ülkede kamusal alanlarda sergilenen görsel sanat eserlerinde hayvanlara yer verilmiştir. Mağara duvarlarına çizilen ilk resimlerin hayvan tasvirleri olması ile başlayan fauna odaklı kamusal sanat; mitler, masallar ve semboller üzerinden bin yıllar boyunca sürse

de hayvanların koruma odaklı olarak kamusal sanata konu edilmesi nispeten yeni bir uygulamadır ve koruma düşüncesinin gelişmesi ile birlikte uygulanmaya başlanmıştır. Mersin balıklarının morfolojik özellikleri ve gastronomik önemi nedeniyle Rönesans sonrası resim sanatında betimlendiği görülmektedir. 16. yüzyılın ünlü balık ressamı John White'ın "Sturgeon" isimli sulu boya eseri (Şekil 1) ve 17. yüzyılın en önemli balık natürmortu ressamlarından biri olarak gösterilen Isaac van Duynen'in yağlı boya kompozisyonları (Şekil 2, Şekil 3), Rönesans sonrası resim sanatının mersin balığı temalı örnekleri arasında sayılabilir. Ancak mersin balıklarına yer verilen bu resimler, yapıldıkları dönem ve yapılış amaçları bakımından korumacılıkla ilişkilendirilemez. Diğer taraftan, balık biyolojisi alanında akademik eğitimi olan günümüz balık ressamlarından Paul Vecsei'nin resimleri ise bilimsel amaçlı olmakla birlikte kamusal alanla buluşmadığından koruma bilincine katkı bakımından sınırlı etkiye sahiptir.



Şekil 1. John White'ın "Sturgeon" isimli sulu boya eseri [16]



Şekil 2. Isaac van Duynen'in odağında mersin balığı olan yağlı boya natürmort kompozisyonu [17]



Şekil 3. Isaac van Duynen'in mersin balığı içeren yağlı boya natürmort kompozisyonu [18]

Posta haberleşmesinin artması ve posta pullarının yaygınlaşmasıyla pul üzerindeki görseller de mesaj iletmenin aracı haline gelmiş ve çeşitli alanlarda bilgi ve mesaj veren tasarımlarla konu çeşitliliği artmıştır. Bu bağlamda flora ve fauna öğelerine de yer verilen pul görselleri, nesli tehlike altındaki bitki ve hayvan türlerinin tanıtılması ve koruma bilincinin geliştirilmesine katkıda bulunmuştur.



Şekil 4. Romanya'dan mersin balığı görselli pul örneği [19]

Mersin balıkları da pullar üzerinde yer verilen türler arasındadır. Amerika Birleşik Devletleri, Almanya, Arnavutluk, Azerbaycan, Beyaz Rusya, Bulgaristan, Büyük Britanya, Çin Halk Cumhuriyeti, Güney Kore, Gürcistan, Hırvatistan, İspanya, Kanada, Kazakistan, Kırgızistan, Kuzey Kore, Litvanya, Macaristan, Moğolistan, Moldova, Özbekistan, Romanya, Rusya, Tacikistan ve Ukrayna, pullarında mersin balığı görsellerine tanıtım ve koruma bilincinin oluşturulması amacıyla yer veren ülkeler arasında sayılabilir (Şekil 4, Şekil 5) [19], [20]. Ayrıca mersin balıklarının korunmasında uluslararası iş birliklerine bir örnek olarak İran ve Rusya 2003 yılında çift dilli ortak pul basmıştır. Sovyetler Birliği ve Yugoslavya gibi dağılmış ülkelere çıkarılmış mersin balığı temalı pullar da tarihi bir karakter kazanmıştır.



Şekil 5. Almanya'dan mersin balığı görselli pul örneği [20]

Pullar yanında Amerika Birleşik Devletleri, Çin Halk Cumhuriyeti, Kanada, Kazakistan, Rusya, Türkmenistan, Ukrayna gibi ülkelerde hatıra paralarında da mersin balıklarına yer verilmiştir. Ülkemizde ise ilk defa 2021 yılında T.C. Hazine ve Maliye Bakanlığı Darphane ve Damga Matbaası Genel Müdürlüğü tarafından 925 ayar gümüşten 3000 adet mersin balığı hatıra parası basılmıştır (Şekil 6).



Şekil 6. Ülkemize ait mersin balığı hatıra parası [21]

Mersin balıklarının görsel sanatlardaki kullanımı, sanatın işlevsel gelişimine paralel olarak çeşitli alanlara yayılsa da koruma amaçlı verilmek istenen mesajın halkla en fazla buluşma imkânı kamusal alanlarda mümkün olmaktadır. Kamusal sanatın en önemli ayırt edici özelliği, konuyla ilişkisi olmayan sıradan insanların da aralarında olduğu geniş kitlelere ulaşarak onların bilgi dağarcıklarını ve bilinç düzeylerini geliştirecek bir işleve sahip olmasıdır. Bu bakımdan heykeller, üç boyutlu ve mekân içinde her yönden algılanan yapılarıyla kitlelere iletilmek istenen mesajların aktarımında önemli kamusal sanat öğeleridir. Morkoç'un [22] belirttiği gibi, her kamusal sanat eseri yapısıyla uyumlu bir mekânda sergilenmelidir. Eser-mekân ilişkisi dikkate alınarak, dünyada mersin balıklarının habitatları ile ilişkili olan yerleşim yerlerinde, uygun mekânlara yerleştirilen mersin balığı temalı eserlerle bu balığın varlığına, önemine, koruma tedbirlerinin gerekliliğine dikkat çekilmekte ve insanlarda koruma bilinci uyandırılarak bunu destekleyici davranışların gelişmesine katkı sağlanmaya çalışılmaktadır. Tanıtım ve koruma bilinci oluşturmak amacıyla mersin balıklarının kamusal alanlarda özellikle heykel olarak sergilendiği ülkeler arasında Almanya, Amerika Birleşik Devletleri, Kanada ve Rusya sayılabilir. Bu konudaki en dikkat çekici heykellerden biri Kanada'nın Manitoba Eyaletindeki Dominion City'de bulunmaktadır (Şekil 7).



Şekil 7. Göl mersin balığı heykeli (Dominion City, Kanada) [24]

Bu devasa heykel, Dominion City'nin doğusundan akan Roseau Nehri'nde 1903 yılında yakalanmış olan 4.6 m boyunda ve 184 kg ağırlığındaki göl mersin balığının (*Acipenser fulvescens*) gerçek boyutlardaki örneği olup Manitoba'da yakalanmış en büyük mersin balığını temsil etmektedir [23, 24]. Kanada'nın en büyük tatlı su balığı olarak özel önem verilen göl mersin balığının 2.5 metre boyunda ve 140 kg ağırlığındaki bir başka heykeli ise, Saskatchewan Eyaleti sınırlarındaki Leader Kasabası'nda bulunmaktadır (Şekil 8). Göl mersin balığına ait devasa heykeller aracılığıyla hem bu önemli ve değerli balığa dikkat çekilerek tanıtımı yapılmakta, hem de heykellerin bulunduğu kentlere turistik çekicilik kazandırılmaktadır [25, 26].



Şekil 8. Göl mersin balığı heykeli (Leader, Saskatchewan-Kanada) [25]

Kanada'daki çarpıcı mersin balığı heykellerinden biri de Britanya Kolombiyası Eyaletinde Revelstoke Kasabası'nda sergilenmektedir. Bu kasabadan geçen ve Kuzey Amerika'nın en büyük nehri olan Columbia Nehri'ndeki beyaz mersin balığı (*Acipenser transmontanus*) ve kızıl som balığı (*Oncorhynchus nerka*) türlerinin varlığına dikkat çekmek ve balıklar hakkında halkı bilgilendirmek üzere yerel yönetim tarafından kasabanın merkezinde 2010 yılında yaptırılan metal heykel grubu, doğal ortam tasarımıyla dikkat çekmektedir (Şekil 9, Şekil 10) [27].



Şekil 9. Beyaz mersin balığı ve kızıl som balığı heykelleri (Revelstoke-Kanada) [27]



Şekil 10. Beyaz mersin balığı ve kızıl som balığı heykelleri (Revelstoke-Kanada) [28]

Mersin balığı heykelleri aracılığıyla bilinç uyandırılmaya çalışılan bir başka ülke Amerika Birleşik Devletleri'dir. New York'ta Hudson Nehri üzerindeki Vali Mario M. Cuomo Köprüsü yakınında sergilenen "Leaping Sturgeon" (Sıçrayan Mersin Balığı) adlı 4.5 metre boyundaki heykel, çeşitli özelliklerdeki hurda metal parçalardan yapılmış olup Hudson Nehrinden dışarı sıçrayan bir mersin balığını çağrıştırmaktadır (Şekil 11). Bu heykelin hem bölgenin tarihinde önemli bir yeri olan mersin balığını tanıttığı hem de nesli tükenme tehlikesindeki türleri geri kazanma amacıyla gösterilen çabayı vurguladığı ifade edilmektedir [29].



Şekil 11. "Sıçrayan mersin balığı" heykeli [29]

Amerika Birleşik Devletleri'ndeki bir başka mersin balığı heykeli New York Hyde Park'ta bulunmaktadır. 11 metre boyundaki heykel, The Culinary Institute of America adlı mutfak sanatları enstitüsü tarafından, 19. ve 20. yüzyılda Hudson Nehri'nde bulunan ve bölgede gıda kaynağı olarak büyük ekonomik değere sahip olan mersin balığının önemine dikkat çekmek üzere 2015 yılında yaptırılmıştır (Şekil 12). Heykelin en dikkat çekici özelliği, 700 adet bıçak, 400 adet çatal ve 600 adet

kaşıktan yapılmış olmasıdır (Şekil 13). The Culinary Institute of America tarafından yaptırılan bu devasa mersin balığı heykeli aracılığıyla bir taraftan mutfak sanatları enstitüsü öğrencilerini ve toplumu bölgedeki yerel yemeklerin tarihi hakkında bilgilendirilme, diğer taraftan Hudson Nehri'ndeki canlı yaşamını koruma çabaları konusunda toplumsal farkındalık yaratma hedefleri öne çıkmaktadır. Heykel sayesinde Atlantik mersin balığının (*Acipenser oxyrinchus*) Hudson Nehri'ndeki tarihsel önemine ve mersin balıklarının dünya çapında karşı karşıya kaldığı büyük tehlikeye dikkat çekilmektedir. Hudson Nehri'nde mersin balığı popülasyonunun aşırı avlanma, kirlilik ve yumurtlama alanlarına ulaşımı engelleyen barajlar nedeniyle kritik derecede azaldığı ve bu durumu düzeltmek amacıyla eyalet ve federal hükümet tarafından tedbirler alınarak izleme faaliyetlerinin yürütüldüğü bildirilmektedir [30, 31].



Şekil 12. New York Hyde Park'taki mersin balığı heykeli [31]



Şekil 13. New York Hyde Park'taki mersin balığı heykelinden görüntüler [30, 32]

Mersin balığı'ndan söz edildiğinde akla gelen ilk ülkelerden biri olan Rusya'da da birçok şehirde mersin balığı heykelleri bulunmaktadır. Bu heykellerden en dikkat çekici olanı dünyanın en derin nehirlerinden

biri olan Yenisey Nehri üzerinde 1971’de inşa edilmiş olan Krasnoyarsk Hidroelektrik Santrali yakınlarındaki 100 metrelik bir uçurumun kenarına yerleştirilmiştir (Şekil 14). Rus yazar Victor Astafyev’in 1976 yılında yayımlanmış olan *Çar Balığı* romanına adanmış bir anıt özelliğinde olan ve 300 kiloluk bir mersin balığını simgeleyen heykel 2004 yılında yapılmıştır [33, 34]. Rus edebiyatındaki ilk eko eleştirel çalışma olarak kabul edilen *Çar Balığı* romanı [35], doğa için mücadeleye önem vermiş olan Victor Astafyev’in insan ve doğanın ilişkisi ve mücadelesi hakkındaki kitaplarından biri olup kaçak avcılık temasını işlemektedir [36].



Şekil 14. Yenisey Nehri- Krasnoyarsk Hidroelektrik Santrali yakınındaki mersin balığı heykeli [34]

Rusya’nın Astrahan şehri merkezinde bulunan bir başka mersin balığı heykeli ise Şekil 15’te yer almaktadır.



Şekil 15. Astrahan’da bir mersin balığı heykeli [37]

Almanya’nın önemli nehirlerinden biri olan Elbe Nehri’nin Oberndorf’tan geçen Oste kolu üzerine 2009 yılında yerleştirilmiş olan mersin balığı heykeli de dikkat çekmek ve koruma bilinci uyandırmak üzere gerçekleştirilmiş önemli bir uygulamadır. Heykel, dışarıdan bakıldığında yüzüyor izlenimi verdiği için dünyanın ilk “Yüzen Mersin Balığı Heykeli” olarak nitelendirilmiştir (Şekil 16).



Şekil 16. “Yüzen Mersin Balığı” Heykeli (Elbe Nehri, Almanya) [38]

Ahşaptan yapılmış olan heykel, kışın sudan çıkartılarak bakımı yapıldıktan sonra ilkbaharda tekrar nehre yerleştirilmektedir. Dünya çapında en geniş alanda yayılış gösterdiği bilinen ve günümüzde Avrupa sularında nesli neredeyse tamamen tükenmiş olarak kabul edilen *Acipenser sturio*'nun bir zamanlar Elbe Nehri ve kollarında bulunduğu ve günümüzde ise yok olduğuna dikkat çekmek üzere yaptırılan bu heykel, aynı zamanda *Acipenser sturio* için Elbe Nehri ve kollarında yürütülen restorasyon/rehabilitasyon faaliyetlerini de temsil etmektedir [38], 39].



Şekil 17. Samsun-Çarşamba'daki Mersin morinası heykeli (Fotoğraf: Güven Genç)

Ülkemizdeki ilk ve tek mersin balığı heykeli ise 2016 yılında Samsun'un Çarşamba İlçesi'nde Çarşamba Belediyesi'nce yaptırılıp bir tanıtım tabelası eşliğinde halkın dikkatine sunulmuştur (Şekil 17, Şekil 18) Mersin morinası (*Huso huso*) türünü temsil eden bu heykel ve bilgilendirme tabelası aracılığıyla mersin balıklarının Yeşilırmak Nehri ve bu nehrin mansabına yakın bir yerde kurulmuş Çarşamba İlçesi için ne denli önemli olduğuna ve korunması gerektiğine dikkat çekilmiştir.



Şekil 18. Çarşamba'daki Mersin morinası (*Huso huso*) heykeli ve bilgilendirme tabelası (Fotoğraf: Güven Genç)

Sonuç

Dünya çapında kamusal mekânlarda yer alan görsel sanat eserleri sadece estetik amaca yönelik değer taşıyabildikleri gibi aynı zamanda topluma verilmek istenen çeşitli tarihsel, kültürel veya siyasal içerikli mesajlara da aracılık edebilmektedir. Kamusal alanlarda yer alan görsel sanat eserleri, nesli tükenme tehlike altında olup korunmaya muhtaç hayvan ve bitki türlerinin tanıtımına katkı sağlayarak toplumu bilgilendirme, bilinçlendirme ve farkındalık oluşturma amaçlarına da hizmet edebilmektedir. Bu konuda ülkemizdeki örnekler arasında Akdeniz foku (Datça ve Foça), deniz kaplumbağası (Köyceğiz ve Dalyan), flamingo (İzmir Gediz Deltası Kuş Cenneti ve Afyon), kelaynak (Birecik) türlerine ait heykeller örnek verilebilir. Dünya çapında olduğu gibi ülkemiz sularında da nesli tükenme tehlikesinde olan mersin balıklarının tanıtımı ve koruma bilinci oluşturma amacıyla birçok ülkedeki örnekler gibi ülkemizde de özellikle Yeşilirmak, Kızılırmak, Sakarya Nehirleri olmak üzere birçok alanda görsel eserler eşliğinde tanıtıcı bilginin sunulmasının toplumumuzda farkındalık yaratarak koruma bilincinin oluşmasına katkı sağlayacağı düşünülmektedir. Mersin balıklarını diğer balıklardan farklı kılan ve dikkat çeken morfolojik özellikleri yanı sıra, yaklaşık 200 milyon yıldır dünya üzerinde var olması, altı metre boya ve iki ton ağırlığa ulaşabilen dünyanın en büyük tatlı su balığı olması, 100 yaşına kadar yaşayabilmesi gibi bilgiler, kamuoyunun ilgisini çekecek ve özellikle çocuklarda ve gençlerde farkındalık ve ilgi oluşturacaktır. Mersin balıklarının geçmişte çok değerli havyarı için aşırı avlanması, üreme alanlarını oluşturan nehirlerdeki çeşitli unsurların (barajlar, HES'ler, karayolu köprüleri, kumçakıl ocakları, su alma yapıları, akarsu yatağındaki ıslah çalışmaları gibi) üreme imkânlarını kısıtlaması ve su kirliliği gibi nedenlere bağlı olarak yok olma tehlikesiyle karşı karşıya kalması üzerine, günümüzde uygulanan koruma tedbirlerine dair yazılı bilgilerin görsel sanat eserleriyle birlikte sunulması, kamuoyunda ülkemiz sularındaki biyolojik çeşitliliğin çok önemli bir ögesi olan mersin balıkları konusunda duyarlılık oluşturmada ve koruma tedbirlerinin etkinleştirilmesinde faydalı olacaktır.

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