INTERNATIONAL JOURNAL OF AUTOMOTIVE SCIENCE AND TECHNOLOGY

2022, VOL. 6, NO: 4, 379-385 www.ijastech.org e-ISSN: 2587-0963

The Effect of Basalt Fiber Addition on Physical Dry Wear in Al-Cu Alloy Used in the Automotive Industry

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Abstract

In this study, Al-Cu alloy, which is used in various fields of the automotive industry, was produced as powder metallurgical and additionally basalt fiber was added into it. Thus, it is aimed to increase the wear resistance. The samples produced in two types as fiber rein-forced and non-reinforced were sintered at 600 degrees after pressing. Scanning electron microscope (SEM) and integrated Energy Dispersive X-ray (EDX) detector were used for microstructure and chemical analysis of the samples. After the SEM and EDX examinations, the hardness measurements were carried out, and finally, the wear test was applied to the samples. As a result of the data obtained from the experimental studies, it was determined that the fiber addition increased the amount of porosity in the microstructure, caused a de-crease in the hardness value and increased the abrasion resistance approximately 6 times.

Keywords: Powder metallurgy, Al-Cu alloy, basalt fiber reinforcement, wear.

Research Article

https://doi.org/10.30939/ijastech..1196790

Received 05.10.2022
Revised 14.11.2022
Accepted 18.11.2022

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1. Introduction

Powder metallurgical materials have started to be used frequently in traditional productions in the automotive industry and recently especially in the production of electric vehicles. The biggest reason why this method is preferred is that the ratios of the alloying elements they contain can be adjusted and thus the desired properties can be obtained. Today, while the ratio of powder metallurgical parts used in traditional automotive production is 30%, this ratio rises to 50% in electric vehicle production [1, 2].

Aluminum (Al), copper (Cu) and their alloys are used in many industrial areas such as industry and technology [3, 4]. In particular, AlCu alloys are used as power collectors in electric trains, in parts that require high electrical conductivity and high strength. However, the casting method alone is not sufficient for its use here. In this case, the first preferred method is the powder metallurgy method. Thanks to the powder metallurgy method, the control of the grain structures are better. This increases the wear resistance [5, 6].

It is known that fiber reinforced composites exhibit much better properties than other composites. Boron, graphite (carbon), alumina, and silicon carbide are the most commonly used fiber types. These fiber types have high temperature stability, low thermal conductivity, low heat storage, etc. Although they provide such features, they have a high cost [7, 8].

Fibers called basalt fibers are obtained from the melting of basalt rocks. The chemical structure of these fibers is predominantly SiO_2 (43-47%), Al_2O_3 (11-13%), CaO (10-12%), MgO (8-11%), Fe_2O_3 (9-11%). In addition, Na_2O, TiO_2, K_2O and Mn_2O_3 elements are also around 5%. Thanks to the presence of so many different chemical components, the fibers provide high abrasion resistance and high hardness to the sample to which they are added [7].

In addition to these strong mechanical properties, basalt fiber reinforced powder alloys also have high sliding wear resistance, high load carrying capacity and low density properties. In this way, they are widely used in automotive and aircraft brakes [9-13]. In addition, due to the high temperature resistance of these reinforced alloys, they are also used in diesel piston engines [14, 15].

This study, it is aimed to increase the wear resistance of AlCu alloy, which is a material used in the automotive industry. The wear rate is reduced with the help of basalt fiber added to the alloy produced by the powder metallurgy method. The produced materials were examined in all aspects in terms of microstructure, hardness and wear. Improvement of AlCu alloys has been achieved by increasing the wear resistance up to 6 times. Thus, the wear resistance feature that basalt fiber gives to the material has been revealed.

2. Materials and methods

2.1 Materials

Al and Cu elements used in this study were used in powder form. The powders were obtained from the company Nanografi located in Türkiye. Powders have sizes in the range of 1-20 µm. Powders fraction is specified as D_{90}-14 µm. X-ray fluorescence (XRF) analysis was also applied to the powders. In addition, scanning Electron Microscope (SEM) images of the powders before the experiments are shown in Figure 1.

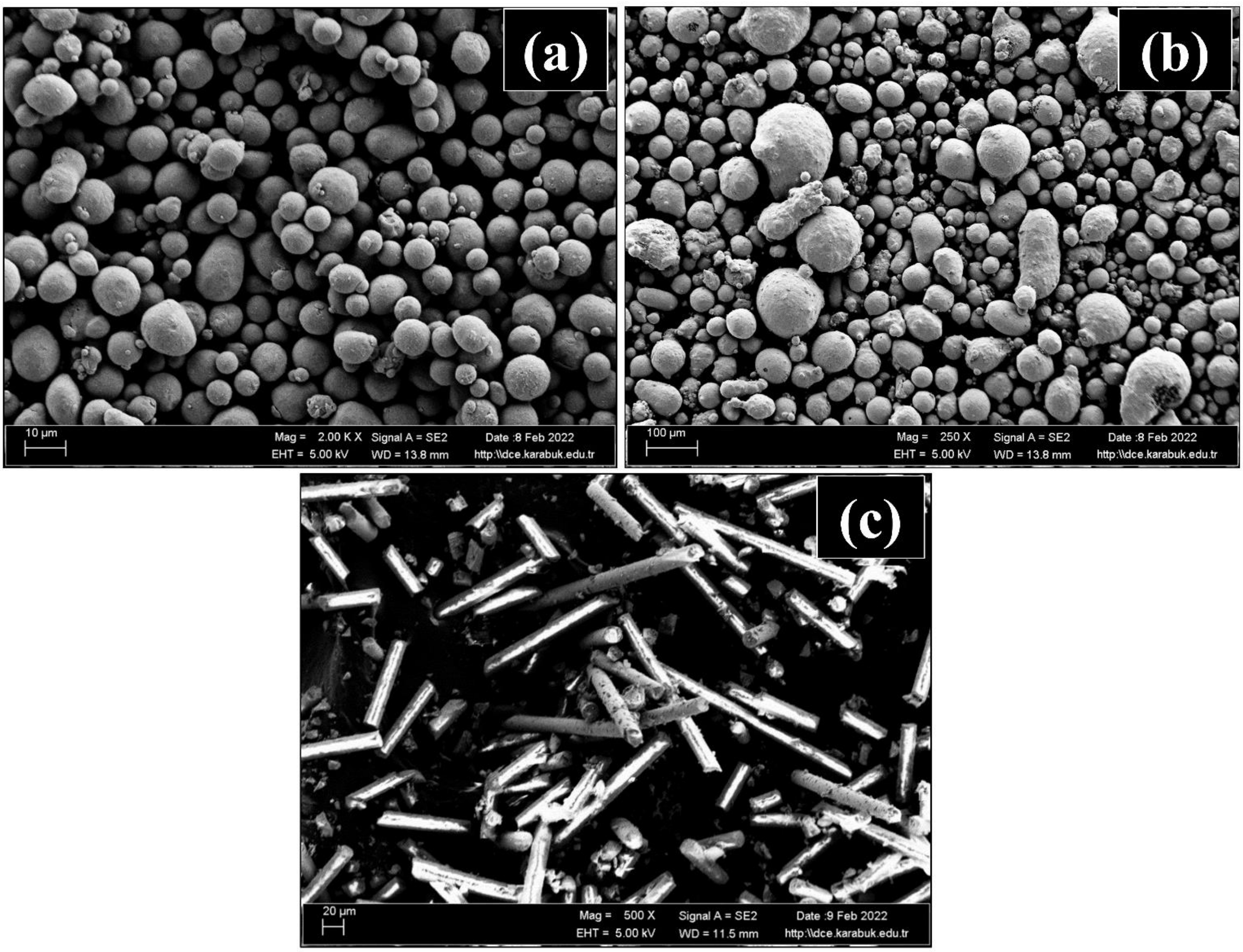


Fig. 1. SEM images of the powders and fiber reinforcement (a) Al, (b) Cu, and (c) Basalt fiber

The basalt fiber used as additional material was obtained from Dost Kimya/Türkiye. XRF analysis was also applied to the basalt fiber. Basalt fiber technical specifications (company catalog) are listed in Table 1. Basalt fiber SEM image is shown in Figure 1.

Table 1. Technical parameters of basalt fiber

Parameters	Amount
Yield Strength / Elastic modulus	4840 MPa / 89 GPa
Application Temperatures	-260°C / +982°C
Melting Temperature	1450°C
Specific weight	2.70 g/cm^3
Diameter / Length	9-23 µm / 6-12 mm

2.2 Pressing and sintering

The powders were prepared by the mixing method given in Figure 2. The powders were first mixed in ethanol at 400 rpm and 1 hour. Afterward, the added fiber was mixed again for more 1 hour. Finally, it was dried by laying on hydrophobic filter paper (70°C/24 hours). Element and fiber ratios used in two different mixtures are given in Table 2.

The powder mixture was pressed in a mold with a diameter of 16 mm with a pressure of 20 kg/mm^2. After the pressing process was completed, the samples were sintered at 600°C for 4 hours, and then they were left to cool in the furnace for approximately 24 hours. The sintering process was applied in a normal heat treatment furnace without atmosphere control. The sample surfaces were simply wrapped with aluminum foil to prevent oxidation.

Table 2. Sample preparation rates

% wt	Al powder	Cu powder	Basalt fiber
AlCu	50	50	0
AlCuBsl	47.5	47.5	5

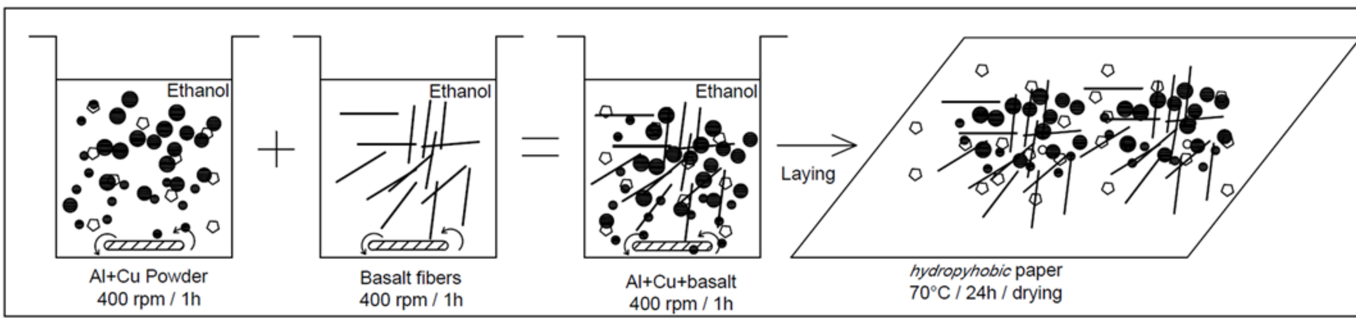


Fig. 2. Mixing process

2.3. Characterization

Microstructure images of the sintered samples were carried out on Carl Zeiss Ultra brand SEM, and EDX analyzes were performed with Gemini FESEM brand detector integrated into SEM.

Vickers hardness measurements were carried out in a Q-ness brand micro-hardness device using 1000 g weight. Hardness values were obtained from the average of five measurements taken at 5 mm intervals.

Wear tests were carried out on a UTS Tribometer T10 brand device under a load of 10 N at room temperature on a dry surface. A total of 100-meter sliding distance was applied with a reciprocating motion of ±10 mm. After the test, the worn surfaces were examined with SEM images. Worn surface morphology was measured on the wear morphologies with the Mitutoyo SJ-410 profilometer.

The "wear rate" was calculated according to Formulas 1 and 2 [16, 17] using profilometer morphologies and other variables.

$$WS = TA(mm^2)\ \ x\ \ RM(mm) \qquad (1)$$

$$WR = {WS(mm^3)}\Big/{F(N)\ \ x\ \ TSD(m)} \qquad (2)$$

where;

WS - worn surface volume

TA - trace area

RM - reciprocating motion amount

WR - wear rate

F - load

TSD - total sliding distance

3. Results and discussions

XRF analysis results for the powders and basalt fiber used in this study are given in Table 3 and Table 4, respectively.

Table 3. XRF analyzes of Al and Cu powders

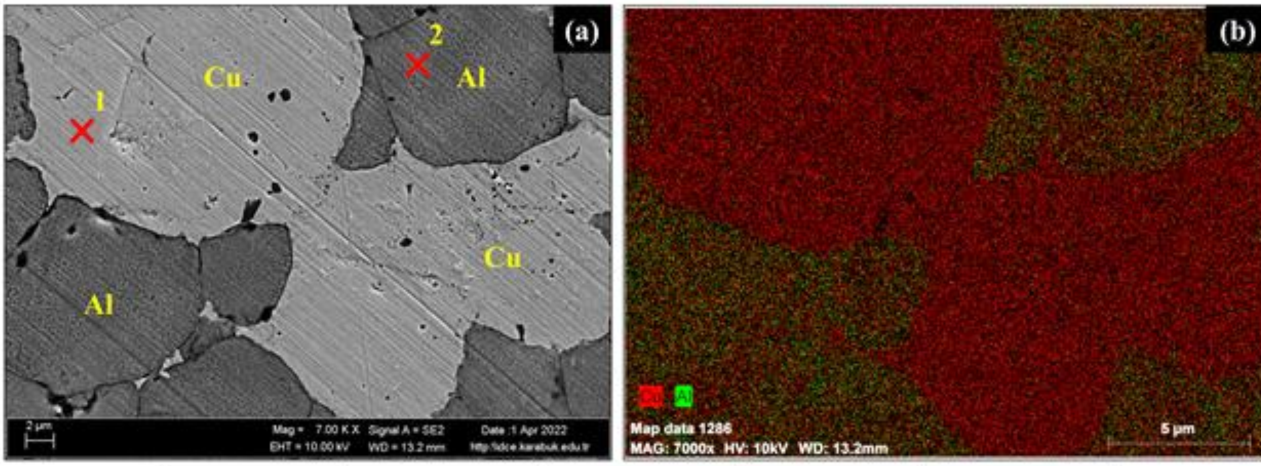
% wt	Al	Cu	Zn	Mg	Ag	Other
Al Powder	99.85	0.01	0.02	0.01	0.01	0.1
Cu Powder	0.01	99.78	0.01	0.03	0.02	0.13

Table 4. XRF analyzes of basalt fiber

% wt	Al_2O_3	SiO_2	CaO	Fe_2O_3	K_2O	MgO	Na_2O	TiO_2
Basalt	15.76	53.43	11.08	9.20	1.44	5.04	2.57	1.44

After 4h sintering process, metallic samples were obtained. Figure 3 shows the sintered samples.

Al and Cu elements are observed in the SEM images of the AlCu sample. Cu-Al ratios support the microstructure in EDX-MAP and EDX-point analysis. The amount of oxide detected in the EDX analysis is approximately 1%.



% wt	Al	Cu	O	Other elements
1	0,01	98.63	1.01	0.35
2	99.01	0.01	0.85	0.13

Fig. 3. SEM image (a) and EDX analyzes (b) of AlCu specimen

The porosity ratio is important in powder metallurgy alloys [18]. In this context, the amount of porosity in the AlCu sample is low. High rates of voids and inclusions were not detected between the grains.

The amount of oxide in the materials produced by this method can be up to 4%. In this study, the amount of oxide was observed at the level of 1%. Thus, it can be said that the sinter temperature and application method did not cause oxide [19].

SEM back scattered electron (BE) images of the AlCuBsl are given in Figure 4 below.

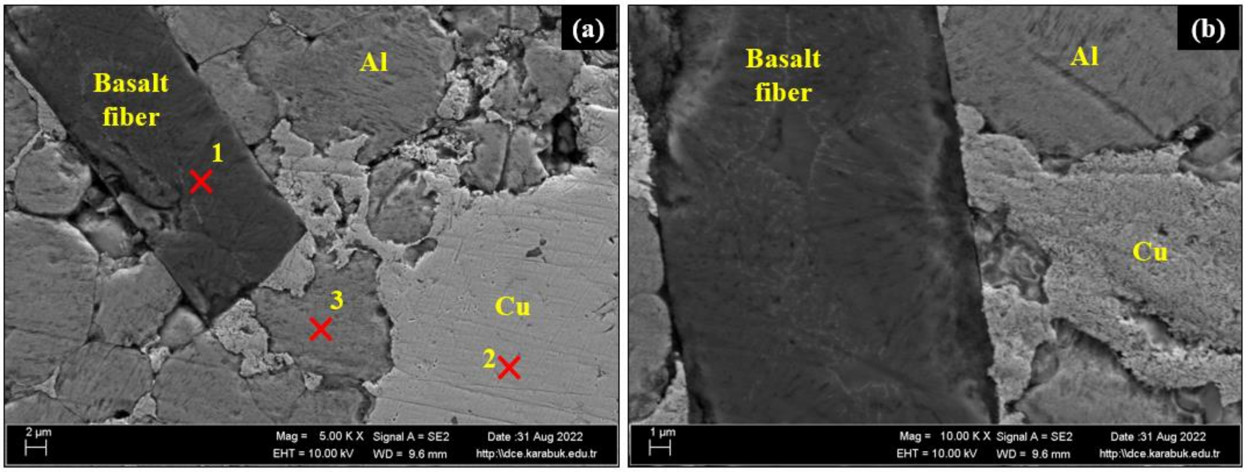
Basalt fiber, Cu and Al became visually distinguishable with SEM (BE) images and confirmed by point analysis. However, the amount of oxide in Cu and Al was determined to be less than 1%. Although the amount of oxide in the basalt fiber was determined by EDX analysis, it cannot be said to give a clear result since it mostly consists of oxide-containing compounds. Porosity formations are observed around the basalt fibers. The porosity rate increases in fiber and ceramic reinforced powder metallurgy materials [7, 18, 20]. Inclusions formed on the surface of the reinforcement product increase this porosity rate. Thus, porosities are seen around the fibers in the microstructure.

The hardness test results are shown in Table 5 in detail. According to the hardness test results, the hardness level decreased with the addition of basalt fiber. The hardness decreased depending on the porosity ratio that emerged with the fiber addition [7, 18]. The inverse ratio of the porosity ratio and the hardness level was observed.

The surface images and profilometer morphology obtained as a result of the wear tests are shown in Figure 5.

Table 5. Hardness test results

$HV_{1.0}$	1	2	3	4	5	Avg.
AlCu	306	345	315	324	336	325.2 ±21
AlCuBsl	265	257	241	239	227	245.8 ±20



% wt	Al	Cu	O	Fe	K	Mg	Si	Ca	Na	Ti	Other
1	20.52	0.02	29.50	8.85	1.81	6.27	18.52	8.50	3.01	2.01	0.99
2	0.01	99.63	0.07	-	-	0.01	-	-	-	-	0.28
3	99.21	0.12	0.42	0.01	-	-	0.02	0.05	-	-	0.17

Fig. 4. SEM images of AlCuBsl specimen (a-b) high-low magnification

After the abrasion surface examinations, the preserved grains in the AlCu sample are observed. However, the surface generally exhibited an "abrasive" mechanism.

The grain structure is generally preserved in the AlCuBsl sample. The wear mechanism exhibited an “adhesive (or sliding)” structure. At the same time, porosities are also observed on the eroded surface. Basalt fibers are generally broken at the wear surface.

The WR was calculated over the profilometer indentation using formula 1 and is given in Table 6.

Table 6. Wear rates

Specimens	Wear rate (mm^3/N.m)
AlCu	0.00118 ±0.00020
AlCuBsl	0.00024 ±0.00006

According to the WR results, the basalt fiber added to the structure increased the abrasion resistance approximately 6 times. The calculated WR in AlCu alloys is close to the literature [14, 21]. Basalt fiber fragmented during wear, delaying the wear. The delay of wear of fiber structures by this mechanism showed similar results to the literature [20]

4. Conclusions

This study reviewed the effect of basalt fiber addition on the physical dry wear of Al-Cu alloy. First, the effect of basalt fiber was compared with that of the unmodified alloy. This effect was investigated using microstructure and wear test methods. The main results are that the porosity rate is higher in the basalt fiber added sample. Thus, the hardness of the modified alloy decreased and, as a result, its wear resistance increased. In addition, the purity of Al and Cu elements was preserved during the chemical analysis process and the basalt fiber took its place in the structure without being oxidized. In this context, the following main results were obtained.

1. Microstructures bearing the basic features of the powder metallurgy method were formed in the samples. The porosity rate was higher in the sample with basalt fiber added.

2. The purity of Al and Cu elements was preserved during the chemical analysis process. Basalt fiber has taken its place in the structure without being oxidized.

3. As a result of the micro hardness test, the increase in the porosity rate with the addition of fiber caused a decrease in the hardness. The hardness has decreased by about 25%.

4. As a result of the abrasion test, the "Abrasion rate" is approximately six times lower in the fiber-added sample. On the worn surfaces, the oxide ratio was determined as maximum 1%.

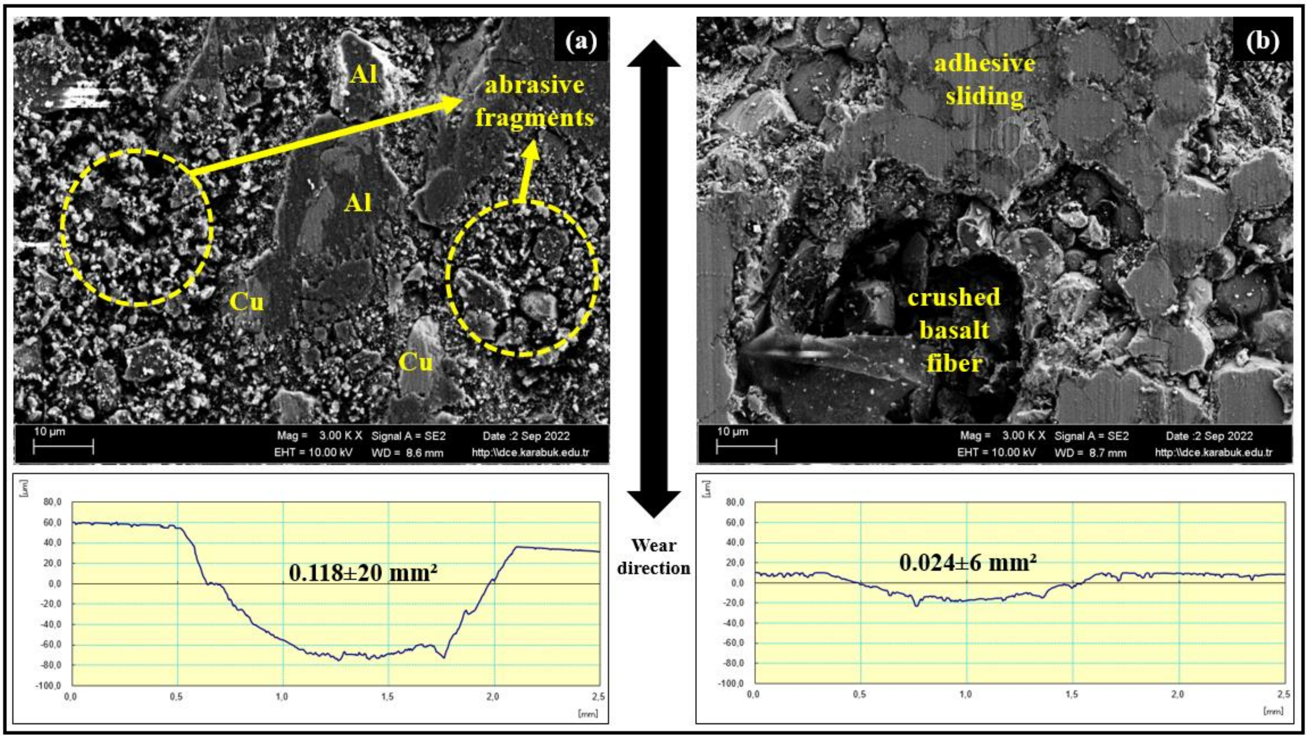


Fig. 5. Worn surfaces SEM images (a) AlCu, (b) AlCuBsl and profilometer measurements

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Bünyamin Çiçek: Conceptualization, Supervision, Writing-original draft

Tuna Aydoğmuş: Conceptualization, Writing-original draft, Validation, Formal analysis.

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