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İÇİNDEKİLER / CONTENTS

Araştırma Makalesi / Research Article

Derleme Makalesi / Review Article

International Journal of Engineering Approaches

Araştırma Makalesi / Research Article

Financing table olive cultivation with diminishing musharakah: Financial analysis of a project in Bursa province

Sofralık zeytin yetiştiriciliğinin azalan müşareke ile finansmanı: Bursa ilinde bir projenin finansal analizi

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ABSTRACT

Despite the high demand for olives, there has been a decline in cultivated olive acreage in Türkiye in recent years. An important reason for this is the financial sustainability issues associated with the current interest-bearing debt financing model. The irregularity of income versus the regularity of loan repayments exposes farmers to commercial and seasonal risks, shifting the entire risk burden onto them without shared accountability from lending institutions. This study conducted a comparative financial analysis over a ten-year horizon for an olive orchard project in Bursa province, utilizing current market data, property values, and insights from table olive growers and it is revealed that the Diminishing Musharakah financing model is significantly more profitable for farmers compared to the interest-bearing debt financing model. Although the initial cost of establishing the orchard is similar under both models, interest-bearing debt financing model leads to a higher total repayment amount due to interest, whereas Diminishing Musharakah financing model maintains the initial cost without any interest, allowing for greater profitability. Additionally, this model provides distinct advantages in managing cash flow, as it aligns repayment schedules with harvest periods, thereby reducing the financial strain on producers. This financing structure also facilitates risk sharing among partners, effectively addressing challenges related to yield fluctuations and market volatility. The study shows that enhancing the financial sustainability of olive cultivation requires the adoption of alternative financing models.

ÖZET

Zeytine olan yüksek yerel ve uluslararası talebe rağmen son yıllarda Türkiye'de zeytin ekili alanlarda bir azalma görülmektedir. Bunun önemli bir nedeni mevcut faizli borç finansmanı modeli ile ilişkili finansal sürdürülebilirlik sorunlarıdır. Gelirlerin düzensizliği ile kredi ödemelerinin düzenliliği arasındaki uyumsuzluk, çiftçileri ticari ve mevsimsel risklere maruz bırakmakta ve kredi veren kurumlarca sorumluluğun paylaşılmaması risk yükünü tamamen çiftçilerin üzerine bırakmaktadır. Bu çalışma, Bursa ilinde bir zeytin bahçesi projesi için güncel piyasa verileri, arazi değerleri ve sofralık zeytin yetiştiricilerinin görüşlerini kullanarak on yıllık bir dönem için karşılaştırmalı bir finansal analiz gerçekleştirmiş ve Azalan Müşareke finansman modelinin, faizli borç finansmanı modeline göre çiftçiler için önemli ölçüde daha kârlı olduğunu ortaya koyulmuştur. Her iki modelde de bahçenin başlangıç maliyeti benzer olmakla birlikte, faizli borç finansmanı modeli, faiz nedeniyle daha yüksek bir toplam geri ödeme tutarına yol açmakta; buna karşın Azalan Müşareke finansman modeli faiz olmaksızın ilk maliyeti koruyarak daha yüksek kârlılık sağlamaktadır. Ayrıca, bu model, ödeme takvimlerini hasat dönemlerine uyarlayarak nakit akışının yönetiminde üreticiler için mali baskıyı azaltıcı avantajlar sunmaktadır. Bu finansman yapısı aynı zamanda ortaklar arasında risk paylaşımını kolaylaştırmakta, verim dalgalanmaları ve piyasa oynaklığı ile ilgili zorlukları etkin bir şekilde ele almaktadır. Çalışma, zeytin yetiştiriciliğinin finansal sürdürülebilirliğini artırmak için alternatif finansman modellerinin benimsenmesi gerektiğini göstermektedir.

1. Introduction

Türkiye's agricultural sector holds significant global importance due to its ability to meet increasing food demands driven by population growth, contribute to employment and national income, supply raw materials needed for the industrial sector, and provide direct and indirect contributions to exports. As technology advances, it has become evident that many factors once deemed important are not as critical as ensuring sustainable food production. Türkiye's geographical location further enhances its agricultural advantages, making it highly suitable for farming and bringing numerous benefits. Additionally, its location serves as a crucial bridge in global agriculture.

Türkiye's extensive coastline with a Mediterranean climate highlights its significant potential for olive cultivation. Olive cultivation dates back to ancient times, with the olive tree being considered the ancestor of all trees. Its importance in human history is underscored by its presence in all sacred texts and creation myths. Today, planting olive trees not only supports future food production but also contributes to economic development. In the 2022-2023 season, Türkiye achieved $184.5 million in olive exports [1]. However, recent challenges in financial sustainability have led to the uprooting of many olive trees, especially in the Marmara region. Vacant and fertile lands from olive groves are either being repurposed for other uses or converted to grow agricultural products with easier financial management. While mature olive trees capable of yielding hundreds of kilograms of produce are used for decorative furniture production [2-4], the high prices of olives [5] have made domestic access to olive oil increasingly difficult [6-7], prompting significant portions of the harvest to be exported abroad [8]. Therefore, establishing olive orchards holds crucial importance for both Türkiye and the global community.

Türkiye's domestic and international market potential underscores the significant economic contributions that olive cultivation can provide if its financial sustainability is ensured. Despite the government's support and the financial burdens, it assumes for farmers, challenges persist regarding the financial sustainability of olive cultivation. Therefore, the Financing Models (FMs) used when establishing olive orchards are crucial. Typically, investors prefer the Interest-bearing debt financing model (IBDFM), in other words credit financing, where farmers face high cash flow imbalances throughout the year and shoulder all commercial and seasonal risks. Any market fluctuation can significantly impact the financial sustainability of olive production.

In this study, the impacts of financing olive cultivation through alternative models on sustainability and profitability have been examined. The alternative FM discussed in this study is the Diminishing Musharakah Financing Model (DMFM), a subcategory of Islamic finance. One significant advantage of the Musharakah Financing Model (MFM) is its avoidance of interest-based financing, making it viable for farmers seeking to manage their cash flows effectively. Using real market data, a comparative analysis of both IBDFM and MFM has been conducted through a sample scenario, evaluating their respective internal rates of return. The findings not only address financial implications but also discuss risks associated with each FM.

The structure of the study is organized as follows: Section 2 introduces the DMFM, Section 3 provides general information on olive cultivation, Section 4 compares scenarios of financing olive cultivation using IBDFM and DMFM, calculates relevant economic metrics, and Section 5 interprets and discusses the obtained results, while Section 6 presents conclusions and future research recommendations.

2. Musharakah Financing Model

MFM, which means "partnership" or "joint venture," involves two or more parties pooling capital to engage in business together, sharing profits or losses according to agreed terms [9]. It is a partnership where each party contributes capital according to their own preferences, aiming to undertake joint commercial activities and share resulting profits or losses based on the principle of profit and loss sharing. MFM is a FM designed for use in interest-free banking, operating on the profit-loss sharing principle. This arrangement allows individuals and institutions to combine their capital to engage in business activities, providing an avenue for financing without interest. MFM is particularly used as an alternative to conventional interest-based banking systems for sectors such as real estate, business ventures, residential property, land, and agricultural fields, catering to those sensitive to interest rates.

In MFM, the capital contributions from parties involved can vary in amounts. The profit-loss relationship dictates that profits generated from the partnership are distributed according to an agreed profit-sharing ratio, which may not necessarily be proportional to the capital contributions. In case of losses, however, the losses are shared based on the initial capital contributions of each party [10-11].

MFM involves an interest-free financial institution becoming a partner in a newly established or existing company. Through MFM, the institution acquires shares of an independent legal entity under an MC, which is considered permissible from a religious standpoint. MFM can also involve the financial institution holding shares of another entity for investment purposes or to diversify its risk [12].

The structure of the MFM is highly suitable for financing agricultural products. This can be justified as follows:

- Production quantity and quality can vary due to factors such as weather conditions, diseases, and market prices. MFM relies on a profit-loss partnership, where partners share in the profits earned and bear losses proportionate to the capital they have invested. This makes it an appropriate FM for uncertainties and risks that may arise in olive production.
- Olive production is a sector that requires long-term investment. The growth and productivity of olive trees take time. MFM enables pooling of resources among parties to facilitate larger and more comprehensive investments, thereby promoting more efficient and higher-quality olive production.
- Olive producers may be sensitive to interest rates and may prefer not to use IBDFM. MFM offers a non interest-based-FM, allowing producers to meet their financial needs without the burden of interest payments.

- MFM is a FM that requires collaboration and solidarity among partners. In olive production, partnerships in areas such as knowledge and experience sharing, technical support, and marketing are crucial for success. MFM encourages and strengthens such collaborations.
- Olive production is susceptible to risks such as natural disasters, diseases, and market fluctuations. MFM facilitates the sharing of these risks among parties, preventing one party from bearing large losses alone and making risks more manageable.
- MFM is a long-term and sustainable FM. Parties engage in long-term cooperation and investment planning rather than focusing solely on short-term profits. This is crucial for enhancing the sustainability and quality of olive production.

2.1. Diminishing musharakah financing model

DMFM is a FM based on profit-loss sharing agreement conducted among two or more parties on a project. One of the parties gradually purchases the shares of their partner in specified amounts over a determined period, eventually becoming the sole owner of the project. Throughout DMC, profits and losses are shared according to the agreed-upon shares [13]. This allows individuals with Islamic sensitivities to acquire property and assets without engaging in interest-based transactions. When forming a Diminishing Musharakah Contract (DMC), the transfer of shares according to agreed conditions over a specified period suitable for buying and selling is considered [13]. An example scenario for DMFM flow is illustrated in Figure 1.

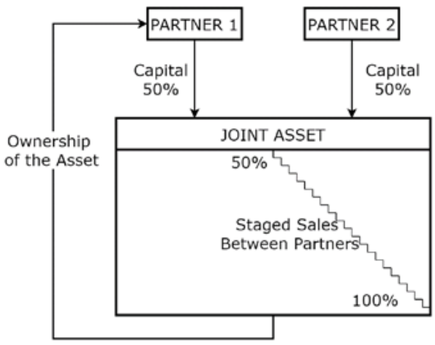

Figure 1. Diminishing musharakah flow for an example scenario

In DMFM, the aim is to bring together the party in need of financing with the party interested in investing to generate profit. DMFM has various economic and social benefits. Some of these can be listed as follows:

- Providing an opportunity for investment and funding without interest,
- Opening an investment gateway for individuals with capital to contribute their capital to the service of the economy,
- Contributing to fair benefit sharing from production and raising societal welfare,
- Offering financiers, the opportunity to enter into projects, make profit at the end of the project, terminate the partnership after a certain period, and redirect towards other investment opportunities,
- For customers, it provides the opportunity to own the entire property in the project at the end of the project.

2.2. Permanent musharakah financing model

Permanent Musharakah Financing Model (PMFM) means “a partnership established based on the principle of profit and loss among two or more parties to carry out a profitable project” [12]. The main point in this FM is that the partnership established at the outset is permanent and continuous. The difference between DMFM and PMFM, as the name implies, is that in PMFM, the parties do not have the intention to terminate the partnership at a specific time or gradually over a period [12].

3. Olive Cultivation

Olive is the fruit of the olive tree, which is native to the Mediterranean climate. Olive leaves, which are renewed approximately every three years and do not all fall off at once in autumn, have high durability. The cuticle and stomatal structures of these leaves allow for both moisture retention and high-capacity CO_2 absorption. Moreover, their densely packed and numerous leaves can reduce the adverse effects of heavy rainfall and regulate the flow of water into the soil, minimizing the risk of erosion. One of the significant reasons olives can grow in different soil types is their robust and deep root system. These roots protect against erosion and soil loss by drawing water from deep layers. All these biological and ecological characteristics contribute to olives forming a pattern intertwined with other living and non-living systems in the same ecosystem, supporting and sustaining biodiversity. In today's world, where climate crisis and ecological damage are rapidly continuing, preserving and strengthening olive groves is of vital importance [14].

Olive is a versatile fruit used for olive oil production and consumption as a table fruit. Olives can sometimes develop different flavors when soaked in salt and vinegar. Additionally, olives are used as essential raw materials in the production of creams, soaps, skincare, and the cosmetics industry. Olive cultivation involves processes such as selecting suitable land, soil analysis, planning irrigation systems, and planting olive seedlings. Olive orchards require special care in the initial years. During this period, regular maintenance is essential to support seedling growth, prevent diseases, and improve overall health. As olives mature, the harvesting process begins, and the harvested products are transported to processing facilities.

Choosing the right location for olive farming is crucial. For regions aiming to withstand cold climates, south-facing slopes are more suitable as they protect against cold. The suitability of the site for establishing facilities should be investigated based on climate conditions and soil structure. Areas with temperatures above -7 degrees Celsius throughout the year and moderate groundwater levels are preferred. Necessary soil analyses should be conducted, and based on these results, appropriate fertilizers should be selected to enhance soil quality [15].

Olive tree maintenance requires specific processes and careful practices. Firstly, olive trees thrive best in well-drained and lightly clayey soils. Before planting, the soil is thoroughly cultivated and enriched with organic fertilizers. Seedlings are usually planted at intervals of 5-7 meters. Although olive trees are resilient to drought, irrigation should be regular, especially during their youth and flowering periods. Pruning is important for shaping the trees and ensuring air circulation, typically done at the end of winter or early spring. Fertilization with nitrogen, phosphorus, and potassium-containing fertilizers is regularly carried out during the growth season, in spring and summer. Regular control measures against pests such as the olive fruit fly, olive moth, and various fungal diseases are essential, using both chemical and biological methods [16].

The yield of olive trees varies depending on the tree's age, care, and climatic conditions. A well-cared-for olive tree can yield between 20-40 kilograms of olives annually during maturity (approximately 10-15 years). This amount can increase up to 90 kilograms in subsequent years. Olive trees thrive in regions with a Mediterranean climate, with the Aegean, Mediterranean, and Marmara regions of Türkiye being prominent in olive production. The Aegean Region is the largest olive production center in Türkiye [17].

The financing of olive production is facilitated through various FMs. Banks and agricultural credit cooperatives offer farmer loans to olive producers. These loans provide support to producers with low-interest rates and long-term repayment options. Additionally, olive grove owners can enter into agreements with processors to process their olives. Processors typically handle grove maintenance and harvesting, taking a third of the resulting product. In Türkiye, the Ministry of Agriculture and Forestry provides various grant and support programs to olive producers [18]. These supports include financial assistance for organic farming, seedling support, and irrigation projects. Olive producers can also benefit from bulk purchasing, marketing, and financing advantages by joining cooperatives. These cooperatives alleviate financial burdens for producers and help sell their products at better prices.

The process of leasing land to processors in olive cultivation is strengthened through various financial support and cooperation models. Farmers can undertake costly investments such as land preparation, irrigation systems, and seedling procurement for olive cultivation with resources like agricultural loans, grant programs, and government support. Furthermore, through partnerships with the private sector, farmers can efficiently manage their operations by accessing specialized consultancy and investment services. By coming together through cooperatives and associations, farmers gain advantages in joint marketing and trading, thereby enhancing their financial capabilities. Private investors and venture capital also support farmers who see potential in olive cultivation, promoting innovation and sustainability in the sector. These financed initiatives enable olive growers to establish more efficient, profitable, and sustainable agricultural enterprises.

Olive is an agricultural product that plays an important role in the agricultural sector of Mediterranean countries and also has high economic value. Besides being valued as table olives, it can be processed into oil, making it a valuable food item that has gained prominence in recent years due to its health benefits. Approximately 90% of olives produced worldwide are used for oil, while the remaining 10% are used as table olives. About 90% of olive cultivation worldwide takes place in the Mediterranean Basin, with the remainder occurring in Latin American countries [19]. Globally, olive production covers approximately 10.6 million hectares, yielding 16.6 million tons of olives [20]. Due to increasing demand for olive products worldwide, olive cultivation has expanded not only in countries bordering the Mediterranean but also in other countries with Mediterranean climates such as Argentina, Chile, and Peru, where it has become economically viable. Although global production of table olives has shown an increasing trend in the last five years since 2016, fluctuations in production have occurred due to diseases or natural conditions. The top five countries in table olive production include Italy, Spain, Greece, Türkiye, and Morocco [20-21].

The comparison of olive production quantities cultivated area sizes, and production efficiency for the countries producing 95% of olive production in 2021 are presented in Figure 2 [22].

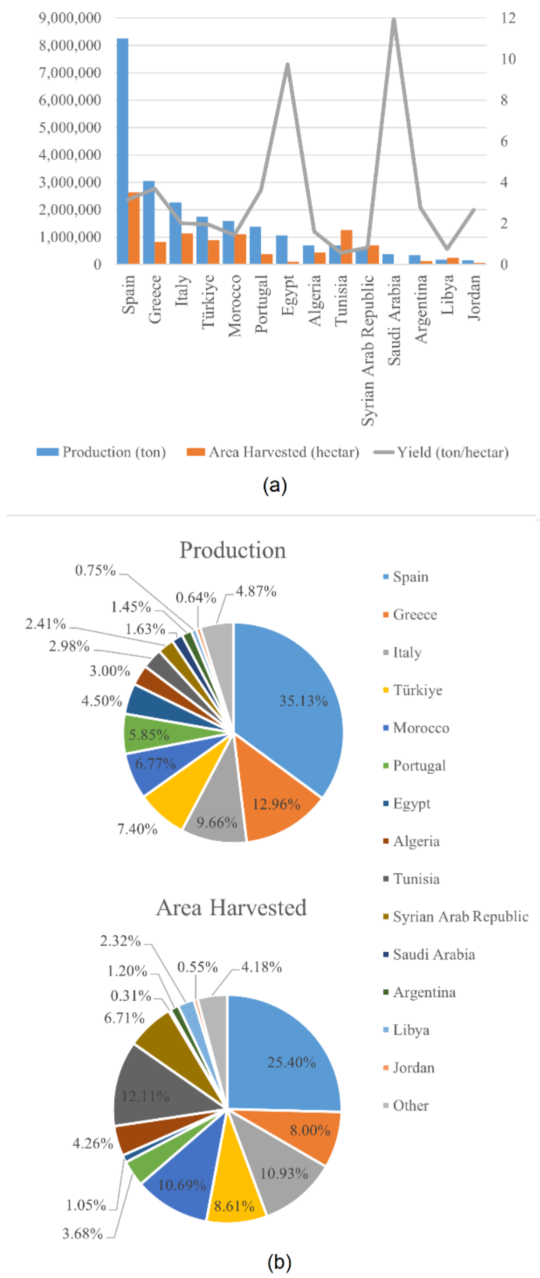

Figure 2. Comparison of countries in terms of olive production

The change in olive production and olive growing areas between 1994 and 2022 is given in Figure 3 [22].

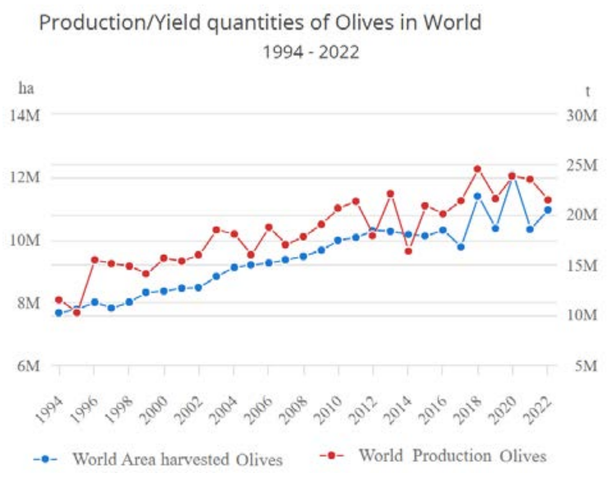

Figure 3. Change in total olive production by years

Olive production is one of the most important activities in Türkiye's agricultural sector. A significant portion of olives produced in Türkiye is directed towards domestic consumption. Of the table olives produced in Türkiye, 85% are processed as black, 15% as green, and some as partially ripened [19]. Türkiye exports about 89,000 tons annually of table olives primarily to Romania, Bulgaria, Russia, and Germany [15]. Considering all these aspects, olives hold a crucial place in the country's economy as a significant source of income for numerous producers and as an industrial raw material. Investments in this sector are expected to have a positive impact by meeting domestic demand and promoting exports. Establishing olive orchards emerges as a financially viable investment. However, careful attention to climate, land, and other ecological factors during the investment period is essential. Proper technical maintenance, suitable climate and ecological conditions, correct variety selection, proximity to major markets, and domestic/international trade opportunities all contribute to making olive fruit production a profitable sector.

4. Application

In this section, financial analysis for olive cultivation has been conducted using information obtained from farmers and land pricing values from real estate sales platforms. Land prices in a suitable region for olive cultivation in Bursa, which includes vacant land with mature table olive trees, were considered. Calculations were made assuming the acquisition of one of the vacant alternative lands deemed suitable for olives, and a 10-year project was planned. Basic cost and income expectations for olive cultivation on the selected land are determined as shown in Table 1.

4.1. Financing with interest-bearing debt

Ziraat Bank and Agricultural Credit Cooperatives encourage the use of certified seedlings to meet the financing needs in agricultural production. Producers intending to establish olive orchards are offered interest-free discounted investment and operating loans. Within this framework, for loans extended for olive cultivation, an interest rate reduction of 75% is set [15]. However, when certified seedlings approved by the Ministry of Agriculture and Forestry are used, an additional incentive increases the interest rate reduction by 20%, totaling a reduction of 95% [15]. Therefore, the interest rate applied in the investment plan is set at 15%.

However, while the maximum limits of these loans are sufficient to meet the investment and annual needs of current landowners, they may be insufficient for those starting agricultural production by acquiring new land. Therefore, investors may need to obtain loans under market conditions. Considering that obtaining loans under market conditions may involve very high interest rates, a more reasonable and realistic annual interest rate of 15% is chosen in this study to establish a balanced comparison between government loans and market loans. The loan is calculated with a grace period for the first 3 years. Since using only this rate for analysis would be insufficient, comparative analysis was conducted using different interest rates, as presented in the comparison section. Cash flow calculations using a 15% interest rate to illustrate the general structure are provided in Table 2.

4.2. Financing with diminishing musharakah

DMFM can occur between two or more individuals, as well as between an Islamic bank and a customer. This partnership involves one party's share increasing while the other's decreases. By the end of the partnership, all shares of the agreed-upon asset are transferred to one of the parties. Throughout the DMC period, profit sharing is based on the ratios determined while considering the share percentages and the nature of the effort contributed.

In this study, calculations have been made from the perspective of two investors who come together without the intermediation of Islamic banks and who assume that both contribute equally in terms of effort. The results are presented in Table 3.

Table 1. Income and expense expectations for table olive cultivation

Market Data	Value	Investment Item	Value
Vacant Land Price per Hectare (TL)	700,000	Capital	3,400,000
Mature Olive Grove Price per Hectare (TL)	1,100,000	Area to be Acquired (Hectares)	4.86
		Number of Trees to be Planted	121
Number of Trees per Hectare	25	3rd Year Yield (kg)	1,214
Yield per Tree at 3 Years (kg)	10	10th Year Yield (kg)	10,321
Yield per Tree at 10 Years (kg)	85	3rd Year Revenue (TL)	123,452
Cost per Sapling (TL)	50	3rd Year Cost (TL)	33,332
Annual Maintenance Cost Rate	0.27	10th Year Revenue (TL)	1,049,345
Price per kg for Olive Grade 1 (TL)	125	10th Year Cost (TL)	283,323
Price per kg for Olive Grade 2 (TL)	100	Initial Year Sapling Cost (TL)	6,071
Price per kg for Olive Grade 3 (TL)	80	1st Year Maintenance Cost (TL)	4,000
Average Price per kg of Olive	102	2nd Year Maintenance Cost (TL)	10,000
		10th Year Land Value (TL)	5,342,857

4.3. Comparison of results

In the study, the initial cost of establishing the orchard is 3,406,071 TL. However, in IBDFM, the total repayment of the loan includes interest, resulting in a total cost of 5,714,255 TL under the current FM. In the DMFM, since there is no interest involved, the initial cost remains 3,406,071 TL. Despite the fixed returns due to reduced costs, profitability percentage has increased. Interest rates in IBDFMs can vary over time. This variability affects repayment costs and can lead to liquidity issues. The absence of interest rates in DMFM eliminates these risks associated with IBDFM. The study includes sensitivity analysis for different interest rates, and the comparison of FMs is presented in Figure 4.

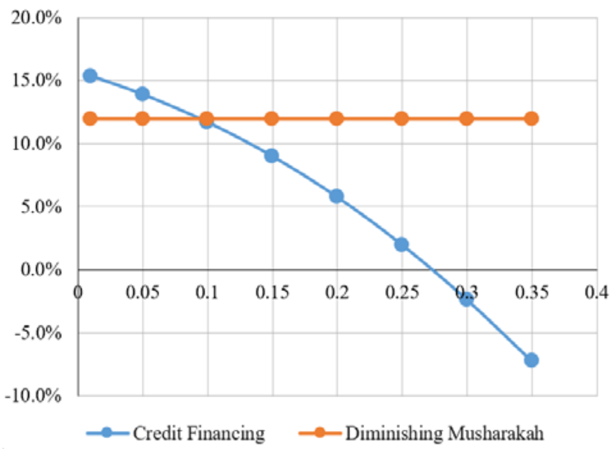

Figure 4. Comparison of financing models for different interest rates

It is observed that the Internal Rate of Return (IRR) increases for IBDFM at lower interest rates than the current rate. However, the same does not apply to DMFM. For DMFM, the internal rate of return values remain constant across different interest rates.

5. Discussion

The demand for olives in Türkiye is expected to follow a positive trend in the coming years. Several key factors contribute to this optimistic outlook. Firstly, increasing awareness of healthy eating and consumer demand for organic products are driving the rising demand for olives thanks to the positive health effects of the many minerals, vitamins, and antioxidant oils they contain. Türkiye's potential to be a global player in olive production offers export opportunities beyond meeting domestic demand. However, factors such as climate conditions and technical details in agricultural practices, and others need to be considered. Regular market analysis and sectoral assessments will be crucial for making future demand predictions more definitive.

The future projection of olive orchard establishments can vary based on several factors. Overall trends and developments impacting the olive sector include increasing health consciousness, demand for organic and natural products, innovative products and flavors, international market growth, sustainable agriculture and production, climate change and harvest cycles, technological advancements, digital marketing, and global collaborations. A combination of these factors can influence the future growth and evolution of the olive sector. Olive producers and businesses can succeed by monitoring market developments, adapting to changing demands, and embracing sustainable production practices.

Table 2. Cash flow for financing scenario with interest-bearing debt

Year	Capital Investment	Land Sale Revenue	Agriculture			Financing Cost	Net Amount
			Income	Expanses	Profit		
0	-1,700,000			6,071	-6,071	0	-1,706,071
1				4,000	-4,000	0	-4,000
2				10,000	-10,000	0	-10,000
3			123,452	33,332	90,120	-501,023	-410,902
4			255,723	69,045	186,678	-501,023	-314,345
5			387,993	104,758	283,235	-501,023	-217,788
6			520,264	140,471	379,792	-501,023	-121,230
7			652,534	176,184	476,350	-501,023	-24,673
8			784,804	211,897	572,907	-501,023	71,885
9			917,075	247,610	669,465	-501,023	168,442
10		5,342,857	1,049,345	283,323	766,022	-501,023	5,607,856
						Internal Rate of Return	8.985%

Table 3. Cash Flow for financing scenario with diminishing musharakah

Year	Capital Investment	Land Sale Revenue	Land Share Transfer	Agriculture			Rate to be Paid from Profit	Net Amount
				Income	Expanses	Profit		
0	-1,700,000				6,071	-6,071	0.50	-1,703,036
1			-179,714		4,000	-4,000	0.50	-181,714
2			-189,429		10,000	-10,000	0.45	-194,928
3			-199,143	123,452	33,332	90,120	0.40	-145,071
4			-208,857	255,723	69,045	186,678	0.35	-87,517
5			-218,571	387,993	104,758	283,235	0.30	-20,307
6			-228,286	520,264	140,471	379,792	0.25	56,559
7			-238,000	652,534	176,184	476,350	0.20	143,080
8			-247,714	784,804	211,897	572,907	0.15	239,257
9			-257,429	917,075	247,610	669,465	0.10	345,090
10		5,342,857	-267,143	1,049,345	283,323	766,022	0.05	5,803,435
							Internal Rate of Return	11.96%

In comparing DMFM and IBDFM, DMFM is more cost-effective due to the absence of interest costs, making the project more attractive. From the perspective of banks, it has been concluded that IBDFM is not an attractive investment concerning repayment. In an analysis based on a Minimum Attractive Rate of Return (MARR) of 5%, IBDFM appears attractive, but DMFM is deemed more appealing. DMFM has yielded better results in terms of feasibility compared to IBDFM, primarily because the absence of interest costs has facilitated a more comprehensive income-expense analysis.

Olive cultivation is a significant economic activity, especially in countries with a Mediterranean climate, and businesses in this sector may face various commercial risks. Among these risks, yield and market fluctuations are prominent. Yield risk arises from various natural factors affecting olive trees, such as unexpected weather events, pests, or diseases which significantly impacting both the quantity and quality of olive production. This creates considerable income uncertainty for olive and olive oil producers. On the other hand, market fluctuations also play a crucial role among commercial risks. Global and local economic conditions, changes in consumer preferences, and regulations in export-import policies can influence the prices of olive products. These two primary risk factors directly impact the financial performance of olive cultivation businesses. Therefore, effective implementation of risk management strategies is critical for the sustainability of these enterprises.

DMFM offers significant advantages in financing olive production and plays an effective role in managing various risks. This FM eliminates additional costs that may arise from interest payments, thus reducing financial obligations for olive producers. Fixed repayment plans help olive producers manage cash flows more effectively and facilitate financial planning. Additionally, in DMFM, initial costs and profits are shared among partners, reducing startup costs and mitigating investment risks.

DMFM also presents important advantages in terms of commercial risks such as yield fluctuations and market volatility. This model allows risks to be shared among parties; in adverse situations like low yields or market fluctuations, the producer does not bear the entire risk alone. Partners collectively shoulder such risks. DMCs can offer flexible repayment terms during unfavorable market conditions, preventing financial pressure on producers and enabling them to continue operations. Moreover, partners typically establish long-term relationships in this model, allowing producers to make long-term plans and investment decisions with greater confidence.

Another significant advantage of the DMFM is its ability to manage cash imbalances throughout the year. In IBDFM, monthly installment payments create a regular burden, while olive harvesting occurs only once a year, with production expenses concentrated at specific times of the year. This can lead to cash flow imbalances and financial strain for the producer. In contrast, repayments in the DMFM can be more flexible and tailored to the production cycle based on the DMC. This flexibility helps producers balance cash flow, meet financial obligations focusing on the harvest season, and manage unexpected expenses throughout the year more effectively. Thus, DMFM stabilizes cash flow for olive producers, enhances financial sustainability, and offers a more advantageous option compared to IBDFM.

The DMFM also ensures investment protection. By pooling their capital, partners can invest in larger and more efficient projects, thereby increasing production capacity and efficiency. Partners support olive producers by sharing market knowledge and commercial networks, enabling producers to be better prepared for market fluctuations and achieve better prices for their products. DMFM effectively reduces financial and commercial risks for olive producers. Its features such as interest-free financing, risk sharing, flexible repayment terms, and long-term partnerships help maintain financial stability, enhance resilience against market fluctuations, and support the sustainability and profitability of olive production.

In the comparison between IBDFM and DMFM in olive cultivation, DMFM stands out with its advantages in managing cash flow imbalances. While IBDFM typically involves monthly installment payments, the DMFM allows farmers to benefit from income during the harvest season. Since olive crops are usually harvested once a year, the DMFM enables farmers to manage this income more effectively. The monthly installment structure of IBDFM can lead to financial difficulties for farmers before harvest, whereas the DMFM synchronizes income with the harvest period, allowing farmers to more comfortably meet pre-harvest expenses. Furthermore, the DMFM allows other costs in olive cultivation to be distributed more evenly, offering farmers the opportunity to manage cash flow more sustainably. This demonstrates that, in terms of cash flow imbalance, the DMFM is more advantageous compared to IBDFM.

There are other steps that can be taken to enhance the effectiveness of MFM. Establishing organizations to organize partnership-based FMs (like Mudarabah) (e.g., cooperatives, agricultural chambers, Ministry of Agriculture, Ministry of Trade, public participation banks, etc.) can effectively utilize capital resources for agriculture. Partnerships with pharmaceutical and fertilizer companies through MCs can facilitate profit-sharing trade models, providing both parties with high profit potential and easing cash management. If these partnerships are guaranteed by an intermediary institution, mechanisms such as insurance, financial intelligence, and public institution queries can establish trust, enhancing security for both investors and farmers. On a broader scale, these organizations can organize as regional and national exchanges, increasing liquidity potentials.

Today's agricultural sector has significant transformation potential through diversification of FMs and more efficient allocation of resources. In this context, partnership-based FMs, especially FMs like Musharakah and Mudarabah, can offer innovative and effective solutions for financing agricultural production. Establishing organizations to effectively organize these FMs can create opportunities to utilize idle capital for agriculture while meeting the financial needs of the agricultural sector.

Cooperatives, agricultural chambers, Ministry of Agriculture, Ministry of Trade, and various institutions such as public participation banks can support these FMs. These organizations can act as bridges between farmers and investors, facilitating risk sharing and more efficient use of resources. For example, Musharakah Contracts (MCs) between pharmaceutical and fertilizer companies and farmers enable trade based on profit-sharing models, offering high profit potential for both sides. This approach also contributes to financial sustainability by facilitating cash management ease for businesses.

The success of partnership-based FMs is directly related to establishing a trust environment. Therefore, conducting such partnerships under the guarantee of an intermediary institution is important. Establishing trust through FMs such as insurance mechanisms, financial intelligence, and public institution queries can create a secure investment environment for both investors and farmers.

On a larger scale, organizing these entities as regional and national exchanges can increase liquidity potentials. Such a structure ensures that financial transactions in the agricultural sector are more transparent, efficient, and accessible. Additionally, enhancing financial depth and diversity in the agricultural sector can reduce overall risks, paving the way for more stable growth. Implementing partnership-based FMs in the agricultural sector can not only ensure effective use of capital but also contribute significantly to the sustainability of agricultural production. This approach expands the financial capacity of the agricultural sector while creating an ecosystem where farmers and investors mutually benefit.

6. Conclusion

The uprooting of olive trees in Türkiye reflects issues related to financial sustainability. Despite high olive exports, farmers' struggles with financial difficulties and the conversion of olive groves for other purposes are increasing sustainability concerns in the sector. Addressing Türkiye's agricultural potential, particularly through olive cultivation, is strategically important given its geographic advantages. This is because, considering the contributions of olives not only as a food product but also to economic development, the financial sustainability of olive cultivation holds vital importance for the national economy.

This study examines the burden of the current IBDFM on farmers and discusses significant commercial risks arising from yield and market fluctuations. The proposed collaboration-based financing approach offers a more sustainable option for farmers looking to establish new olive orchards. This approach not only presents attractive return potentials for investors but also helps farmers balance their cash flows by reducing financial burdens. Additionally, financing through the DMFM has been seen as a more appealing alternative for farmers sensitive to interest. The findings underscore the need to evaluate alternative FMs to enhance the financial sustainability of olive cultivation. DMFM, particularly in its reduced form, emerges as a more suitable and sustainable financing option for olive cultivation.

Future studies could comparatively analyze the performance of other alternative FMs suitable for olive cultivation. Similar analyses could also be conducted for other agricultural products of strategic importance to Türkiye.

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Araştırma Makalesi / Research Article

Naringine Filtration By Polyacrylonitrile-co-poly(2-ethylhexyl acrylate) Copolymers

Poliakrilonitril-ko-poli(2-etilhegzil akrilat) Kopolimerleri İle Narinjin Filtrasyonu

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ABSTRACT

Polyacrylonitrile-co-poly(2-ethylhexyl acrylate) copolymers with different acrylonitrile/2-ethylhexyl acrylate ratios were synthesized and tested in terms of filtration performance for naringine removal. The flux increased with poly(2-ethylhexyl acrylate) content of the copolymer membrane. Moreover, the filtration performance increased with increasing polyacrylonitrile content of the copolymer membrane. The percent removal of naringin was found as 53.5%, 74.9% and 92.6% for PAN(84)-co-P2EHA(16), PAN(88)-co-P2EHA(12) and PAN(92)-co-P2EHA(8), respectively. Also, copolymer membranes could preserve its 83% of its initial performance after the fifth use.

ÖZET

Farklı akrilonitril/2-etilhegzil akrilat oranlarına sahip poliakrilonitril-ko-poli(2-etilhegzil akrilat) kopolimerleri sentezlenmiş ve narinjin filtrasyonu performansları test edilmiştir. Akış hızı kopolimer zardaki poli(2-etilhegzil akrilat) miktarıyla artmıştır. Filtrasyon performansı ise kopolimer zardaki artan poliakrilonitril miktarıyla artmıştır. Narinjinin yüzde filtrasyon değerleri PAN(84)-ko-P2EHA(16), PAN(88)-ko-P2EHA(12) ve PAN(92)-ko-P2EHA(8) kopolimerleri için sırasıyla %53.5, %74.9 ve %92.6 olarak bulunmuştur. Ayrıca kopolimer zarlar beşinci kullanımdan sonra başlangıç performanslarının %83'ünü korumuşlardır.

1. Introduction

Naringine is a flavonoid having a bitter taste that gives bitternes to various citrus juices such as mandarin and grapefruit (Figure 1) [1]. Also it has applications depending on its antioxidant, anti-ulcer and anti-inflammatory features. [2-5]. For the filtration of this flavonoid, various filtration methods have been used. They can be named as adsorption, solvent extraction, filtration, supercritical carbon dioxide, chemical processes, enzymatic and biological processes [1, 6-10]. In this study, filtration method with a membrane was used for its removal from aqueous solution. Membranes used in this study were obtained by the copolymerization of aniline with 2-ethylhexyl acrylate. Aniline ratio in the copolymer was varied from 84 to 92 mole percent while 2-ethylhexyl acrylate ratio was varied from 16 to 8 mole percent. The copolymer having acrylonitrile/2-ethylhexyl acrylate ratio of 84/16 was denoted as PAN(84)-co-P2EHA(16). Similarly, copolymers having acrylonitrile/2-ethylhexyl acrylate ratios of 88/12 and 92/8 were defined as PAN(88)-co-P2EHA(12) and PAN(92)-co-P2EHA(8), respectively.

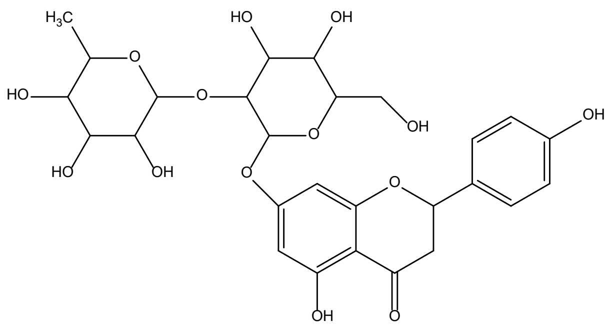

Figure 1. The chemical formula of naringine

2. Experimental

2.1. Materials

Acrylonitrile (Sigma-Aldrich, 99%) and 2-ethylhexylacrylate (Sigma-Aldrich, 98%) monomers were used for copolymerization. They were distilled before usage. Sulfuric acid (Sigma-Aldrich, 95-97%), isopropyl alcohol (Sigma-Aldrich, 99.9%) and ammonium persulfate (Sigma-Aldrich, 98+%) were directly used. 1-dodecanethiol (Sigma-Aldrich, 98+%) was used for chain transfer. DMF (Sigma-Aldrich, 99+%), NMP (Sigma-Aldrich, 99+%), magnesium sulfate (Sigma-Aldrich, 99+%) and DOWFAX 8390 (Dow Chemical Company) surfactant were used directly.

2.2. Copolymer Synthesis

Copolymers were synthesized via emulsion polymerization method. Polymerization was performed as follows:

20% of total 2-ethylhexylacrylate/acrylonitrile mixture, chain transfer agent, ammonium persulfate (65%), water and DOWFAX 8390 were mixed in a flask with three nakes. The flask contained thermocouple, dropping funnel, stirrer and condenser. Before and during the polymerization process, nitrogen gas was fed to the solution. The temperature was set at 66°C. The rest of 2-ethylhexylacrylate/acrylonitrile mixture was provided in 2 hours. When the monomer addition was finished, the remaining of DOWFAX 8390 was provided via dropping funnel. The solution was kept at 66°C for extra 40 min. Then the produced copolymer was obtained by precipitation in a 10% (w/w) aqueous solution of $MgSO_4$. Then, it was washed with distilled water and kept at 60°C in a vacuum oven for a day.

Aniline ratio in the copolymer was varied from 84 to 92 mole percent while 2-ethylhexyl acrylate ratio was varied from 16 to 8 mole percent. The amount of compounds in the copolymerization process is listed in Table 1.

Table 1. The amount of compounds for copolymerization process

Polymer	**Aniline** *(g)*	**2-ethylhexyl acrylate** *(g)*	**Surfactant** *(g)*	**Initiator** *(g)*	**Chain transfer agent** *(g)*	**Water** *(ml)*
PAN(84)-co-P2EHA(16)	3.39	2.25	0.45	0.006	0.11	7.1
PAN(88)-co-P2EHA(12)	3.42	1.61	0.40	0.005	0.09	7.1
PAN(92)-co-P2EHA(8)	3.38	1.02	0.35	0.004	0.08	7.1

2.3. Membrane Preparation

Synthesized copolymers (1.4 g) were added to DMF (9.0 g) and stirred for a day. After they were completely dissolved and obtaining homogeneous solution, the solution was poured on glass plate. Then, it was immersed in an IPA for 1 h and put in water for a day.

2.4. Characterization

FTIR of copoylmers was obtained by Spectrum100 FTIR spectrometer (Perkin Elmer). Flux and filtration measurements were conducted via a dead end filtration instrument under 2 bar pressure. The initial concentration of naringin solution was 7.5 ppm. The removal percent of naringine was obtained by UV-Vis spectrophotometer (Perkin Elmer Lambda 35). The area of membranes was 8.0 cm^2. Flux was calculated by Eq. 1;

$$J = \frac{V}{At} \qquad (1)$$

where V, A and t are volume (L) of the solution passed through the membrane, membrane area (m^2) and filtration time (h), respectively.

The removal of naringine (R) was calculated by Eq. 2;

$$R = \left(1 - \frac{C_f}{C_i}\right)x100 \qquad (2)$$

where C_f and C_i are the final and initial concentrations of naringine solutions before and after the filtration process, respectively.

3. Results and Discussions

The copolymers' chemical structure is seen in Figure 2.

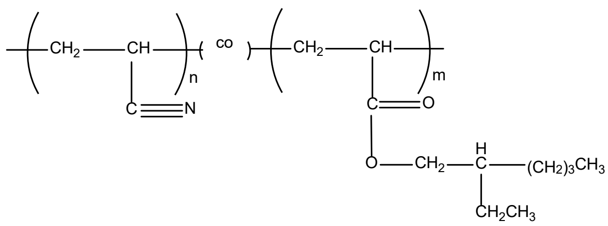

Figure 2. The chemical formula of polyacrylonitrile-co-poly(2-ethylhexylacrylate)

The FTIR analysis of copolymers were in Figure 3. CN and CH (aliphatic) stretchings were observed at 2241 and 2932 cm^{-1}, respectively. The CH bending was seen at 1453 cm^{-1}. Moreover, 2-ethyl acrylate ester group's C=O and C-C-O/O-C-C signals were found at 1726 and between 1064-1268 cm^{-1}, respectively.

As shown in Table 2, both water and filtrate fluxes were increased with increasing 2-ethylhexyl acrylate amount in the copolymer membranes. Water fluxes were found as 38.7, 94.4 and 116.8 L m^{-2} h^{-1} for PAN(92)-co-P2EHA(8), PAN(88)-co-P2EHA(12) and PAN(84)-co-P2EHA(16), respectively. Also, filtrate fluxes were calculated as 29.9 for PAN(92)-co-P2EHA(8), 61.8 for PAN(88)-co-P2EHA(12) and 78.3 L m^{-2} h^{-1} PAN(84)-co-P2EHA(16). This behaviour may arise from the increase in the amount of branching group 2-ethlyhexyl acrylate. As the branching group amount increases, pore diamaters of membranes may increase also. Thus, water and filtrate can pass through membrane more easily.

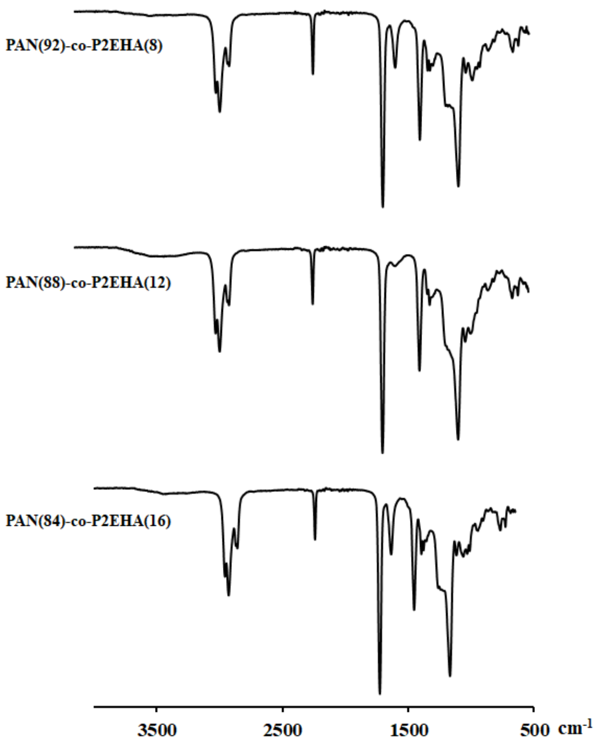

Figure 3. The FTIR spectra of PAN(92)-co-P2EHA(8), PAN(88)-co-P2EHA(12) and PAN(84)-co-P2EHA(16)

Table 2. Flux of membranes and permeates.

Membrane	Thickness (μm)	Pure water flux (L/m²h)	Filtrate Flux (L/m²h)
PAN(84)-co-P2EHA(16)	549	116.8	78.3
PAN(88)-co-P2EHA(12)	553	94.4	61.8
PAN(92)-co-P2EHA(8)	550	38.7	29.9

On the other hand, as the 2-ethylhexyl acrylate amount and the flux of filtrate decreased, the filtration performance increased. The decrease in flux shows that membranes get denser. Thus, the filtrate passed through membranes slower since its passing got more difficult. This led to that more naringin was prevented from passing through membrane without filtration. Hence naringine could be filtered more effectively with denser membrane and this increased the filtration performance. Removal percents of naringine was found as 92.6%, 74.9% and 53.5%, for PAN(92)-co-P2EHA(8), PAN(88)-co-P2EHA(12) and PAN(84)-co-P2EHA(16), respectively (Figure 4).

When reusage of membranes was tested, it was found that filtration performance of PAN(92)-co-P2EHA(8) membrane decreased from 92.6% to 76.6% (Figure 5). In other words, the membrane conserved 83% of its initial performance after the fifth use. Thus, it can be deduced that the membrane had reasonable durability upon reusage.

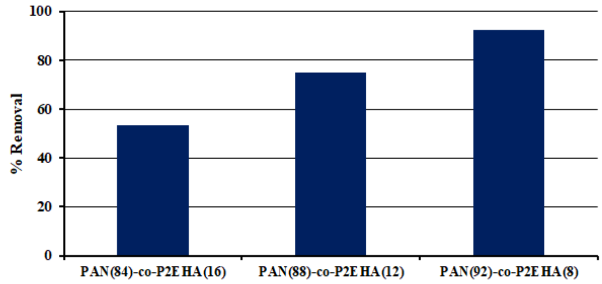

Figure 4. Filtration performances of PAN(92)-co-P2EHA(8), PAN(88)-co-P2EHA(12) and PAN(84)-co-P2EHA(16)

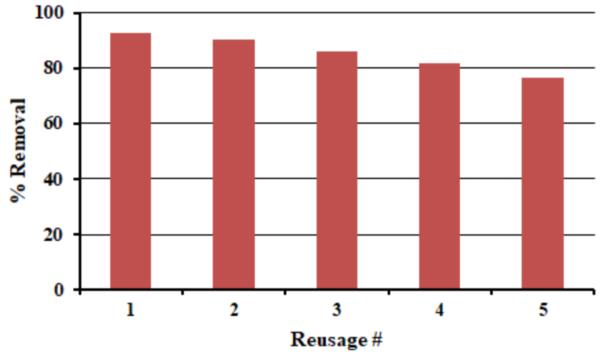

Figure 5. Reusage performance of PAN(92)-co-P2EHA(8) membrane

4. Conclusion

Naringine containing solution (7.5 ppm) was filtered by PAN(92)-co-P2EHA(8), PAN(88)-co-P2EHA(12) and PAN(84)-co-P2EHA(16) membranes. Fluxes increased with increasing poly(2-ethylhexyl acrylate) amount in the copolymer structure. On the other hand, filtration performance of membranes increased in the order of PAN(84)-co-P2EHA(16), PAN(88)-co-P2EHA(12) and PAN(92)-co-P2EHA(8). The highest naringin removal is obtained as 92.6% with PAN(92)-co-P2EHA(8). Also, this membrane preserved 83% of its initial performance after the fifth use. As a result, PAN(92)-co-P2EHA(8) copolymer membranes can be considered as a candidate for naringine filtration.

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Farklı amper değerlerinde MIG ve TIG kaynağı ile birleştirilen AL5083 plakaların mekanik özelliklerinin incelenmesi

Investigation of mechanical properties of AL5083 plates joined by MIG and TIG welding at different amperage values

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ÖZET

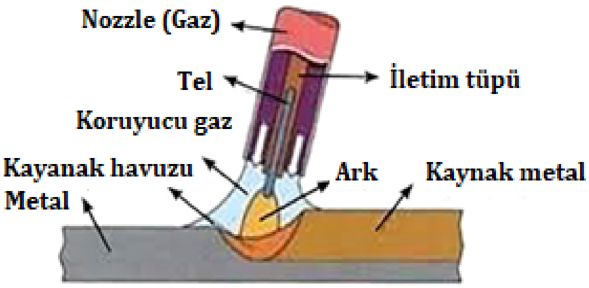
Sanayi endüstrisinde en çok kullanılan metallerden biri de alüminyumdur. Alüminyum metalinin üretiminden sonra endüstriyel olarak kullanımı için birbirleriyle birleştirmeleri önem arz etmektedir. Alüminyum metalleri birbirleriyle farklı kaynak yöntemleriyle birleştirilebilmektedir. Bu çalışmada, AL5083 plaka MIG ve TIG kaynak yöntemleri kullanılarak farklı kaynak parametrelerinde birleştirilmiştir. Kaynakla birleştirilen malzemelere çekme deneyi, eğme deneyi uygulanmıştır. Çalışma sonucunda, 5083 serisi alüminyum alaşımı için çekme deneyi sonuçları incelendiğinde MIG kaynağı için 90 amperde, TIG kaynağı için 100 amper değerinde maksimum çekme dayanımı elde edilmiştir. Çekme testi sonrası alın birleştirmelerinde kopma, ısı tesiri altında kalan bölge veya kaynak bölgesinde meydana gelmiştir. Eğme deneyi sonuçlarına göre ise birçok deney parçasının kaynak bölgesinden kırıldığını görmekteyiz. Sonuç olarak bu çalışma ile AL5083 plakanın MIG ve TIG kaynağı ile birleştirilmesinde optimum kaynak parametreleri belirlenmiştir.

ABSTRACT

One of the most commonly used metals in the industrial industry is aluminum. After the production of aluminum metal, it is important to combine them with each other for industrial use. Aluminum metals can be combined with each other with different welding methods. In this study, AL5083 plate was combined with different welding parameters using MIG and TIG welding methods. Tensile test and bending test were applied to the materials joined by welding. As a result of the study, when the tensile test results for 5083 series aluminum alloy were examined, the maximum tensile strength was obtained at 90 amperes for MIG welding and 100 amperes for TIG welding. After the tensile test, rupture in butt joints occurred in the region under the influence of heat or in the weld region. According to the bending test results, we see that many test pieces broke from the weld region. As a result, the optimum welding parameters were determined in the joining of AL5083 plate with MIG and TIG welding with this study.

1. Giriş

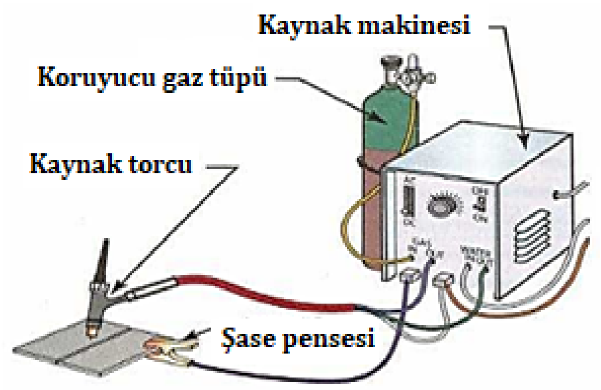
Çeşitli metal malzemelerin birleştirilmesinde kullanılan kaynak yöntemleri olarak elektrik ark kaynağı, MIG-MAG, TIG, plazma arkı, nokta direnç, elektron ışın, sürtünme karıştırma, difüzyon ve toz altı kaynağı sıralanabilir [1]. Ancak bu çalışmada alüminyum plakalar için sanayide çok fazla kullanım alanına sahip olan MIG ve TIG kaynağı kullanılmıştır. Gaz altı kaynağı olarak tanımlanan MIG kaynağı iner gaz olarak Argon veya Argon-Karbondioksit karışımı kullanır. MIG kaynağı, kaynak işlemi sırasında kaynak teli ile kaynak edilecek malzeme arasında bir ark oluşturur. Kaynak teli, bir makaradan beslenir ve kaynak işlemi sırasında malzeme ile birlikte ilerler. Ark, kaynak teli ve kaynak edilecek malzeme arasında oluşur ve bu ark, kaynak teli ile malzeme arasındaki bağlantıyı sağlar. Gaz altı kaynağı olarak tanımlanan MIG ve MAG kaynağı, benzer bir prensiple çalışır [2]. MIG ve MAG yöntemlerini ayıran özellik koruyucu gazın değişmesidir. MIG kaynağında asal gazlar kullanılırken, MAG kaynağında karbondioksit gazı kullanılmaktadır [3]. MIG-MAG kaynak, diğer kaynak yöntemlerine kıyasla daha kolay kullanılır. Bu, kaynak işlemi için gerekli eğitim süresini azaltır ve kaynak işleminin daha hızlı gerçekleştirilmesini sağlar [4]. Şekil 1'de MIG kaynağının şeması ayrıntılı olarak gösterilmiştir.



Şekil 1. MIG kaynak Şeması [5]

TIG kaynak, bir tungsten elektrot ile kaynak edilecek malzeme arasına yerleştirilmiş ince bir metal tel yardımıyla gerçekleştirilen bir kaynak yöntemidir. Bu yöntem, ince ve hassas kaynak işlemleri için idealdir ve yüksek kaliteli kaynaklar elde etmek için kullanılır. TIG kaynak işlemi, yüksek frekanslı bir elektrik kaynağı kullanarak bir ark oluşturmakla başlar. Ark, tungsten elektrot ile kaynak malzemesi arasındaki boşluğa yönlendirilir ve aynı anda bir gaz akışı (genellikle argon) kullanarak kaynak bölgesini korur. Bu gaz akışı, kaynak işlemi sırasında oluşan erimiş metalin havada okside olmasını önleyerek kaynak kalitesini arttırır [6]. TIG kaynağı, diğer kaynak yöntemleri gibi yüksek seviyelerde duman ve gürültü üretmez. Bu nedenle, TIG kaynağı işlemleri daha temiz ve daha rahat bir çalışma ortamı sağlar [7].

Kaynak parametreleri, yapılan işlemin en iyi kalitede yapılmasında önemli bir etkiye sahiptir. Kullanılan her malzeme için kullanılan parametreler değişiklik gösterir. Kaynak işlemine başlamadan önce, malzeme özelliklerine en uygun kaynak yöntemi, kullanılacak ilave tel, akım değeri, ark boyu vb. parametreler önem arz etmektedir. Şekil 2'de TIG kaynağının şeması ayrıntılı olarak gösterilmiştir.



Şekil 2. TIG kaynak Şeması [8]

Kaynak işlemlerinde birleştirilecek malzemenin mikroyapı özellikleri, ısı iletkenliği, boyutları gibi birçok unsur kaynak kalitesini etkilemektedir. Bütün bu unsurlardan dolayı doğru kaynak parametrelerini belirlemek zordur. Bu nedenle kaynak parametreleri uygun seçilmelidir. Bu çalışmada, Al5083 malzemesinin MIG ve TIG kaynaklarında optimum amper değerlerinin belirlenmesi amaçlanmıştır.

2. Materyal ve Metot

Bu çalışmada Al5083 plakaları MIG ve TIG kaynakları ile birleştirilmiştir. Birleştirmeler farklı kaynak parametreleri ile gerçekleştirilmiş ve birleştirme sonrasında malzemelerin mekanik özelliklerine bakılmıştır. Test sonuçlarından elde edilen mekanik özelliklere göre optimum kaynak parametreleri belirlenmiştir. Deneylerde MIG kaynağı için Fronius TP330 marka MIG-MAG kaynak makinesi kullanılmıştır. TIG kaynağı için de ESAB tarafından üretilen hem AC hem de DC akımlarda kaynak kabiliyeti olan DTG 253 TIG kaynak makinesi kullanılmıştır.

2.1. Al 5083 Plaka

Deneylerde 3x150x300 mm ölçülerinde Al5083 plakalar kullanılmıştır. Deney numuneleri alın (Küt Alın) kaynak ağzı biçiminde kaynak edilecek şekilde hazırlanmışlardır. Kaynak öncesinde, birleştirilecek malzemelerin yüzeyinde bulunan ve kaynakta birleşme zorluğuna yol açan oksit tabakası ve kirlilikler temizlenmiştir. Yüzeyler önce tel fırça ile mekanik temizleme yapılmış, daha sonra yağ alma, oksit alma gibi kimyasal temizleme yapılmıştır. Tablo 1'de deneylerde kullanılan Al5083 malzemesinin kimyasal içeriği, Şekil 3'te deneylerde kullanılan numunelerin boyutları ve kaynak yapılış şekli verilmiştir.

Şekil 3. Deney numunelerinin ölçüsü ve kaynak yapılmış şekli

Tablo 1. Al5083 alaşımının kimyasal içeriği

Element	Si	Fe	Cu	Mn	Mg	Cr	Ti	Diğer	Al
%	0,40	0,40	0,10	0,40-1,0	4,0-4,9	0,05-0,25	0,15	0,15	Kalan

2.2 MIG ve TIG kaynağında kullanılan elektrotlar

Al5083 alaşımının MIG kaynağında 1,00 mm çapında AlMg5 teli kullanılmıştır. Kullanılan ilave tel %3'ten fazla Mg içeren alüminyum alaşımlarının kaynağında kullanılmaktadır. Bileşiminde %0,15 Si, %4,50 Mg elementi içerirler. Korozyona karşı dayanıklıdırlar. Geniş ağızlı kaynak uygulamalarında iş parçasına kaynaktan önce 150 °C ön tav uygulanması ve kaynak yapılacak bölgenin iyice temizlenmesi gerekir. MIG kaynağından önce kaynak yapılacak bölge mekanik ve kimyasal olarak temizlenmiş ve 150 °C ön tav uygulaması yapılmıştır. Al 5083 alaşımının TIG kaynağında da aynı özelliklere sahip 2 mm çapında AlMg5 ilave teli kullanılmıştır. Ergimeyen TIG kaynak elektrotu için 175 mm boyunda, 1,6 mm çapında tungsten elektrot kullanılmıştır. MIG ve TIG kaynak yöntemi kullanılarak parçaların kaynak edilmesinde argon gazı kullanılmıştır. Gaz çıkış debisi 10 lt/dk olarak ayarlanmıştır.

2.3. MIG ve TIG kaynağında kullanılan kaynak parametreleri

MIG kaynağı ile birleştirme işleminde farklı akım değerleri kullanılmıştır. Alüminyum alaşımı için üç farklı akım değeri kullanılmış olup, her bir parçanın kaynak parametreleri Tablo 2'de verilmiştir.

Tablo 2. Al5083 alaşımının MIG kaynak parametreleri

	Amper	Volt	Elektrot Çapı (mm)	Süre (sn)	Akım Türü
MIG70A	80	14	1,00	53	AC
MIG80A	90	16	1,00	45	AC
MIG90A	100	19,4	1,00	43	AC

TIG kaynağı ile birleştirme işleminde farklı akım değerleri kullanılmıştır. Alüminyum alaşımı için üç farklı akım değeri kullanılmış olup, her bir parçanın kaynak parametreleri Tablo 3'te verilmiştir.

Tablo 3. Al5083 alaşımının TIG kaynak parametreleri

	Amper	Elektrot Çapı (mm)	Süre (sn)	Akım Türü
TIG80A	80	2,00	224	AC
TIG90A	90	2,00	219	AC
TIG100A	100	2,00	208	AC

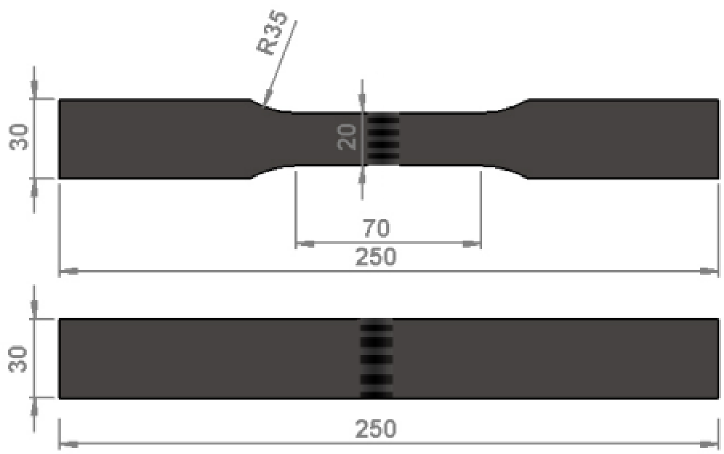
3. Deneysel Sonuçlar ve Tartışma

3.1. Mekanik Deneyler

MIG ve TIG kaynak yöntemiyle alın alına getirilerek kaynak işlemi gerçekleştiren alüminyum alaşımı levhalara çekme ve eğme deneyleri uygulanmıştır. Böylece optimum kaynak parametreleri belirlenmiştir.

3.1.1. Çekme deneyi

Çekme deneyi numuneleri, TIG kaynağı ile alın alına birleştirilmiş AlMgSi (1070) levhaların kaynak bölgelerinden alınarak TS 5789 standartlarına göre Lazer kesim ünitesinde Şekil 3'te gösterildiği boyutlarda hazırlanmıştır. Çekme işlemi Sakarya Üniversitesi Teknik Eğitim Fakültesi Makine Eğitimi bölümünün Teknik Laboratuvarı'nda DARTEC servo – hidrolik çekme – basma tipi makine kullanılarak yapılmıştır. MIG ve TIG kaynak yöntemiyle birleştirilen her bir levhadan 3 adet çekme numunesi çıkarılmıştır. Alınan 3 adet çekme numunesi test edilmiş ve ortalama değerleri belirlenmiştir.

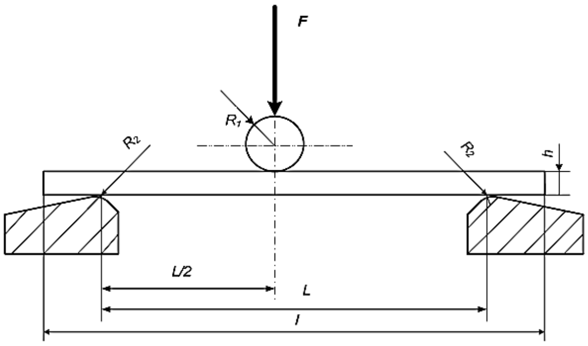


Şekil 4. TS EN 5789 standartlarına göre çekme numunesi ölçüleri [9]

Çekme numunelerinin parametrik değerlerine bağlı kalınarak çekme ve akma mukavemetleri belirlenmiştir. Çekme deneyi, alın alına birleştirilen malzemelerin mekanik özelliklerini belirleyebilmek amacıyla yapılmıştır. Kaynak akımının birleşme özelliklerini nasıl etkilediği tespit edilmeye çalışılmıştır.

3.1.2. Eğme deneyi

Eğme deneyinde her bir parametreden hazırlanan levhalardan ISO 178 standartlarına göre 50X50 mm boyutlarında numuneler kesilmiştir. Çapakları alınan numuneler Sakarya Üniversitesi Yapı Eğitimi laboratuvarında eğme deneyi cihazına yerleştirilmiştir. Eğme deneyi ve çekme deneyi aynı cihazda yapılmaktadır. Şekil 5'te eğme deneyi numunesi gösterilmiştir.



Şekil 5. Eğme deneyi numunesi [10]

4. Deneysel Sonuçlar

4.1. Çekme Deneyi Sonuçları

Çekme deneyi, TIG ve MIG kaynak yöntemiyle birleştirilen alüminyum alaşımlı malzemenin mekanik özelliklerini belirleyebilmek amacıyla yapılmıştır. Alüminyum alaşımının MIG kaynağı ile farklı amper değerlerinde birleştirilmesinden elde edilen çekme deneyi sonuçları Tablo 4'te gösterilmiştir.

Tablo 4. MIG kaynağı sonrası alüminyum alaşımı için çekme deneyi sonuçları

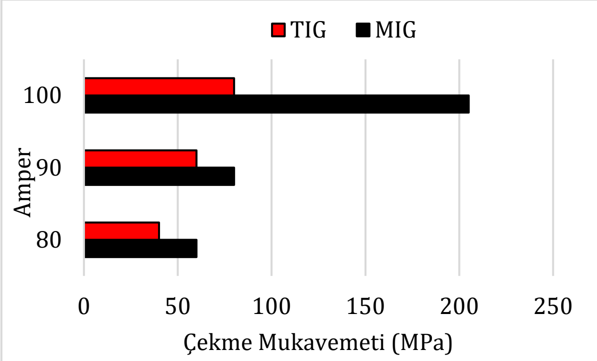
Deney Numunesi	Akma Mukavemeti (MPa)	Çekme Mukavemeti (MPa)	Uzama Yüzdesi (%)
MIG80A	40	60	4
MIG90A	50	80	6
MIG100A	100	205	24

Al5083 alaşımının 80 amper değerinde MIG kaynağı ile birleştirilmesinden oluşan çekme mukavemeti en fazla 60 MPa değerlerine ulaşmıştır. Aynı kaynak yöntemiyle 90 amperde birleştirilen numunede de çekme mukavemeti 80 MPa değerlerine ulaşmıştır. Ancak akım değeri 100 amper seviyelerine gelindiğinde ortalama 3 katından daha fazla çekme dayanım ve uzama değerleri elde edilmiştir.

Alüminyum alaşımının TIG kaynağı ile farklı amper değerlerinde birleştirilmesinden elde edilen çekme deneyi sonuçları Tablo 5'te gösterilmiştir.

Tablo 5. TIG kaynağı sonrası alüminyum alaşımı için çekme deneyi sonuçları

Deney Numunesi	Akma Mukavemeti (MPa)	Çekme Mukavemeti (MPa)	Uzama Yüzdesi (%)
TIG80A	20	40	3
TIG90A	30	60	4
TIG100A	60	80	6



Şekil 6. MIG ve TIG kaynaklarının çekme mukavemeti

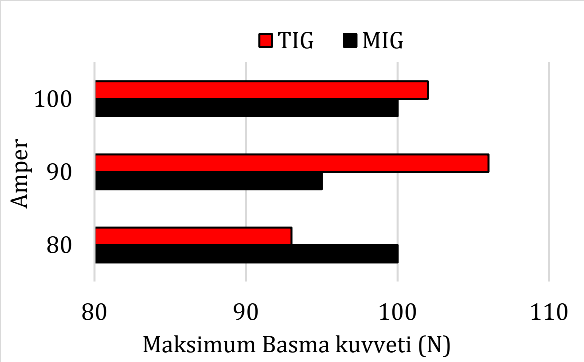
MIG ve TIG kaynakları sonucunda amper değerleri arttıkça çekme mukavemetleri de artmıştır. Her iki kaynak yönteminde de en yüksek çekme mukavemeti 100 amper değerinde elde edilmiştir. 5083 serisi Alüminyum alaşımının 80 amper değerinde TIG kaynağı ile birleştirilmesinden oluşan çekme mukavemeti en fazla 40 MPa değerlerine ulaşmıştır. Aynı kaynak yöntemiyle 100 amperde birleştirilen numunede 80 MPa değerlerine ulaşılmıştır. 90 amper değerlerinde ise maksimum olarak 60 MPa'a ulaşmıştır. En yüksek çekme mukavemeti 100 amperde elde edilmiştir. TIG kaynağındaki bu değişim ise alüminyumun 100 amper değerinde kaynatılmasında yüksek ısı girdisi ve buna bağlı olarak mikro yapıdaki değişimler sebep olabilir. Sachin ve arkadaşları (2014), Al5083 malzemenin TIG kaynağında daha yüksek kaynak akımında kaynaklanan numunelerin nihai çekme dayanımı daha yüksek ve tane inceliğinin daha iyi olduğunu belirtmişlerdir [11]. Fauzi ve arkadaşları (2017), Al4043 malzemesini MIG ve TIG yöntemleri ile kaynatmışlar ve TIG kaynağında daha iyi mikro yapısal ve mekanik özellikler sergilediğini belirlemişler [12]. Ancak bu çalışmada, MIG kaynağı ile yapılan Al5083 malzemesinin çekme mukavemeti TIG kaynağına kıyasla daha iyi çıkmıştır.

4.2. Eğme Deneyi Test Sonuçları

MIG ve TIG kaynak yöntemiyle üç değişik kaynak akımında birleştirilen alüminyum alaşımı malzemenin eğme deneyi yapılmıştır. Alüminyum alaşımının MIG ve TIG kaynak yöntemiyle değişik amperlerde birleştirilmesinden elde edilen eğme deneyi sonuçları Tablo 6'da verilmiştir. Basma kuvveti ve maksimum gerilme değerlerine bakıldığında MIG kaynak yöntemi için en yüksek dayanım 90 amperde kaynatılan malzemeden elde edilmiştir. Bu durum, TIG kaynağında da 90 amperde sağlanmıştır.

Tablo 6. Al5083 alaşımının MIG ve TIG kaynak yöntemiyle değişik amperlerde birleştirilmesinden elde edilen eğme deneyi sonuçları

Deneyler	Eğme Deneyi	
	Maksimum Basma kuvveti (N)	% Uzama
MIG80A	100	4,01
MIG90A	95	4,24
MIG100A	100	4,9
TIG80A	93	4,45
TIG90A	106	4,63
TIG100A	102	4,36



Şekil 7. MIG ve TIG kaynaklarının basma mukavemeti

90 ve 100 amper değerlerinde yapılan TIG kaynaklarının basma mukavemetleri MIG kaynağına kıyasla daha yüksek çıkmıştır. Ancak 80 amper değerinde MIG ile yapılan kaynakta basma mukavemeti TIG kaynağına göre daha yüksek çıkmıştır.

5. Sonuçlar ve Öneriler

Bu çalışmada, Al5083 alaşımına MIG ve TIG kaynak yöntemleri uygulanmıştır. Kaynaklı bağlantılara çekme ve eğme testleri yapılmıştır. Böylece Al5083 alaşımı için hangi kaynak akımının ve kaynak yönteminin daha uygun olduğu belirlenmeye çalışılmıştır.

Yapılan incelemeler sonucunda:

- Çekme testi sonrası alın birleştirmelerinde kopma, ITAB'da (Isı Tesiri Altında Kalan Bölge) veya kaynak bölgesinde meydana gelmiştir. Bu sonuçlar, bazı kaynak dikişlerinin güvenli, bazılarının da güvenli olmadığını göstermektedir.
- Yapılan çekme deneyi sonuçlarına göre Al5083 alaşımının MIG kaynağında 90 amper değerindeki birleştirmenin çekme mukavemetinin daha yüksek olduğu gözlenmiştir.
- Yapılan çekme deneyi sonuçlarına göre Al5083 alaşımının TIG kaynağında 100 amper değerindeki birleştirmenin çekme mukavemetinin daha yüksek olduğu gözlenmiştir.
- Yapılan eğme deneyi sonuçlarına göre birçok deney parçasının kaynak bölgesinden kırıldığı görülmüştür. Akım değerlerinin artırılarak birleştirme yapılması daha sağlıklı olacağı düşünülmektedir.

Yapılan deneysel çalışma ve elde edilen sonuçlar neticesinde aşağıda bazı öneriler sunulmuştur.

- Bazı akım değerlerinin yeterli olmadığı, akımın artırılarak yapılan çalışmaların daha verimli olabileceği düşünülmektedir.
- İleriki çalışmalarda koruyucu gaz türü, ilave tel cinsi gibi parametreler üzerine çalışmalar yapılabilir.
- Farklı metallerin birleştirilmesinde kaynak yöntemlerinin verimlilikleri üzerine çalışmalar yapılabilir.
- Birleştirme işlemlerinin optimum değerleri verebilmesi için otomatik kaynak yöntemi seçilmelidir.

Çıkar Çatışması Beyanı: Yazarlar herhangi bir çıkar çatışması olmadığını beyan etmişlerdir.

Teşekkür: Bu yayın Amasya Üniversitesi Fen Bilimleri Enstitüsü Yüksek Lisans Tezinden alınmıştır. (YÖK Tez No: 813753).

Yazar katkısı: Yazarlar, çalışmanın tasarlanması, verilerin toplanması, sonuçların analizi ve yorumlanması ve makalenin hazırlanması ile ilgili sorumluluklarını onaylamaktadır.

Veri Kullanılabilirlik Beyanı: Bu çalışma sırasında üretilen ve/veya analiz edilen veriler kamuya açık değildir, ancak veriler makul bir talep üzerine ilgili yazar tarafından sağlanabilir.

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Advances in phase change materials and their application in buildings

Faz değiştiren malzemeler ve bina uygulamalarındaki gelişmeler

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ABSTRACT

Due to increasing environmental concerns, efficient energy use has become very important. Therefore, energy storage, saving, and efficiency issues have become increasingly important, especially in engineering studies. Two different methods are used in thermal energy storage systems, which are the subheadings of energy storage technologies: latent heat and sensible heat. Phase change materials (PCMs), which allow thermal energy to be stored and used later, have been increasingly used in construction, automotive, air conditioning, textile, logistics, electronics, health, and many other areas. These materials, divided into organic, inorganic, and eutectic, must have high latent heat storage capacity and appropriate phase change temperature. This study reviews literature, considering types of phase change materials, application methods, and application areas. In this study, where the effects of PCMs on the amount of energy consumed, especially in meeting the heating and cooling demands of buildings, were investigated, it was seen that the use of PCM contributed to both the energy used in heating and cooling processes and the indoor temperature changes. In addition, it was explained in detail which methods and parameters are prominent in the use of PCM in both buildings and other areas.

ÖZET

Günümüzde artan çevresel kaygılardan dolayı enerji kullanımının verimli bir şekilde gerçekleştirilmesi oldukça önem kazanmıştır. Bundan dolayı özellikle mühendislik çalışmalarında enerji depolanması, tasarrufu ve verimi konuları giderek önemli hale gelmiştir. Enerji depolama teknolojilerinin alt başlığı olan ısıl enerji depolama sistemlerinde gizli ısı ve duyulur ısı olmak üzere iki farklı yöntem kullanıldığı bilinmektedir. Isıl enerjinin depolanarak gereksinim anında kullanılmasını sağlayan faz değiştiren malzemelerin (FDM) son yıllarda kullanımı inşaat, otomotiv, iklimlendirme, tekstil, lojistik, elektronik, sağlık ve daha birçok farklı alanda kullanımı giderek artmaktadır. Organik, inorganik ve ötektik olmak üzere temelde üçe ayrılan bu malzemelerin yüksek gizli ısı depolama kapasitesi ve uygun faz değişim sıcaklığına sahip olması önemli unsurlardandır. Bu çalışmada, faz değiştiren malzemelerin çeşitleri, uygulama yöntemleri ve uygulama alanlarının incelendiği bir literatür taraması gerçekleştirilmiştir. FDM'lerin özellikle binaların ısıtma ve soğutma ihtiyaçlarının karşılanmasında tüketilen enerji miktarına olan etkilerinin araştırıldığı bu çalışmada FDM kullanımının hem ısıtma ve soğutma işlemlerinde harcanan enerji kullanımına hem de iç ortam sıcaklık değişimlerine katkı sağladığı görülmüştür. Ayrıca FDM kullanımının hem binalarda hem de diğer alanlarda hangi yöntemler ile ve hangi parametrelerin ön plana çıktığı detaylı bir şekilde açıklanmıştır.

1. Introduction

Considering the increasing environmental concerns today, efficient use of energy is gaining importance [1]. The amount of energy used in heating and cooling buildings to provide thermal comfort conditions has a significant proportion of all energy consumption [2]. Different applications are carried out to use energy efficiently in both existing buildings and newly constructed buildings. In this context, first, if the existing buildings are insufficient, heat loss is tried to be prevented by insulation [3]. While carrying out this insulation process, many parameters such as the geography where the building is located, the climatic characteristics of this geography, and the directions in which the buildings are constructed are considered [4]. At the same time, insulation is also applied to newly constructed buildings, aiming to consume less energy for the same heating or cooling process. In addition, energy efficiency can be achieved by making improvements to the existing heating or cooling systems in buildings. Different applications such as the use of air conditioning systems with higher COP values can be implemented for cooling. For heating, improvements can be made by adding fans to panel radiators, which are also widely used in our country. Thanks to panel radiators with added fans, indoor heating demands can be achieved with lower inlet temperature values. Or, similarly, panel radiators can be evaluated in the low-temperature heating system category by using ventilated-fan radiator systems [5-7].

The two most important methodologies for storing thermal energy directly as heat are the use of PCMs to utilize the large amounts of thermal energy absorbed/released by state changes such as “sensible” heat media or melting/freezing. These idealized enthalpy changes with temperature can be shown in Figure 1 [8].

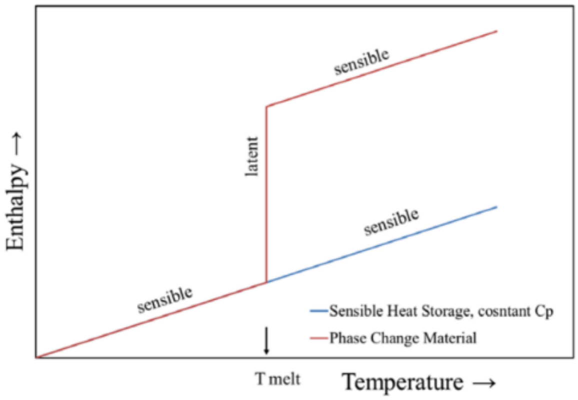


Figure 1. Heat-temperature relationship of latent and sensible heat storage methods [8]

Solid-liquid PCMs are basically divided into three groups: organic, inorganic and eutectic (Figure 2).

Organic PCMs are classified as paraffin and non-paraffin PCMs. Since paraffins have a straight chain structure, their melting temperatures and phase change enthalpies increase as the length of the carbon chain increases. When the number of carbon atoms in their molecular structures is between 13 and 28, their melting temperatures are between -5 and 60°C. Non-paraffin PCMs do not have similar properties to paraffins, and each phase change substance exhibits its own unique properties [9]. Organic PCMs are not corrosive, are chemically stable and do not have excessive cooling behavior. On the other hand, they have low thermal conductivity and can be high cost. To overcome this deficiency of thermal conductivity, the charge and discharge times should be reduced by using together with metal foam, nanoparticles, or geometrical improvements with fins [10-12].

Inorganic PCMs are classified as alloys, metals, salts and salt hydrates. Salt hydrates constitute an important part of heat storage materials due to their high heat storage density. The advantages of inorganic PCMs can be listed as low cost and easy availability, non-flammability, high latent heat of fusion and high thermal conductivity. Their disadvantages can be summarized as phase deterioration and decrease in the number of hydrates, excessive cooling and corrosiveness.

Eutectic PCMs can be a combination of two or more materials. The two most important factors when combining these materials are high latent heat and appropriate phase change temperature. By mixing in the required proportions, melting temperatures can be adjusted and high quality PCMs are formed. Among all the PCMs investigated, the most advantageous feature is high proportion fatty acids. A eutectic mixture with a lower phase change temperature can be created by mixing two or more fatty acids.

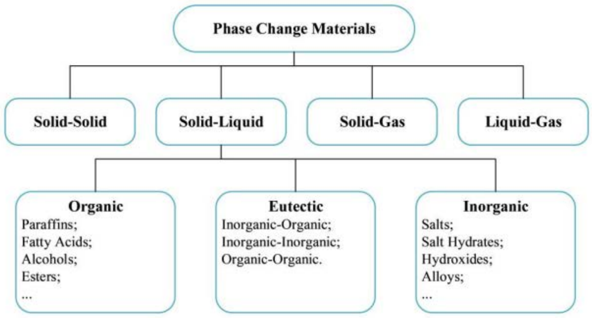


Figure 2. Classification of PCMs [13]

The advantages and disadvantages of these materials according to their types are given in Table 1.

Table 1. Advantages and disadvantages of Solid-liquid PCMs [14, 15]

PCMs	Advantages	Disadvantages
Organic PCMs	High specific heat Small volume change during phase transition Chemical and thermal stability Non-corrosives Compatibility with other materials Recyclable	Low thermal conductivity Lower phase change enthalpy Non compatible with plastic containers Flammability
Inorganic PCMs	High latent heat of fusion High thermal conductivity Low volume change Non-flammable Low cost Wide temperature range Compatible with plastic containers	High volume change High vapor pressure Corrosive and irritant Lack of thermal stability
Eutectic PCMs	Wide temperature range	Extreme cooling High cost

PCMs basically contribute to the heating or cooling load of the building by releasing the energy it stores during the day or night according to the heating or cooling mode later on [16]. PCM can be applied to both existing buildings and newly constructed buildings with different methods such as cement, brick, ceiling, floor, window [17].

In this paper, a comprehensive review on the research area of the phase change materials was performed considering the classification entitled as: i) Application methods of the PCMs ii) Application areas of the PCMs.

2. Application Methods of The PCMs

FDMs can be used in a stable structure by being encapsulated in macro/micro/nano size in practice or by creating a composite structure. The thermal capacity, strength and service life of the materials can be increased by applying different technologies [18]. Salt hydrates, one of the phase change materials, flow in humid regions and there may be changes in the number of hydrates with the change in humidity. When hydrocarbons melt, their viscosity may decrease and thus they may flow into the environment where they are applied. As a result of evaporation, they may increase the volatile organic composition of the air above the limit values. For this reason, phase change materials should be used in a micro-capsule that surrounds them. This method protects the material from external effects for a long time in the core-shell structure (Figure 3).

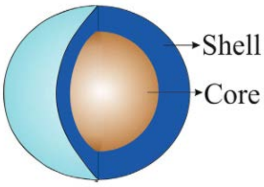


Figure 3. Encapsulated phase change material [19]

When the micro-encapsulation method is considered among these methods, chemical and mechanical methods come to the fore in obtaining PCMs, as seen in Table 2.

Table 2. Micro-encapsulation methods [20]

Chemical Methods	Mechanical Methods
1.Interfacial Polymerization	1.Spray Drying 2.Centrifuge Method
2.In-situ Polymerization	3.Rotational Method
3.Complex Coacervation	4.Fluidized Bed Method
4.Simple Coacervation	5.Electrostatic Method
5.Super Critical Fluid Method	6. Cooling Drying 7. Hot Melt Method

These materials, which are manufactured in addition to the basic production methods of PCMs, also have different application methods in buildings. The basic methods of adding PCMs to the building materials in buildings are explained in items below [21].

Direct incorporation method: In this method, liquid or powder PCM building material is added directly to the wet mixture during production (Figure 4). Although it is a simple method, it has disadvantages such as leakage and incompatibility with materials.

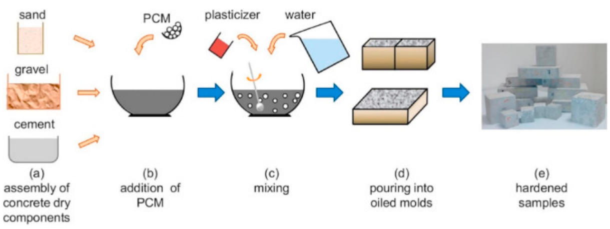


Figure 4. Direct compounding method [22]

Immersion method: In this method, porous building materials are immersed in liquid PCM, and the material absorbs the PCM. Leakage and incompatibility with building materials have also been reported in this method (Figure 5).

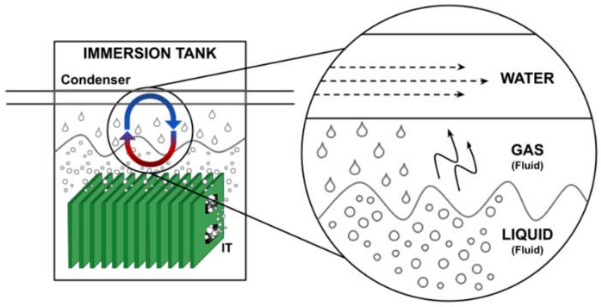


Figure 5. Immersion method [23]

Vacuum impregnation method: In this method, air is drawn from porous aggregates with a vacuum pump and FDM is placed in its place (Figure 6).

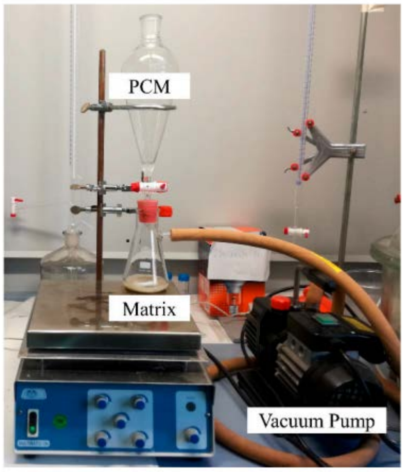


Figure 6. Vacuum impregnation method [24]

Encapsulation method: This method is divided into two as micro and macro (Figure 7). In microencapsulation, PCM of 1-1000 µm size is placed in thin solid capsules made of natural or synthetic polymers and added directly to the building material. This method is both expensive and can affect the mechanical properties of concrete. In macroencapsulation, PCM is packaged in a tube, sphere or panel and combined with the building material in a suitable manner. Although the possibility of leakage is prevented with this method, they can be damaged during use. In addition, the heat transfer area is limited.

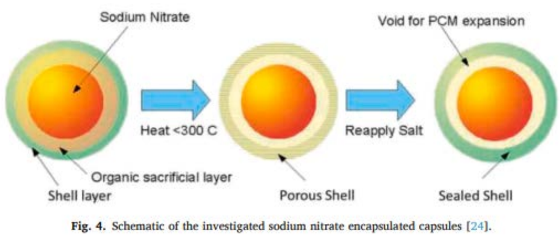


Figure 7. Encapsulation method [25]

Shape-stabilization method: PCM is melted and mixed with an additive material at high temperature. The mixture is then cooled to become solid (Figure 8).

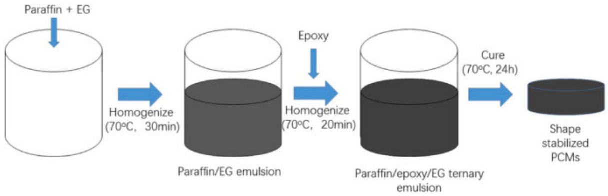


Figure 8. Steady state method [26]

Form stable composites method: This method does not require additional material. FDM is melted at high temperature and cooled after mixing with the building material (Figure 9).

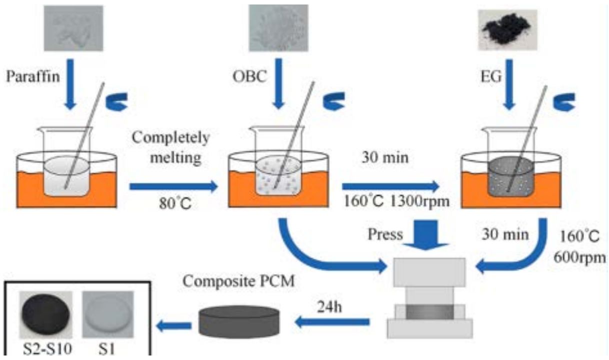


Figure 9. Stable composite method [27]

3. Application Areas of The PCMs

Nowadays, it is aimed to make phase change materials useful in various application areas by using their thermal energy storage properties. In this context, as seen in Figure 10, they have applications in different fields such as environmental science, physics, chemistry and material science, especially in engineering applications [10, 14].

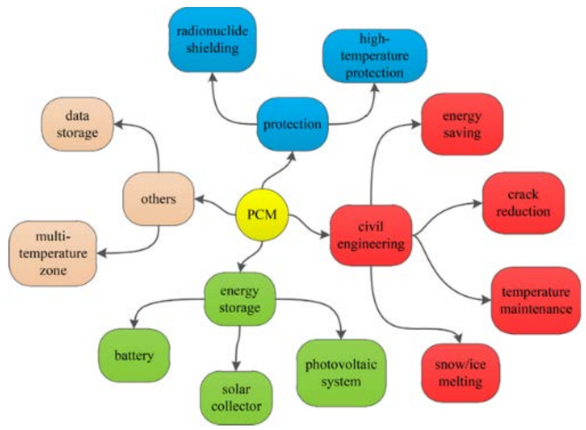


Figure 10. Application areas of using the phase change materials [28]

PCMs are used in different fields in engineering and with tube heat exchangers, which are the most basic heat exchangers. In a study conducted within this scope, a study was conducted by comparing 1, 2 and 4 tube tanks on cold storage applications using tube-in-tank filled with PCM. It was stated that the latent heat energy storage capacity decreased with the increase in the number of tubes. In addition, it was stated that PCM melted more quickly due to the increase in the number of tubes [29].

In another study where tube based storage tank was used, an experimental study was carried out for the heat transfer improvement of this heat exchanger. Two equivalent tanks with tubes inside, one of which had 196 transversal squared fins, were compared. It was concluded that the addition of fins caused an increase in the effectiveness of thermal conductivity between 4.11% and 25.83% depending on the thermal power loaded to the PCM [30].

In a study about the spiral coil tube heat exchanger, the effects of tube diameters, spiral coil diameter and heat transfer fluid parameters were investigated. The results of the study indicated that coil diameter had the most effect and when this value was increased from 50 mm to 70 mm, the total melting time decreased by 71.4%. It was also stated that tube diameter had the least effect [31].

In an experimental study on energy storage in coil in tank heat exchangers, it was stated that the most effective heat transfer mechanisms in charging and discharging processes were natural convection and conduction, respectively. In addition, it was stated that the inlet temperature of the working fluid had more effective than the flow rate [32].

PCMs have also been seen in the automotive field where they store energy and then use this stored energy later in the process. This stored energy is made useful in areas such as vehicle battery cooling systems or during short stops such as traffic lights HVAC systems [33, 34]. In a study examining the application of PCMs in vehicles, the effect of PCM application on heating performance in an innovative heat pump system developed for electric vehicles was experimentally investigated [34]. The flow paths of both the refrigerant and the coolant in this system of the innovative heat pump system developed are given in Figure 11. When the results obtained from the experiments carried out at different ambient temperatures are examined, it is concluded that the stored energy contributes to meeting the heating needs of the vehicle when the heating systems are not in operation. It is also stated that HVAC systems containing PCM can be used to maintain thermal comfort conditions in the vehicle cabin and to prevent temperature fluctuations in the cabin in NEDC and WLTP cycles with stop durations of 23.73% and 13%.

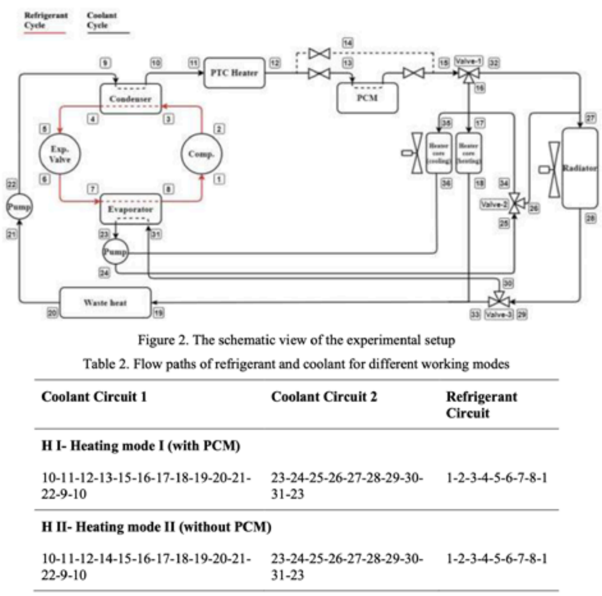


Table 2. Flow paths of refrigerant and coolant for different working modes

Coolant Circuit 1	Coolant Circuit 2	Refrigerant Circuit
H I- Heating mode I (with PCM)		
10-11-12-13-15-16-17-18-19-20-21-22-9-10	23-24-25-26-27-28-29-30-31-23	1-2-3-4-5-6-7-8-1
H II- Heating mode II (without PCM)		
10-11-12-14-15-16-17-18-19-20-21-22-9-10	23-24-25-26-27-28-29-30-31-23	1-2-3-4-5-6-7-8-1

Figure 11. The schematic view of the experimental setup with the explanations of the flow paths [34]

Latent heat storage using phase change materials can be used for free cooling purposes due to its high storage density (Figure 12). In free cooling using PCM as a storage material, cold air is used to solidify PCM during the night and the collected cold is removed on hot days. A detailed review of the studies conducted by different researchers on PCM-based free cooling is presented. The key challenges in the design of PCM-based free cooling systems; their thermo-physical properties and the geometry of the encapsulation are discussed in detail. The charging and discharging of PCM, phase change temperature and climatic conditions affecting the thermal performance of the free cooling system are also discussed. Additionally, the potential reduction of CO_2 emissions from the application of free cooling systems in residential and commercial buildings is also discussed [35].

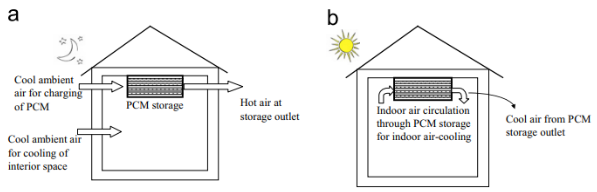


Figure 12. Charging and discharging processes [35]

Osterman et al. investigated the effects of PCMs used in cooling systems on energy consumption and indoor temperature changes. They divided cooling systems into four groups as free cooling applications, encapsulated PCM systems, air conditioning (AC) systems and scorpion cooling systems with integrated PCMs. Paraffin was used as the basis in the study, and in some cases salt hydrates, water and fatty acids were also used. It was stated that PCMs placed in buildings have positive effects on building thermal and energy performance (Figure 13) [36].

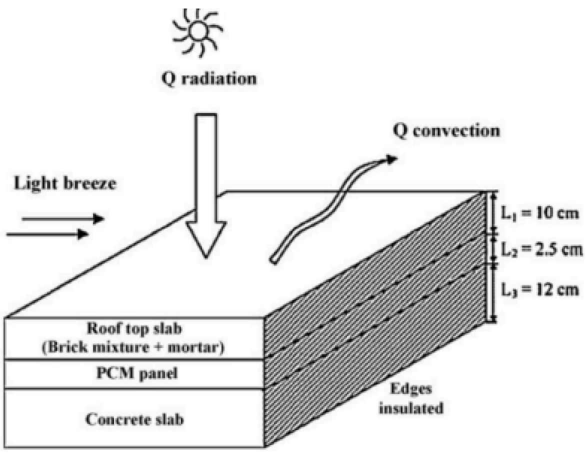
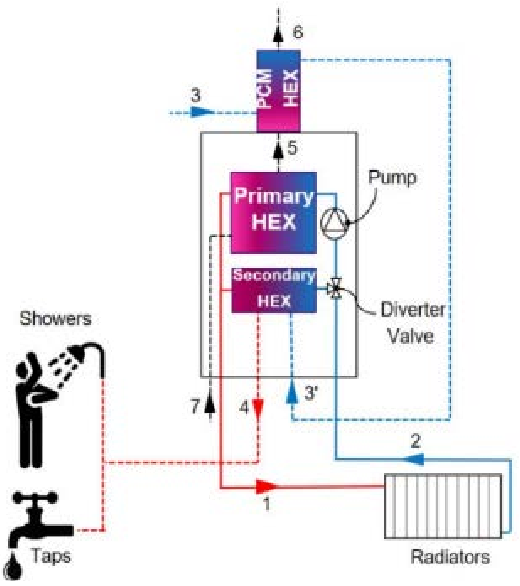


Figure 13. The schematic view of the building roof alignment [36]

In another study, the effect of using PCM materials for insulation purposes on energy consumption was investigated. The thermophysical properties of PCMs used in the study were determined experimentally. The temperature distributions on the walls in the uninsulated and insulated (foam, foam+PCM) cases were investigated in June, July, August and September. It was observed that in the case where the temperature was highest, 39.8 ^{0}C, 33 ^{0}C and 32 ^{0}C values were obtained in the uninsulated, only insulated and both PCM and insulated cases, respectively, and the case with both insulation and PCM was recommended as the best case in terms of cooling load [37].

In another study conducted to benefit from the waste heat generated in the gas combi chimney, a heat exchanger containing PCM was added to the system (Figure 14 and 15). In the three-dimensional numerical study conducted using the ANSYS-Fluent software package program, only the discharge period of the PCM-heat exchanger, that is, the period in which it returns the stored energy, was considered. The effects of the PCM mass, melting temperature and local cold water flow rate were investigated in the study. Four different PCMs were used in the study and their melting temperature values were 40°C, 44°C, 48°C and 54°C. It was observed that the PCM with a high phase change transition temperature provided both higher temperature increases and discharge power. Regarding the discharge power, it was determined that the maximum discharge power varied between 1526 W and 2000 W depending on the PCM melting temperature. It was stated that the amount of solidified PCM at the end of the discharge process also increased with increasing the melting temperature of the material [38].



(1) Central heating inlet, (2) Central heating outlet, (3) Domestic cold water, (3') Preheated domestic cold water, (4) Domestic hot water, (5) Flue gas FDM-heat exchanger inlet, (6) Flue gas PCM-heat exchanger outlet, (7) Gas-air mixture

Figure 14. Schematic of the FDM-heat exchanger gas-fired combi boiler [38]

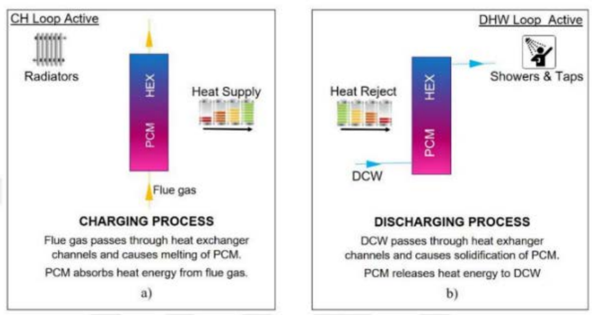


Figure 15. Schematic view of charging and discharging processes [38]

In another study, the effects of using different insulation and phase-changing materials in simultaneously heated and unheated environments in a sample building consisting of a basement, ground floor and two normal floors on energy efficiency and thermal comfort conditions were investigated. Nine different situations were modeled in three types of flooring types, namely uninsulated, insulated and a layer containing PCM in addition to insulation. The effects of the variables on the heat loads of the environments, ambient temperature and energy use were investigated. As a result, it was observed that the heat load of the environments decreased with the use of insulation and PCM in the floor and ceiling. It was concluded that the thermal comfort conditions improved because the ambient temperatures were parallel to the set temperature. It was also stated that the use of insulation and PCM in the floor and ceiling reduced the annual energy use and caused a significant increase in energy efficiency [39].

Considering the summer climate conditions of Elazığ province, instead of insulation material, paraffin-based RT-27, which melts in the range of 28-30 °C in summer conditions, was used on the external walls of buildings facing different directions, and cooling loads were numerically examined in a two-dimensional and time-dependent manner with the ANSYS Fluent program. It was seen that the use of phase-change material on the outside was more efficient and 20 °C lower temperature was obtained on the inner surface compared to the uninsulated wall (Figure 16). It was observed that the heat storage capacity of the wall increased because of the maximum phase shift and minimum damping ratio in places where PCM was applied [40].

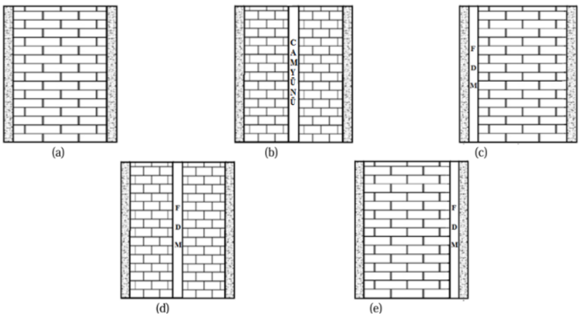


Figure 16. Wall models: (a) Uninsulated wall (b) Wall with glass wool in the middle (c) Wall with PCM on the outside (d) Wall with PCM in the middle (f) Wall with PCM on the inside [40]

Recently, the use of lightweight building walls (LBW) has been increasing due to their easy construction and sustainability in structural terms. In these types of buildings, thermal storage capacities are also low due to the low thermal mass compared to traditional brick buildings. To eliminate this deficiency, PCM applications are carried out in these types of buildings [41-43]. In one of these studies, it was stated that a 25 mm thick PCM wall can store heat equivalent to a 420 mm thick concrete wall [44].

In the study conducted on LBWs, three different wall models with PCM and placed in different locations and a reference wall model without PCM were examined in terms of thermal performance. In the results of the study, it was mentioned that the phase transition temperature parameter was a more effective parameter than the PCM location. It was also stated that for the conditions implemented in this study, the most suitable situation was to position the PCM in the middle of the wall [45]. In another study conducted on LBWs, the effects of the outdoor thermal environment of the wall in different directions were investigated. In this study, where meteorological parameters were examined, it was stated that there were different optimal locations for PCM due to different directions ow the wall [46].

4. Conclusions

In this paper, a detailed literature review about the PCM and its applications is performed. While reviewing the available published extensive studies, we focus on the basic details of the PCM and its applications on heating and cooling process of buildings. According to this study, the main conclusions considering PCM applications on the buildings are listed below.

• Phase change materials are widely used in heating and cooling applications of buildings due to their ability to heat store and then release it again.

• It has been observed that less energy is consumed, and energy is saved in the heating and cooling processes of buildings thanks to phase-changing materials.

• It has been observed that fluctuations in temperature values inside buildings can be prevented thanks to PCMs.

• It has also been determined that by using it in the automotive industry during short stops such as traffic lights, the sustainability of the cabin interior temperature value can be ensured and fluctuations in this value can be prevented.

• It has been observed that the use of PCM in new generation buildings with low thermal masses such as LBW is quite effective in terms of thermal performance.

• It has been observed that PCM thickness, melting temperature and other thermophysical properties of PCM are effective in PCM application on the walls of buildings. In addition, it has been reported that the geographical characteristics of the building where PCM is applied and the direction in which the building is built are also very important.

• It has been stated that PCMs can be easily applied to both existing buildings and newly constructed buildings.

• Thanks to the use of organic PCMs, thermal improvements can be made in the area used without harming the environment.

• Although the amount to be encapsulated in the polymeric structure in microencapsulation is generally not predictable in advance, literature studies have reported that PCMs can be obtained at encapsulation rates of up to 85%.

• It has been seen that different types of heat exchangers such as tubular heat exchangers and plate type heat exchangers can be used in PCM applications, as well as being applied directly as a layer or filling material as in building walls.

The results obtained with this article show that phase change materials can be integrated into different application areas for better understanding and development of thermal management and energy efficiency. After these comprehensive studies, it is anticipated that more experimental and numerical studies can be conducted to clearly reveal the thermal and mechanical behavior of phase change materials.

Conflict of Interest Statement: The authors declare no conflicts of interest.

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Derleme Makalesi / Review Article

Design of 5th generation fighter aircraft engines: key parameters of next-generation technologies

5. Nesil savaş uçağı motorlarının tasarımı: yeni nesil teknolojilerin temel parametreleri

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ABSTRACT

5th generation aircraft engines are designed to meet requirements such as low radar visibility, high maneuverability, and fuel efficiency. This review paper examines how key design parameters like thrust-to-weight ratio, thermal efficiency, fuel consumption, and multi-mission capabilities are prioritized and optimized in this generation. Additionally, comparisons with prior generation aircraft engines are made, analyzing how new technologies bring forth unique advantages in this generation. Special attention is given to the effectiveness of afterburner systems, design innovations enabling low radar visibility, and how engine integration contributes to enhanced aerodynamic performance. The study evaluates how 5th generation engines achieve greater fuel efficiency while simultaneously offering higher speed, maneuverability, and reduced detectability compared to previous generations. This work aims to explain the innovative parameters that are prominent in the design of 5th generation aircraft engines and their critical role in achieving air superiority.

ÖZET

Bu makale, 5. nesil savaş uçaklarında kullanılan jet motorlarının tasarım parametreleri ve özelliklerine odaklanmaktadır. 5. nesil uçak motorları, düşük radar görünürlüğü, yüksek manevra kabiliyeti ve yakıt verimliliği gibi gereksinimleri karşılayacak şekilde tasarlanmıştır. Bu derleme makalesinde, itki-ağırlık oranı, termal verimlilik, yakıt tüketimi ve çoklu görev yetenekleri gibi temel tasarım parametrelerinin bu nesilde nasıl önceliklendirildiği ve optimize edildiği incelenmektedir. Ayrıca, daha önceki jenerasyonların uçak motorlarıyla karşılaştırmalar yapılarak, yeni teknolojilerin bu nesilde sunduğu farklılıklar analiz edilmektedir. Özellikle, art yakıcı sistemlerin etkinliği, düşük radar görünürlüğünü sağlayan tasarım yenilikleri ve motor entegrasyonunun geliştirilmiş aerodinamik performansa katkısı üzerinde durulmaktadır. Çalışma, 5. nesil motorların, önceki nesillere kıyasla daha yüksek hız, manevra kabiliyeti ve azaltılmış tespit edilebilirlik sağlarken aynı zamanda daha yüksek yakıt verimliliği nasıl elde ettiğini değerlendirmektedir. Bu çalışma, 5. nesil uçak motorlarının tasarımında öne çıkan yenilikçi parametreleri ve hava üstünlüğünü sağlamadaki kritik rollerini açıklamayı amaçlamaktadır.

1. Introduction

Due to its strategic location, Turkey has historically faced numerous regional and global threats. Airspace security is at the core of both national defense and external security strategies. In contemporary warfare, the dynamics of conflict and security underscore the critical importance of air superiority. Control of airspace is a decisive factor influencing the success of military operations. Air superiority limits the mobility of enemy forces, enhances intelligence-gathering capabilities, and increases the effectiveness of strikes against ground targets [1]. In this context, fighter attack aircraft, with their ability to effectively strike enemy targets and establish air superiority, have become indispensable elements of modern military forces.

Many nations allocate a significant portion of their defense budgets to air forces, particularly to fighter aircraft. For instance, the United States plans to spend approximately $216 billion of its $835 billion defense budget for 2024 on fighter aircraft and air force technologies [2]. Meanwhile, China is predicted to spend approximately $236 billion budget defense [3]. These figures clearly illustrate how air power plays a decisive role not only in military strategies but also in the power dynamics of international relations. In conclusion, air superiority remains at the heart of modern warfare, continuing to be a critical factor in shaping national security strategies and ensuring future military success.

New-generation aircraft are critical for achieving dominance in modern battlefields. Their ability to conduct missions undetected thanks to low radar signatures, coordinate operations with other elements through network-centric warfare and deliver high speed and maneuverability with advanced engine designs make them an integral part of future military strategies.

From this point of view, it is critical to review past, current and possible future trends in fighter craft engines. This paper will examine the design parameters used in the engines of 5th generation fighter aircraft in detail and analyze how these parameters have evolved since the 1st generation. To do so, books about fighter aircraft and gas turbine engines, military reports, news and official websites of fighter aircraft engine producers were focused and examined. Additionally, comparisons with previous generation aircrafts engine parameters will help better understand the impact of technological advances on 5th and next-generation aircraft engines.

2. Evolution Fighter Aircrafts

The development of fighter aircraft has evolved rapidly since the 1st generation. 1st generation jet aircraft (late 1940s-1950s) participated in basic air combat with designs focused solely on thrust and speed, lacking radar systems. These aircraft were unable to reach supersonic speeds and had limited range. 2nd generation aircraft (1950s-1960s) were equipped with radar and air-to-air missile systems, adapting to more complex combat environments, although they still had low maneuverability and limited electronic warfare capabilities [4].

3rd generation aircraft (1960s-1980s) saw improvements in thrust, range, and maneuverability. Radar systems were further enhanced, and air-to-ground attack capabilities were expanded. 4th generation aircraft (1980s-2000s) became multi-role platforms with advanced radars, sensors, speed, and maneuverability. Iconic aircraft like the F-16 and Su-27 symbolize this era. While thrust-to-weight ratios and long-range supersonic speeds became significant features, stealth capabilities were not yet widely adopted [5].

The subsequent 4.5th generation aircraft can be described as advanced versions of 4th generation planes, equipped with improved electronic warfare systems, technologies reducing radar cross-section, and network-centric warfare capabilities. However, they do not have the comprehensive stealth features of 5th generation aircraft. Models such as the Eurofighter Typhoon and Dassault Rafale are considered part of the 4.5th generation [1].

5th generation fighter aircraft (2000s and beyond) represent a completely new era in air combat. These aircraft differentiate themselves from previous generations with features such as low radar visibility, supersonic cruising, advanced sensor fusion, network-centric warfare capabilities, and high thrust-to-weight ratios. For example, the F-35 Lightning II and F-22 Raptor combine low radar signatures, high thermal efficiency, and optimized afterburner systems, enabling long-range supersonic operations. Over the past 30 years, advancements in fighter aircraft aim not only to ensure air superiority but also to provide operational versatility [6]. The general trends in fighter aircraft generations were summarized in **Table 1**. The parameters represented in the table are generic approximate values of different generations of fighter aircrafts.

Table 1. General overview of fighter aircrafts with different generations [7]

Generation	Period	Aircrafts	Key Features
1st Generation	Late 1940s-1950s	F-86 Sabre, MiG-15, Gloster Meteor, Hawker Sea Hawk	- No radar - Subsonic speeds - Simple weapon systems -No radar - Limited air-to-air missiles
2nd Generation	1950s-1960s	F-104 Starfighter, MiG-21, English Electric Lightning, F-5	- Equipped with radar and missiles - Supersonic speeds - Improved maneuverability
3rd Generation	1960s-1980s	F-4 Phantom II, MiG-23, Mirage III, A-7 Corsair II	-Supersonic speeds -Afterburners - Advanced radar and avionics - Air-to-ground attack capability
4th Generation	1980s-2000s	F-16 Fighting Falcon, Su-27 Flanker, MiG-29, Mirage 2000	-Fly-by-wire controls -Multi-role capability - Advanced sensors and radars - Supersonic cruising
4.5th Generation	1990s-2020s	Eurofighter Typhoon, Dassault Rafale, F/A-18E/F, Su-35	- Advanced electronic warfare - Network-centric warfare capabilities - Stealth technologies
5th Generation	2000s and beyond	F-22 Raptor, F-35 Lightning II, Su-57, Chengdu J-20	- Low radar signature - Supersonic cruising - Sensor fusion and networked warfare capabilities
6th Generation	2030s (expected)	NGAD (USA), BAE Tempest (UK), Future Combat Air System (FCAS - Europe)	-AI integration -Unmanned capabilities -Hypersonic speeds -Directed energy weapons.

3. Propulsion Systems of Fighter Aircraft

The propulsion system is the core component of a fighter aircraft that generates the thrust required for flight. It enables the aircraft to overcome drag, achieve lift, and sustain maneuverability across a wide range of speeds and altitudes. Propulsion systems are integral not only to basic flight mechanics but also to mission-specific performance, influencing critical factors such as speed, agility, endurance, and stealth [8].

Modern fighter aircraft propulsion systems are primarily jet engines, which can be categorized into turbojets, turbofans, ramjets, and scramjets. These systems operate on principles derived from Newton's third law of motion, where air is ingested, compressed, mixed with fuel, and ignited, creating high-velocity exhaust gases that produce thrust.

3.1. Key Requirements of Fighter Aircraft Propulsion Systems

High Thrust-to-Weight Ratio: Fighter aircraft engines are designed to deliver maximum thrust while maintaining minimal weight, enabling rapid acceleration, vertical climbs, and sustained supersonic flight.

Supersonic and Hypersonic Capability: Advanced propulsion systems enable sustained flight at supersonic speeds (Mach 1+) and, in some cases, hypersonic speeds (Mach 5+), crucial for intercept missions and evasion.

Fuel Efficiency: While high thrust is a priority, fuel efficiency ensures extended range and operational endurance, particularly important for long missions or combat patrols.

Agility and Responsiveness: The propulsion system must support sudden throttle changes for quick maneuvers, afterburner activation for bursts of speed, and optimized performance during high-g maneuvers.

Stealth Characteristics: Modern engines often incorporate design features that minimize infrared and radar signatures, critical for avoiding detection in hostile environments.

Reliability and Durability: A robust propulsion system must perform consistently in varying operational conditions, including high temperatures, high altitudes, and combat damage scenarios.

4. Evolution of Propulsion System Parameters Across Fighter Aircraft Generations

The propulsion systems of fighter aircraft have evolved significantly across different generations. The parameters in the **Table 2** highlight key aspects of engine performance and efficiency.

Table 2. Main engine parameters and key features from different generations of fighter aircraft [7], [9], [10], [11], [12], [13], [14], [15]

Parameter	1st Gen.	2nd Gen.	3rd Gen.	4th Gen.	4.5th Gen.	5th Gen.
Type	Turbojet	Turbojet	Turbojet and Turbofan (Rare)	Turbofan	Turbofan	Turbofan
Thrust-to-Weight Ratio	3:1	3:1 - 5:1	5:1 -6:1	5:1 - 8:1	6:1 - 9:1	8:1 - 9:1
Specific Fuel Consumption (lb/lbf-hr)	1-1.2	1.8-2	0.8-1 1.8-2(with afterburner)	0.7-0.9 1.8 (with afterburner)	0.7-0.8 1.6-1.7 (with afterburner)	0.6-0.8 1.8 (with afterburner)
Design Mach Number	0.8 - 0.9	0.8 - 0.9	1.0 - 2.2	1.5 - 2.2	1.5 - 2.5	1.7 - 2.5
Supercruise Speed (Mach)	None	None	Rare (1.2 Mach)	Rare (1.2 Mach)	Common (1.4 Mach)	Common (1.7 Mach)
Overall Pressure Ratio	5:1	9:1 - 13:1	10:1 - 13:1	21:1 - 24:1	25:1 - 26:1	26:1 - 28:1
Bypass Ratio (Turbofan)	N/A	N/A	0.7:1	0.5:1 – 0.6:1	0.4:1 – 0.3:1	0.3
Afterburner Usage	None	Rare	Yes	Yes	Yes	Common
Stealth Compatibility	None	None	None	Partial	Partial	Yes
Radar Cross Section (RCS)	Large (10 m^2 or more)	Large (10 m^2 or more)	Moderate (3-5 m^2)	Small (1-3 m^2)	Small (0.5-1 m^2)	Very Small (<0.1 m^2)
Operational Altitude (m)	12000	12000	15000	18000	18000	20000

Specific fuel consumption (SFC), which measures engine fuel efficiency, has increased significantly over time. 1st to 2nd generation aircraft due to requirements of speed and thrust. As turbofan technology improved in later generations, SFC values dropped, reaching around 0.6 lb/lbf-hr in 5th generation aircraft. This decrease reflects the more efficient fuel consumption of modern engines. On the other hand, to sustain supersonic speeds, there was emerging technology of afterburner which increase SFC after 3rd generation. For the following generations, it seems that SFC are tried to be decreased by reheating and supercruise technologies.

The design Mach number, which indicates the optimal speed for the aircraft, has also increased over generations. Early fighters were designed for subsonic to transonic speeds (Mach 0.8-0.9), while 3rd, 4th, and 5th generation fighters are designed to fly at supersonic speeds, with some capable of reaching Mach 2.5. Supercruise capability, the ability to fly at supersonic speeds without afterburners, has become a key feature in 4th and 5th generation aircraft, providing greater operational efficiency and mission flexibility.

Afterburner usage, though still common in 2nd and 3rd generation aircraft, has become less frequent in modern designs due to the advent of supercruise capabilities. This enables newer fighters to sustain supersonic speeds without the need for afterburners, offering better fuel efficiency.

Stealth technology has significantly reduced the radar cross-section (RCS) of 5th generation fighters. While older aircraft had large RCS values, modern fighters like the F-22 and F-35 have RCS values as low as 0.1 m^2, making them much harder to detect by enemy radar systems.

Finally, operational altitude has increased with each generation. Early fighters operated at altitudes around 12,000 meters, while 4th and 5th generation fighters can fly at altitudes above 20,000 meters, offering tactical advantages in terms of fuel efficiency and mission flexibility.

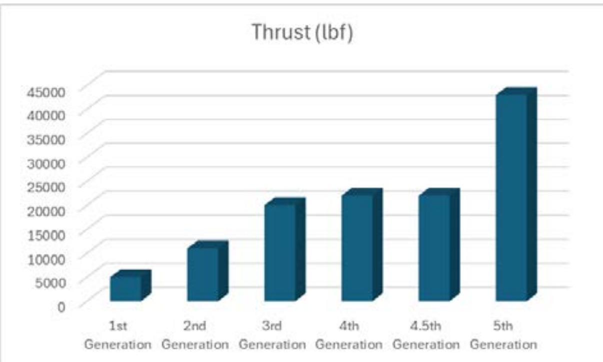

Figure 1. Maximum thrust values at different fighter aircraft generations

Peak thrust (**Figure 1**) has increased substantially from 1st generation to 5th generation fighters. Early turbojet engines in 1st and 2nd generation aircraft produced relatively lower thrust, around 5000-11000 lbf. However, with the introduction of more advanced turbofan engines in later generations, thrust values have risen dramatically, reaching up to 40,000 lbf in modern 5th generation fighters such as the F-22 Raptor and F-35 Lightning II. This increase in thrust has also resulted in a corresponding rise in thrust-to-weight ratios, allowing for better maneuverability and overall performance in modern fighters.

Overall pressure ratio and turbine inlet temperature are important indicators of engine performance. Over the generations, both parameters have improved, with CPR rising from about 5:1 in early jets to over 28:1 in modern aircraft. Similarly, turbine inlet temperatures have increased from around 1000°C up to 2000°C, (**Figure 2.**) allowing modern engines to operate at higher speeds and altitudes with greater efficiency thank to advanced high-technology metals. However, due to comparatively slow material thermal performance improvements, cooling requirements increased significantly [16].

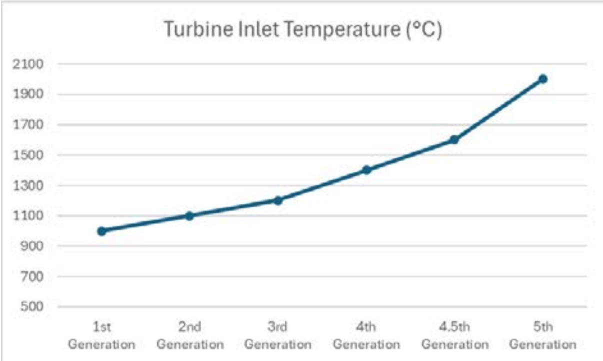

Figure 2. Turbine inlet temperature comparison of different generations

The bypass ratio, which influences engine efficiency and thrust, has decreased over time as well. Early turbojet engines had no bypass ratios due to absence of by-pass air, while modern turbofan engines in 4th and 5th generation aircraft have bypass ratios of up to 0.3:1, improving thrust.

In conclusion, the advancements in propulsion technology across fighter aircraft generations have significantly enhanced performance, fuel efficiency, speed, stealth, and overall mission capability. Modern 4th and 5th generation fighters outperform their predecessors in virtually all aspects of propulsion, providing superior combat capabilities in today's strategic environment.

Fighter aircraft propulsion systems continue to evolve, integrating emerging technologies such as adaptive cycle engines, which can optimize thrust and efficiency in different flight conditions, and electric or hybrid propulsion systems for future sustainability goals. These innovations aim to further enhance performance, reduce maintenance requirements, and meet the growing demands of modern aerial combat.

Conclusion

In this paper, fighter jet aircraft engines from different generations were evaluated from 1st to 5th generation. Main engine parameters were presented and the trend of them was discussed. Data about turbofans and early generation turbojets gas turbine engine acquired from military reports, official websites from producers and the books focusing on the air fighter jets. The evolution of jet engines across generations of fighter aircraft showcases significant advancements in propulsion technology, reflecting the changing priorities and requirements of aerial combat. Outcomings from this investigation can be summarized as following:

- **1st Generation:** Basic turbojet engines characterized by simple designs, limited efficiency, and subsonic performance were predominant. These engines lacked afterburners and were optimized for early jet-powered flight.

- **2nd Generation:** The introduction of afterburner-equipped turbojet engines enabled sustained supersonic speeds and improved thrust capabilities, meeting the demands of evolving aerial combat scenarios.

- **3rd Generation:** Early turbofan engines with low bypass ratios began replacing turbojets, offering better fuel efficiency and maintaining high thrust for supersonic speeds. This marked a shift towards more versatile and efficient propulsion systems.

- **4th Generation:** Low bypass turbofan engines became the standard, emphasizing a high thrust-to-weight ratio, enhanced maneuverability, and better fuel efficiency to support multi-role combat missions.

- **4.5th Generation:** Advanced turbofan engines with improved fuel efficiency and reduced thermal signatures were developed. These engines introduced supercruise capabilities, enabling sustained supersonic flight without afterburners.

- **5th Generation:** Highly advanced turbofan engines prioritize stealth, supercruise capability, and reduced radar and thermal signatures. These engines are optimized for multi-mission flexibility and superior aerodynamic integration.

In future generations, emerging engine technologies focus on adaptive cycle designs to enhance fuel efficiency, operational flexibility, and performance across multiple mission profiles. These engines aim to achieve unprecedented speeds and sustain hypersonic capabilities. To conclude, each generational leap in jet engine technology reflects a progression in design priorities, from fundamental propulsion needs to advanced capabilities like stealth, Supercruise, and adaptability for diverse mission requirements. These advancements underline the critical role of jet engine innovation in shaping the effectiveness and dominance of modern fighter aircraft.

Çıkar Çatışması Beyanı: Yazarlar herhangi bir çıkar çatışması olmadığını beyan etmişlerdir.

Fonlama Bilgileri: Bu çalışma herhangi bir fon tarafından desteklenmemiştir.

Yazar katkısı: Yazarlar, çalışmanın tasarlanması, verilerin toplanması, sonuçların analizi ve yorumlanması ve makalenin hazırlanması ile ilgili sorumluluklarını onaylamaktadır.

Veri Kullanılabilirlik Beyanı: Bu çalışma sırasında üretilen ve/veya analiz edilen veriler kamuya açık değildir, ancak veriler makul bir talep üzerine ilgili yazar tarafından sağlanabilir.

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