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Exploring the Tribological Performance of Mist Lubrication Technique on Machinability Characteristics During Turning S235JR Steel

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ABSTRACT

The primary challenges in turning operations involve the quality of the machined component and the expense associated with tooling. Therefore, optimum machining parameters suitable for turning operations should be selected to achieve the desired quality of the finished product with reduced machining time and cost. This study seeks to identify the optimal machining environments for S235JR low carbon steel without heat treatment. This includes finding the appropriate compound of cutting speed and depth, feed and tool material to provide efficient material removal and reach the desired surface finish. The experimental study, designed with the full factorial method, was carried out with 2 factors of cutting speed and feed rate with selected 2 levels under dry and MQL conditions. The consequence of this study indicated that the mist lubrication technique effectively addresses the machinability challenges associated with S235JR steel, particularly concerning low surface quality, as well as high cutting temperatures and cutting forces. The MQL technique led to a 51.16% improvement in surface roughness, a 19.91% reduce in cutting temperatures and a 57.21% decrease in cutting forces. The results clearly indicate that the MQL technique was particularly effective in reducing the cutting force parameter. Under both machining conditions, a rise in cutting speed and feed rate negatively affected all three parameters being examined. To achieve favorable machinability outcomes, it is advisable to opt for lower cutting speeds and feed rates.

S235JR Çeliğinin Tornalanması Sırasında Yağ Püskürtme Yönteminin İşlenebilirlik Özellikleri Üzerindeki Tribolojik Performansının Araştırılması

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ÖZET

Tornalamadaki ana zorluklar, işlenmiş parçanın kalitesi ve takım maliyetidir. Bu nedenle, daha az işleme süresi ve maliyeti ile bitmiş üründe istenen kaliteyi elde etmek için tornalama işlemlerinde uygun ideal işleme parametreleri seçilmelidir. Bu çalışmanın amacı, verimli talaş kaldırma ve istenilen yüzey kalitesi için ilerleme, kesme hızı, kesme derinliği ve takım malzemesinin doğru birleşimini bulmayı içerebilecek, ısıl işlem uygulanmayan S235JR düşük karbonlu çelik için ideal işleme koşullarını belirlemektir. Tam faktöriyel yöntemle tasarlanan deneysel çalışma, kuru ve MQL kesme ortamı koşullarında 2 faktörlü kesme hızı ve ilerlemenin 2 seviyesi seçilerek gerçekleştirilmiştir. Bu çalışmanın sonuçları yağ püskürtme tekniğinin S235JR çeliğinin düşük yüzey kalitesi, yüksek kesme sıcaklığı ve kesme kuvveti açısından işlenebilirlik zorluklarının üstesinden gelebildiğini göstermiştir. MQL tekniği ile yüzey pürüzlülüğünde %51,16 oranında iyileşme, kesme kuvvetlerinde %57,21 oranında azalma ve kesme sıcaklıklarında %19,91 oranında azalma sağlanmıştır. Sonuçlar, MQL tekniğinin özellikle kesme kuvveti parametresini düşürmede etkili olduğunu açıkça göstermektedir. Her iki kesme koşulunda da ilerleme oranının ve kesme hızının artırılması, incelenen üç parametrenin hepsini olumsuz yönde etkiledi. Olumlu işlenebilirlik sonuçları elde etmek için daha düşük kesme hızları ve ilerleme oranlarının tercih edilmesi önerilir.

1. INTRODUCTION (GİRİŞ)

Steels with a carbon ingredient of up to 0.20% are classified as low carbon steels. They are alloys of carbon and iron and contain lesser amounts of elements from the steel-making process such as

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manganese, silicon, sulphur, and phosphorus. They are used in construction and manufacturing. Due to their mechanical properties, they are also known as mild steels. Mild steel represents the largest share of world steel production [1]. Steel bars and profiles are used in flat products and the construction industry and basic structures are in the low-carbon steel class. All the properties of carbon steels are related to their structure, which depends on the amount of carbon they contain. As the carbon content in steels rises, their tensile strength, yield strength, and hardness also increase, whereas ductility (measured as percentage elongation and percentage area reduction) and impact properties tend to decline. Since low-carbon steel cannot be strengthened by heat treatment, it is suitable for cold work, but its surfaces can be hardened by surface hardening processes such as normalizing [2]. S235JR ferritic steel is one of the most preferred grades in steel structures and is part of the ST 37-2 grade that is made following the EN 10025-2 standard [3]. S235JR is described as the mildest of the hot-rolled steels. Its structure makes it easy to cut. They also have good machinability and weldability. In this condition, the machinability of S235 is parallel to that of mild steel with its yield strength of 235 MPa [4].

An important part of the manufacturing sector, machining is a production process used to shape or work the materials used in manufacturing [5]. Machining is a complex process in which workpiece, tool, chip, and environmental terms have a major influence on the process, with frictional and thermal interactions determining how the process performs. This is where the importance of the use of a cooling environment becomes clear. The purpose of machining technology is multifaceted. It aims to achieve environmentally friendly, clean, and sustainable production while maintaining the highest dimensional accuracy at the lowest possible cost. Sustainable production ensures that resources are not consumed at the expense of the environment and that actions taken today do not pose a threat to future generations [6]. Consequently, alternative lubrication techniques have gained interest among researchers in recent years [7-9]. In the development of sustainable manufacturing processes, machinability studies in minimum quantity lubrication (MQL), dry and cryogenic cutting conditions play a crucial role. During machining, a considerable level of heat is generated on the surface of the cutting tool and the side surface due to friction. Friction and adhesion tend to be higher at the chip/tool interface, especially in dry machining. This results in high wear rates and heat generation, resulting in high tool wear and low surface quality [10]. MQL is a technique where a mixture of pulverised pressurized air and a a minimal amount of coolant is sprayed onto the machining area [11]. The flood cooling method using non-biodegradable fluid uses approximately 10 times more lubricant than the MQL system and requires additional pumping power [9]. It is also an alternative to dry machining as it leaves no residue in the machining zone or on the cutting instrument providing a typical lubrication rate of 5-500ml/h [12]. Furthermore, the vegetable oil used with the MQL process significantly improved these benefits, giving chip removal results comparable to flood cooling methods [13]. There are many studies in the existing literature examining the machinability of steels in different cutting environments Yap et al. [14] examined the impact of different cooling environments on machining performance such as cutting force and surface roughness when machining S45C carbon steel. It was observed that using cryogenic cooling during the turning of carbon steel reduces the friction coefficient and improves the chip removal rate. However, this process was found to significantly decrease the surface characteristics of the steel. The best surface quality value was achieved through low-speed machining in a dry environment. Usluer et al. [15] investigated the effects of various cutting conditions (dry cutting, MQL, MWCNT N-MQL, and MWCNT/MoS2 HN-MQL) on thrust force, cutting force, temperature, overall machining costs, and carbon emissions during the turning of S235JR steel. When evaluating machinability parameters, N-MQL conditions consistently outperformed the others in terms of both temperatures and cutting forces. The results indicated that the feed rate had the largest influence on cutting force, thrust force, contributing 86.8% and 65%, in that order. Additionally, cutting environments had the most significant impact on cutting temperature, with a additive ratio of 93.2%. Yildiz et al. [16] assessed the influence of cutting fluids in determining surface quality during the boring of low carbon steel. Based on the results, In the majority of boring tests, wet cutting did not demonstrate more favourable results compared to dry cutting; however, the application of cutting fluid with a large nose radius and a minimal feed enhanced surface roughness by as much as 80%, ascribed to both effective chip formation and efficient cooling. Maruda et al. [17] studied the effects of MQL on surface quality and chip morphology in the turning of low carbon steels. MQL, air-based cooling, and dry cutting technique were evaluated. The MQL technique proved to be more efficient in machining low carbon steel, delivering improved chip formation and reduced surface roughness. Depending on the machining parameters, MQCL offers a 10% to 30% increase in efficiency compared to dry cutting. Sodavadia and Makwana [18] did an experiment to test how well nano-fluids, like coconut oil (CC) with nano boric acid functioning as a solid lubricant, perform in processing AISI 304. They looked at how different cutting speeds, feed, and cutting depth affect tool wear, surface quality, and tool temperature. They tested different amounts of nano boric acid mixed with coconut oil (0.25%, 0.5%, and 1%) under different conditions. The 0.5% suspension of nano boric acid blended with coconut oil gave the best results, lowering the temperature, tool wear and surface roughness. However, the exact number of tests and the effects of interactions between the factors were not detailed in the paper. Ali et al. [19] present an experimental investigation regarding the influence of MQL using cutting oil on various factors during turning of medium carbon steel. The research examines factors including the ratio of chip thickness, the forces experienced during cutting, the temperature generated during cutting, tool wear, and the roughness of the surface, employing uncoated carbide tools under industrial speed-feed settings. The positive results show a big decrease in tool wear, size related errors, and surface roughness when using MQL instead of dry machining. This improvement happens primarily because MQL lowers the temperature in the cutting area and changes the way the chip interacts with the tool and the workpiece. The findings suggest that the MQL system can lead to better productivity, higher product quality, and overall better machining efficiency, even when considering the extra costs of setting up and using the MQL system. Mia et al. [20] studied the optimization of the MQL application rate to minimize surface roughness and cutting forces while performing end milling on hardened steel with a hardness of HRC 40. Additionally, the study sought to precisely determine the MQL flow rate, as well as the cutting speed and feed rate, by employing the Grey-based Taguchi method and a composite desirability model. The variance analysis revealed that the table feed exerts the most significant influence on cutting force, whereas the lubricant flow rate has a considerable effect on surface quality. The optimal results were achieved with a lower table feed, a higher cutting speed, and a lubricant flow rate of 150 ml/h, leading to the lowest values for the measured outcomes.

This research investigates the turning process of the low-carbon steel S235JR. This steel is commonly used in the metal industry. For this purpose, machining operations have been conducted in a dry environment and an MQL environment, and under different cutting conditions. This will contribute to the literature as original research, as there are an extremely limited number of publications assessing the machinability of S235JR in different cutting environments.

2. MATERIAL AND METHOD (MATERYAL VE YÖNTEM)

2.1. Experimental Setup (Deney Düzeneği)

For this research, S235JR mild steel was selected as the material, known for its prevalent use across multiple manufacturing industries. Table 1 presents the weight-based chemical composition of the steel utilized in this study. The full factorial approach to machining experiments was used to determine the depth of cut, cutting speeds, and feed. The full factorial approach for experimental design, used to evaluate and interpret the effects of factors, is considered to be an optimal approach because every potential combination of various factor levels are evaluated [21]. An equal number of results from each level of each factor are taken and compared in this type of design. This method is only applicable if only a few factors play a role. As the number of factors and their effects increases, the number of experiments needed rises significantly. Consequently, a total of eight experiments were performed in this section. A straightforward systematic design was implemented to estimate both the main effects and their interactions. The initial phase of the experimental design involved identifying the determining cut-off factors that could influence the response. All factors were set at a minimum of two levels, which were selected based on their relevance and appropriateness for the characteristics of this research. Once the variables and their respective levels were established, an experimental design was formulated that incorporated every potential combination of these levels. The next phase involved assigning evaluation points corresponding to each combination of factor levels, ensuring that multiple factors were tested simultaneously during the experiments. Furthermore, the full factorial design approach was employed in this study to evaluate both main effects and interactions.

Table 1. S235JR workpiece chemical composition (S235JR iş parçası kimyasal kompozisyonu)

Elements	Content
C wt%	0.2
Mn wt%	1.4
Si wt%	0.03
P wt%	0.045
S wt%	0.045
N wt%	0.015

Based on practical applications and manufacturer recommendations, the tooling components were selected. Following ISO 3685 [22] a cemented carbide cutting tool of the CCMT 09T308-VM series was used. The workpiece and experimental design are illustrated in Figure 1. The cutting tools were replaced after each test period. Table 2 lists the parameters and their respective levels employed in the experimental investigations.

Table 2. Turning experiments levels (Tornalama deneyleri seviyeleri)

Cutting Parameters	Level I	Level II
Feed rate (mm/rev)	0.2	0.4
Cutting speed (m/min)	40	60
Cutting environment	MQL	Dry

The specimen was 30mm in diameter and 400mm in length. According to the TS EN 10025-2 standard, the yield strength of S235JR steel for thicknesses between 16 mm and 40 mm is 225 MPa (Table 3). During the experimental investigation, the cutting temperature and force were measured and recorded with a Telc InGaAs radiation sensor (Germany) at each cutting level. A portable perthometer (Mahr Co., Ltd., Göttingen, Germany) was utilized to assess the surface roughness of the experimental material The Ra average surface roughness value was determined through three repetitions of roughness measurements with a 10mm tracing length.

Table 3. S235JR steel yield strength TS EN 10025-2 (S235JR çeliğinin akma dayanımı)

Yield Strength (≥ N/mm2); Dia. (d) mm							
Steel series	Steel grade	d≤16	16<d ≤40	40<d ≤100	100<d ≤150	150<d ≤200	200<d ≤250
S235	S235JR	235	225	215	195	185	175

The experiments involving the S235 JR workpiece were carried out under both dry cutting and MQL-supported environments. The full factorial design method was employed to optimize the processing conditions. The study analyzed the effects of three different cutting parameters (Table 2) along with two environmental conditions: MQL and dry cutting. Mineral-based oil (olive oil) was applied by a spray mechanism, timed to the MQL process, and positioned 20 mm away from the workpiece. The nozzle was a 2 mm diameter device, and the spray pressure was 6 bar, with a flow rate of 50 mL/h. The angle of the nozzle was set at 45°. MQL uses sunflower oil, which comes from renewable sources like seeds. As opposed to petroleum-based oils that are limited and cause pollution, sunflower oil is more eco-friendly. It is biodegradable and does not harm the environment. Sunflower oil is also non-harmful and poses no risk to humans or ecosystems, as it contains no harmful chemicals. Because of its biodegradability, low toxicity, and renewability, sunflower oil is a good option for environmentally friendly lubricants [23]. Sunflower oil, having a density of 918.8 kg/m³, a viscosity of 43 cP at 20 rpm, and a smoke point of 232°C, is employed in the process. In this study, which aims to minimize the environmental effect of the process by decreasing the quantity of oil and cooling water used, dry and MQL environments were evaluated separately. Inserts and chips were analyzed utilizing scanning electron microscopy (SEM) imaging to examine their microstructural features after each cutting test. The results of this study suggested that the analysis encompassed cutting forces, temperatures, surface roughness, and chip forms in both dry and MQL conditions. The findings indicate that this method of machining can be defined as sustainable machining in the turning of S235JR steel. Furthermore, the results were presented in graphical format and accompanied by visual materials to illustrate the machining performances.

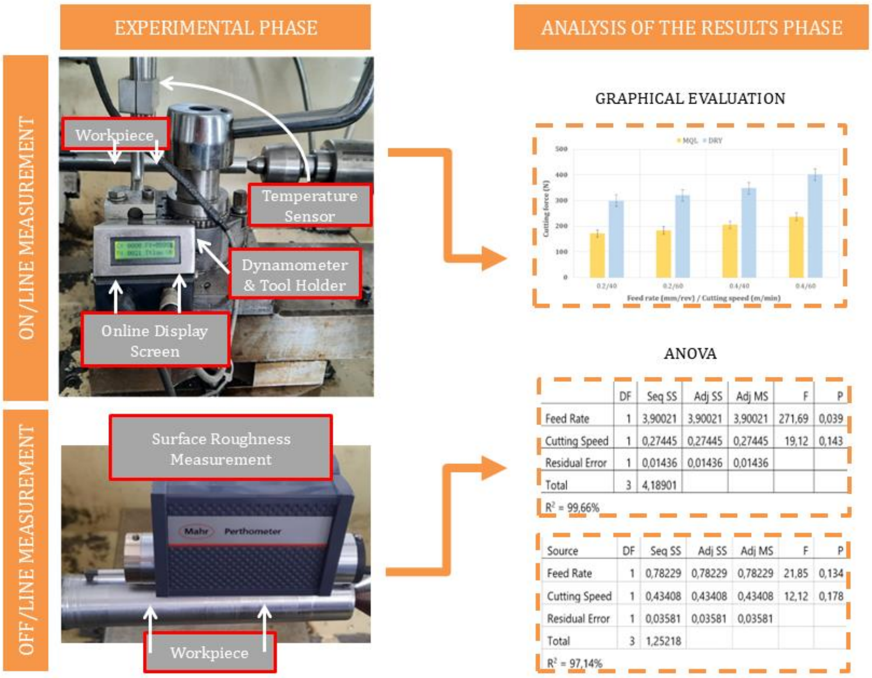

Figure 1. Experimental setup scheme (Deneysel altyapı şeması)

3. RESULTS AND DISCUSSIONS (SONUÇLAR VE TARTIŞMALAR)

To ascertain the impact of machining variables on the cutting process, an in-depth analysis of the machining outputs is essential. Consequently, the cutting force, tool wear, chip morphologies and tool tip temperature, and will be presented in this section through the utilization of graphic and visual materials. Experimental results given Table 4. The provided values will be statistically evaluated using ANOVA analysis.

Table 4. Experimental results (Deney sonuçları)

	Exp. Nu.	Feed Rate	Cutting Speed	Raort	Fc	T
MQL	1	0.2	40	2.1	172	358
	2	0.2	60	2.2	184	362
	3	0.4	40	2.6	206	365
	4	0.4	60	2.8	237	443
	Exp. Nu.	**Feed Rate**	**Cutting Speed**	**Raort**	**Fc**	**T**
DRY	5	0.2	40	3.6	299	370
	6	0.2	60	3.8	321	434
	7	0.4	40	3.9	349	371
	8	0.4	60	4.3	402	447

3.1. Surface Roughness Analysis (Yüzey Pürüzlülüğü Analizi)

Surface roughness plays a crucial role in machining processes, as it influences the characteristics and quality of the final product [24]. Heat treatment, machining parameters, and cutting environment can control surface roughness to some extent. However, low-carbon steels are not heat-treated. The difficulty of chip removal during machining has a considerable influence on surface quality on surface quality and other machining performance [25]. Clearly, the interaction between cutting speed and feed rate significantly affects surface roughness in both dry cutting and MQL conditions, as illustrated in Figure 2. In both cutting environments, a smoother surface finish is achieved at reduced cutting speeds. The results obtained are consistent with the literature. [26-28] By increasing the feed, surface roughness increased significantly. The average Ra roughness values obtained ranged from 2.1 ηm to 4.3 ηm. Optimum surface roughness was obtained in an MQL cutting environment at a low feed and a low cutting speed condition. When machining under both MQL and dry environments, the change in surface roughness value was around the average value. It is thought that the formation of irregular deep serrations in the chip form and the accumulation of chips on the tool will assist the alteration of surface roughness in the dry environment. When utilizing high cutting speeds and feed rates in dry cutting, surface quality was found to be inadequate Comparing dry and MQL machining environments, a significant variation in surface roughness was noted, declining from 2.1 ηm to 3.6 ηm with the least cutting parameters.

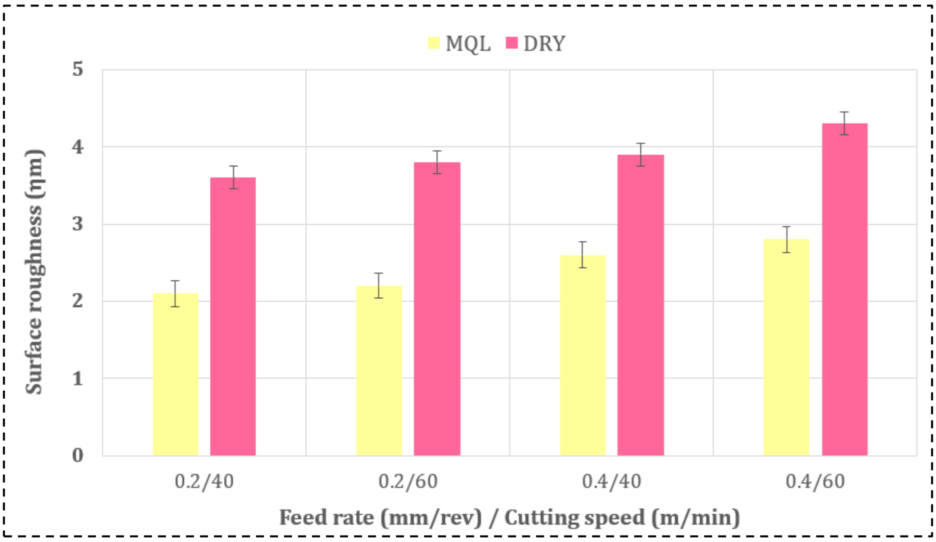

Figure 2. Surface roughness results according to different environments

3.2. Cutting Force Analysis (Kesme Kuvveti Analizi)

Cutting force is an important indicator when considering machinability studies about power consumption. Mild steels are generally considered easily machinable metals due to their high melting temperature values. However, in low-carbon mild steels, the lack of hardening by heat treatment can cause deformation due to the ductility of the metal during machining and can result in high power consumption and increased temperatures [29]. The average cutting forces in a dry cutting environment are in the range of 299-402 N as seen in Figure 3. However, it decreased linearly to 172-237 N as the cutting speed and feed rate were raised in MQL environments. A significant cause of the increase in cutting force is that the material becomes more ductile at elevated cutting speeds as a result of the increased feed. The ribbon type of long chips obtained here is very different from the others in terms of its shape. This sudden increase in cutting force at a high feed is clearly related to the accumulated chip formation in the dry environment. In dry machining, the cutting force increases as the feed increases. The optimum cutting force was observed under machining under MQL conditions with reduced feed and cutting speeds. There is a difference of about 2.33 times between the highest measured cutting force and the minimum value, which is a very significant change. These findings are consistent with the findings presented in previous studies [30-32].

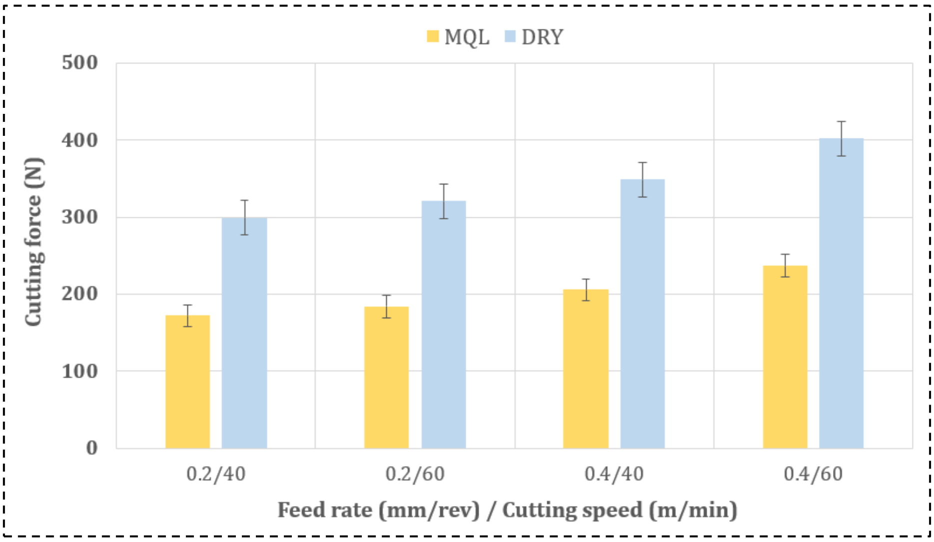

Figure 3. Cutting force results according to different environments (Farklı ortamlara göre kesme kuvveti sonuçları)

3.3. Cutting Temperature Analysis (Kesme Sıcaklığı Analizi)

Tool tip temperature is used as a method of determining the quality and efficiency of machining operations [27]. Cutting temperatures reach up to approximately 447 °C, as represented in the Figure 4. The tool tip temperature, which under a range of 358-443 °C in the MQL condition, while in a dry cutting environment, it rises to over 370-447 °C. As evident in Figure 4, the relatively low temperatures in the MQL environment ensure that the cutting fluid in the cutting area, particularly at the tool/workpiece interface, dissipates heat well and allows the chips to move away from the environment. Under identical conditions, temperatures are reduced at lower cutting speeds. The combination of increased cutting speed and feed rate also results in a rise in temperature during machining under all types of conditions. In earlier concerning the machining of diverse steel materials, higher cutting speeds and feed were shown to raise the cutting temperature, which helps explain the results observed in these experiments. [33-35]

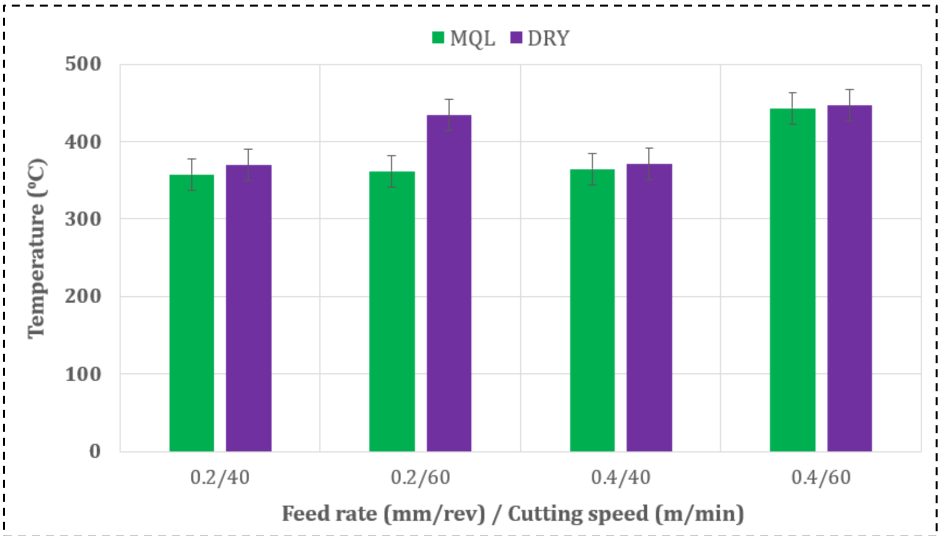

Figure 4. Cutting temperature results for different environments (Farklı ortamlara için kesme sıcaklığı sonuçları)

3.4. Statistical ANOVA Evaluation (İstatistiksel ANOVA Değerlendirmesi)

To analyze the impact of feed rate, cutting speed, and machining environments on surface roughness, cutting force, and cutting temperature, a statistical method known as variance analysis was applied. The F values seen in the tables are accepted as the control factor with the largest value [36-38].

3.4.1. Statistical ANOVA evaluation for surface roughness

When examining Table 5, it is observed that feed emerges as the primary factor affecting surface roughness in the MQL environment. The feed as the effect ratio is 93.1% and the cutting speed is 6.55%. The R^2 value of 99.66% reflects the high reliability of the experiments. Feed is the major determinant of surface roughness. This is anticipated since it is widely understood that the theoretical surface roughness is largely dependent on the feed rate for a specific nose radius and is associated with the square of the feed. [39, 40].

Table 5. The statistical impact of parameters on surface roughness in an MQL environment

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC (%)
Feed Rate	1	3.90021	3.90021	3.90021	271.69	0.039	93.1
Cutting Speed	1	0.27445	0.27445	0.27445	19.12	0.143	6.55
Residual Error	1	0.01436	0.01436	0.01436			0.34
Total	3	4.18901					100
R^2 = 99.66%							

Table 6. The statistical impact of parameters on surface roughness in a dry environment

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC(%)
Feed Rate	1	0.78229	0.78229	0.78229	21.85	0.134	62.47
Cutting Speed	1	0.43408	0.43408	0.43408	12.12	0.178	34.66
Residual Error	1	0.03581	0.03581	0.03581			2.85
Total	3	1.25218					100
R^2 = 97.14%							

Table 6 presents the findings of the ANOVA analysis regarding the influence of cutting parameters on surface roughness in the experiment conducted under dry conditions. According to the table, similar to the MQL environment, the primary factor influencing surface roughness is the feed, accounting for 62.47%. The analysis yielded an R^2 value of 97.14%, demonstrating the accuracy of the experimental results.

3.4.2. Statistical ANOVA evaluation for cutting force

Table 7 shows the findings of the ANOVA analysis was conducted to identify the parameter with the most significant impact on cutting force in the study. According to the table, the feed rate emerges as the leading parameter impacting cutting force, comprising 77.4%. The feed increases the interface between the tool and the workpiece during the cutting process. This leads to an increase in cutting force, as the tool interacts with a greater volume of material. The more significant effect of feed on cutting force in comparison to cutting speed can be attributed to the direct connection between the feed parameter and the cutting area. The R^2 value obtained from the analysis was 96.31%. Therefore, this demonstrates the accuracy of the experimental results.

Table 7. The statistical impact of parameters on cutting force in an MQL environment

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC (%)
Feed Rate	1	1892.25	1892.25	1892.25	20.97	0.137	77.4
Cutting Speed	1	462.25	462.25	462.25	5.12	0.265	18.9
Residual Error	1	90.25	90.25	90.25			3.69
Total	3	2444.75					100
R^2 =96.31%							

Table 8 presents the ANOVA analysis results to determine the parameter with the greatest effect on cutting force in dry conditions. The table indicates that the feed rate is the most influential factor affecting cutting force. The feed rate had the greatest effect at 74.22%, followed by cutting speed at 23.22%. The high precision of the experiments is confirmed by an R^2 value of 97.45%.

Table 8. The statistical impact of parameters on cutting force in a dry environment

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC (%)
Feed Rate	1	2.71839	2.71839	2.71839	29.09	0.117	74.22
Cutting Speed	1	0.85072	0.85072	0.85072	9.11	0.204	23.22
Residual Error	1	0.09343	0.09343	0.09343			2.55
Total	3	3.66254					100
R^2 = 97.45							

3.4.3. Statistical ANOVA evaluation for cutting temperature

Table 9 provides the data from the ANOVA analysis regarding the significance of feed and cutting speed parameters on cutting temperature. As observed, the influence on cutting temperature is ranked as follows: feed at 39.41% and cutting speed at 33.75%. The findings of the research indicate that the influence of cutting parameters on temperature is relatively similar. The R^2 value was found to be an acceptable value of 73.17%.

Table 9. The statistical impact of parameters on cutting temperature in an MQL environment

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC (%)
Feed Rate	1	0.9236	0.9236	0.9236	1.47	0.439	39.41
Cutting Speed	1	0.7910	0.7910	0.7910	1.26	0.464	33.75
Residual Error	1	0.6286	0.6286	0.6286			26.82
Total	3	2.3432					100
R^2 = 73.17%							

Table 10 shows the ANOVA analysis results of the cutting parameters effects on cutting temperature in the experiments conducted in a dry environment. As shown in the table, when considering cutting temperature in a dry environment, the feed has very little influence. However, cutting speed has a substantial influence, contributing to 98.55% of the overall effect. Cutting speed is the primary factor that linearly increases the heat generated per unit time by elevating the friction force. In contrast, feed has an indirect influence on temperature by affecting the material flow into the cutting zone. As a result, cutting speed is determined to be the parameter that most significantly impacts cutting temperature. Achieving an R^2 value of 99.41% indicates that the accuracy of the experiments is very high.

Table 10. The statistical impact of parameters on cutting temperature in a dry environment

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC (%)
Feed Rate	1	0.01957	0.01957	0.01957	1.44	0.442	0.85
Cutting Speed	1	2.25665	2.25665	2.25665	166.40	0.049	98.55
Residual Error	1	0.01356	0.01356	0.01356			0.59
Total	3	2.28979					100
R^2 = 99.41							

4. CONCLUSIONS (SONUÇLAR)

The objective of this research was to examine the effects of cutting parameters on the turning properties of S235JR low-carbon steel in a sustainable cutting context. A series of experiments were carried out to examine two sustainable cutting conditions, which include MQL and dry cutting environments, concerning the following performance characteristics: surface quality, cutting force, tool tip temperature, chip morphology, and tool wear. It has been observed that the dry environment used in turning the S235JR shows superior cutting performance in terms of power consumption. While the manganese and low carbon alloying ratios in the chemical composition of S235JR provide ductility to the material, it also increases the melting temperatures. In addition, due to its low carbon content, S235JR cannot be hardened by heat treatment.

- The optimum surface roughness value has been obtained by using high feed rates and cutting speeds in a dry environment. High feed and cutting speeds can lead to effective chip evacuation and minimized tool-workpiece contact time. This may result in smoother surface finishes.
- Since the effectiveness of the cooling is crucial for prolonging the contact time at low feed rates, higher surface quality was obtained when machining in the MQL environment.
- Reduced cutting forces and temperatures were observed in MQL and dry environments without looking at the cutting parameters. However, with the increase of the material removal, the levels of the temperatures and forces showed an increasing trend.
- The optimal range for the S235JR steel was seen as lower cutting parameters and MQL environment which supports the literature information.
- The cutting forces decreased by 41.72%, The cutting temperature was lowered by 5.79% and surface roughness improved by 37.82% in the MQL environment compared to dry machining.

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