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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 main challenges in turning are the quality of the machined part and the cost of 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. The aim of this study is to determine the optimum machining conditions for S235JR low carbon steel without heat treatment, which could include finding the right combination of cutting speed, feed rate, depth of cut and tool material to achieve efficient material removal and 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 cutting environment conditions. Results of this study showed that mist lubricating technique overcome the machinability challenges of S235JR steel in terms of low surface quality and high cutting temperature and cutting force.

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

MAKALE BİLGİSİ

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Yüzey pürüzlülüğü

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 kalitesini elde etmek için kesme hızı, ilerleme 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.

1. INTRODUCTION (GİRİŞ)

Steels with a carbon content of up to 0.20% are classified as low carbon steels. They are alloys of iron and carbon and contain small amounts of elements from the steel-making process such as 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 mainly in flat products and the construction industry and basic structures are in the low-carbon steel class. All the properties of carbon steels are directly related to their structure, which depends on the amount of carbon they contain. As the carbon content increases, the hardness, yield strength, and tensile strength of steels increase, while the ductility (% elongation and % reduction in area) and impact properties decrease. Since low-carbon steel cannot be strengthened by heat treatment, it is suitable

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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 similar 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 tool, workpiece, chip, and environmental conditions 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]. For this reason, alternative lubrication methods have attracted the attention of researchers in recent years [7-9]. In the development of sustainable manufacturing processes, machinability studies in dry, minimum quantity lubrication (MQL) and cryogenic cutting environments play a crucial role. During machining, a considerable amount 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 tool/chip interface, especially in dry machining. This leads to high wear rates and heat generation, resulting in high tool wear and surface roughness [10]. MQL is a lubrication method where a mixture of pulverised compressed air and a small amount of coolant is sprayed onto the cutting zone [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 cutting zone or on the cutting tool with an average lubrication rate of 5-500ml/h [12]. Furthermore, the vegetable oil used with the MQL process further enhanced these benefits, giving chip removal results similar to flood cooling techniques [13]. There are many studies in the existing literature examining the machinability of steels in different cutting environments [14-16]. Stanford et al. [17] studied the effect of the cutting environment on tool life when machining En32b low-carbon steel. By significantly improving tool wear, cryogenic cutting environments present an important alternative to traditional cutting environments. The chips collected from flood coolant tests demonstrate the superior qualities of this cooling lubrication system. However, the wear on the tool, particularly the flank wear mechanism, is linked to the chemical properties of the wet cutting environment. Yap et al. [18] investigated the effect of different cooling conditions on machining performance such as surface roughness and cutting force 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 quality of the steel. The best surface roughness value was achieved through low-speed machining in a dry environment. The relationship between tool wear and the cutting environment when turning low-carbon EN32 steel was investigated by Stanford and Lister [19]. In experiments with different cutting tools for turning low-carbon EN32 steel, they found a significant reduction in flank wear rates. They found that the dry-cutting environment of compressed air reduced the life of the tools. Hybrid turning processes [20]; it was found that applications such as ultrasonic [21] and laser-assisted [22] increased the machinability of low-carbon steels. It has also been observed that the surface roughness of low alloy steels is improved by the effect of the magnetic field [23].

This study focuses on 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 carried out 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 a very limited number of studies in the literature evaluating the machinability of S235JR steel in different cutting environments.

2. MATERIAL AND METHOD (MATERYAL VE YÖNTEM)

2.1. Experimental Setup (Deney Düzeneği)

In this study, S235JR mild steel, which is widely used in many manufacturing industries, was used as the workpiece. Table 1 shows the chemical composition by weight of the steel used. The full factorial approach to machining experiments was used to determine the depth of cut, cutting speeds, and feed rate. The full factorial approach for experimental design, used to evaluate and interpret the effects of factors, is considered to be an optimal approach because all possible combinations of different levels of factors are evaluated [24]. 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 required increases rapidly. Therefore, a total of 8 experiments were carried out on the part. A simple systematic design was used, which allowed the estimation of main effects and interactions. The first step in the experimental design was to determine the cut-off factors that could influence the response. There are at least two levels for each factor, and the levels were chosen based on what was relevant and reasonable for the characteristics of this study. An experimental design including all possible combinations of levels for each factor was created once the factors and levels had been determined. The next step was to assign test points to each combination of factor levels so that there would be more than one factor in the experiment at any one time. In addition, the main effects and interactions were determined using the full factorial design method in this study.

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 cutting tool and tool holder were selected. Following ISO 3685 [25] a cemented carbide cutting tool of the CCMT 09T308-VM series was used. The workpiece and experimental setup are shown in Figure 1. The cutting tools were replaced after each test period. The parameters and levels used in the experimental studies are given in Table 2.

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. In the experimental study, the cutting temperature and cutting force were measured and recorded with a Telc InGaAs radiation sensor (Germany) at each cutting level. The surface roughness of the workpiece was evaluated using a portable perthometer (Mahr Co., Ltd., Göttingen, Germany). The Ra average surface roughness value was determined through three repetitions of roughness measurements with a 10mm tracing length.

The experiments of the S235 JR workpiece were conducted under MQL-supported and dry-cutting environment conditions. The processing states were optimized by the full factorial design method. The effects of three different cutting parameters (Table 2) and two environmental conditions (dry and MQL) were analysed. Mineral-based oil (olive oil) was applied by a spray mechanism, timed to the MQL process, and mounted at a distance of 20 mm 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°. In this study, which aims to minimize the environmental impact of the process by reducing the amount of oil and cooling water used, dry and MQL environments were evaluated separately. Inserts and chips were analysed using scanning electron microscopy (SEM) imaging to examine their microstructure after each cutting test. The results of the study demonstrated that the cutting forces, surface roughness, cutting temperatures, and chip morphologies were evaluated in the dry and MQL cutting environments. 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.

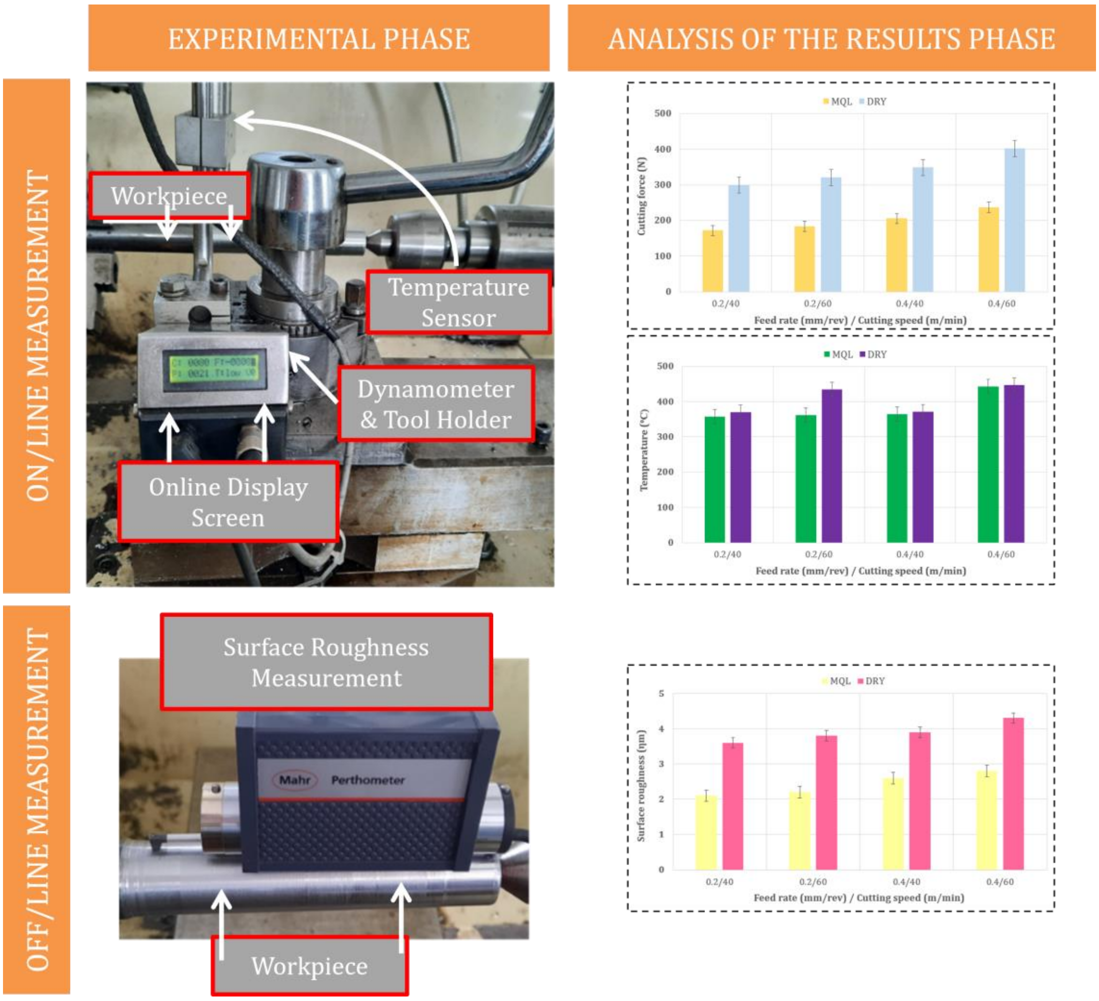

Figure 1. Experimental setup scheme (Deneysel altyapı şeması)

3. EXPERIMENT AND OPTIMIZATION RESULTS (DENEY VE OPTİMİZASYON SONUÇLARI)

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 tip temperature, tool wear, and chip morphologies will be presented in this section through the utilisation of graphic and visual materials.

3.1. Surface Roughness Analysis (Yüzey Pürüzlülüğü Analizi)

Surface roughness is a critical factor in machining operations because it affects the properties and quality of the finished product, [26]. 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 significant impact on surface quality and other machining performance [27]. It can be seen that the interaction of feed rate and cutting speed has a significant effect on surface roughness under dry and MQL environment conditions, as shown in Figure 2. In both cutting environments, lower surface roughness is obtained at lower cutting speeds. By increasing the feed rate, 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 rate 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 change in surface roughness in the dry environment. Poor surface quality was observed when dry machining using a combination of high cutting speed and high feed rate. Comparing dry and MQL machining conditions, a dramatic difference in surface roughness was observed, declining from 2.1 ηm to 3.6 ηm at the lowest cutting parameters.

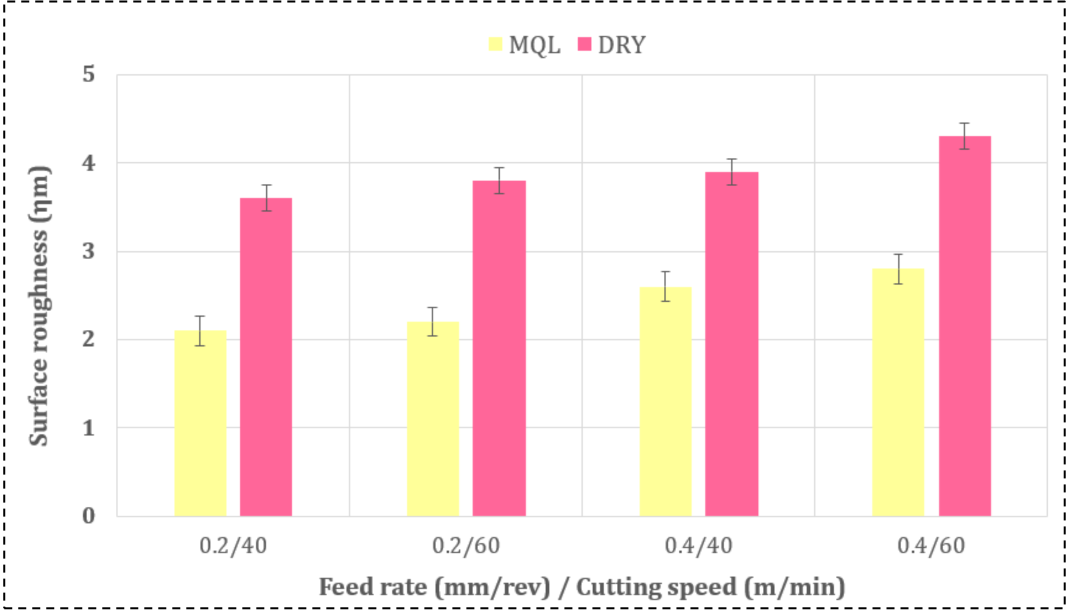

Figure 2. Surface roughness results according to different environments (Farklı ortamlara göre yüzey pürüzlülüğü sonuçları)

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 [28]. 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 feed rate and cutting speed increased under MQL cutting environment conditions. An important reason for the increase in cutting force is that the material becomes more ductile at a high cutting speed due to the increase in feed rate. 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 rate is clearly related to the accumulated chip formation in the dry environment. In dry machining, the cutting force increases as the feed rate increases. The optimum cutting force was observed under MQL machining conditions at a low feed rate and a low cutting speed. There is a difference of about 2.33 times between the highest value of the cutting force and the lowest value, which is a very significant change.

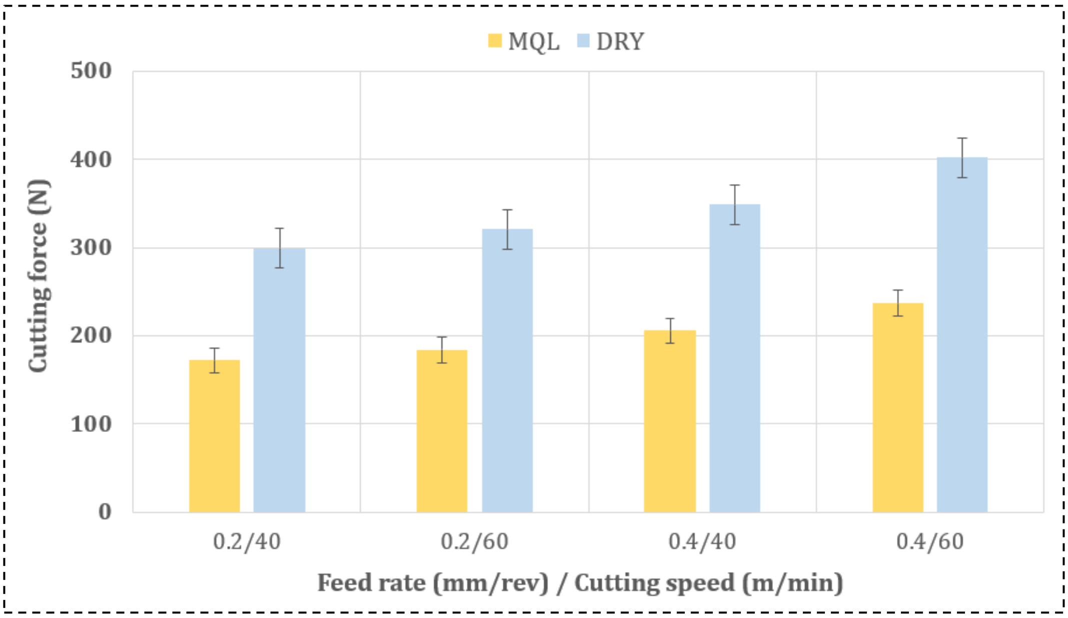

Figure 3. Cutting force results according to different environments (Farklı ortamlara göre kesme kuvveti sonuçları)

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 [29]. Cutting temperatures reach up to approximately 447 °C, as shown in Figure 4. The temperature of the tool tip, which under a range of 358-443 °C in the MQL environment, while in a dry environment, it rises to over 370-447 °C. As can be seen in Figure 4, the relatively low temperatures in the MQL environment ensure that the cutting fluid in the cutting zone, particularly at the tool/workpiece interface, dissipates heat well and allows the chips to move away from the environment. Under the same conditions, the temperature is lower at low cutting speeds. In addition, the parameters of high cutting speed and high feed rate are together responsible for the increase in temperature in machining under all environments.

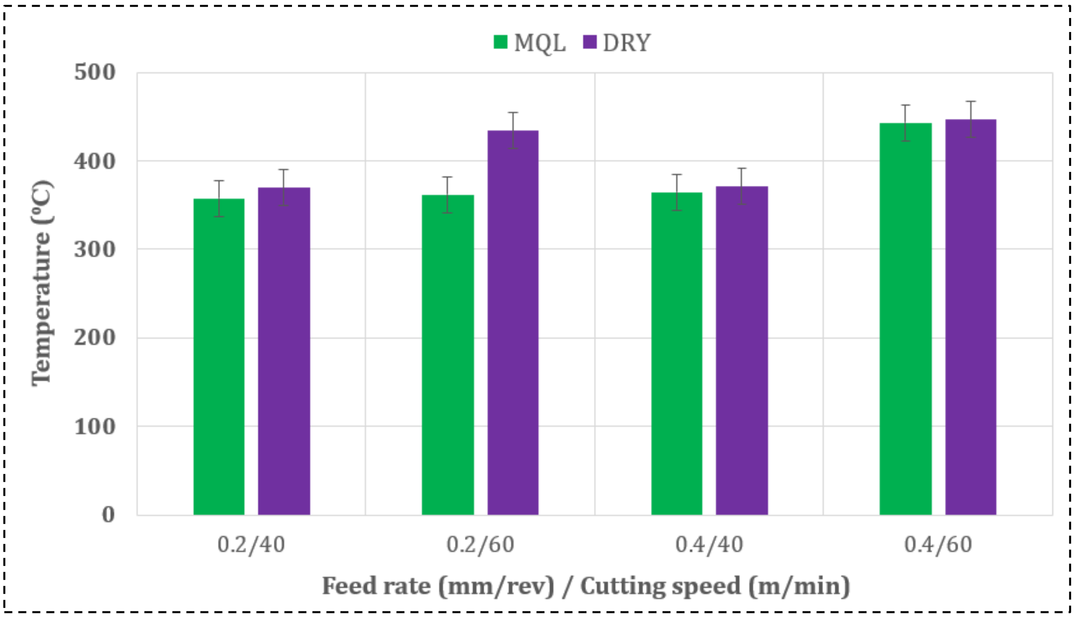

Figure 4. Cutting temperature results according to different environments (Farklı ortamlara göre kesme sıcaklığı sonuçları)

4. CONCLUSIONS (SONUÇLAR)

The purpose of this study was to investigate the effect of cutting parameters on the turning properties of S235JR low-carbon steel under a sustainable cutting environment. An experimental study was carried out to evaluate two sustainable cutting environments, including both MQL and dry conditions, concerning the following performance characteristics: surface quality, cutting force, tool tip temperature, chip morphology, and tool wear. It has been found that the dry-cutting 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 has been achieved by using high feed rates and high cutting speeds in a dry environment. High feed rates and cutting speeds can lead to efficient chip removal and reduced contact time between the tool and the workpiece. This may result in smoother surface finishes.
- Since the effectiveness of the cooling plays an important role by extending the contact time at low feed rates, higher surface quality was obtained when machining in the MQL environment.
- Low cutting forces and cutting temperatures were obtained under 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.

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