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Araştırma Makalesi / Research Article

Evaluation of the Turning Parameters of AISI 5115 Steel in Dry and MQL Cutting Environments with the Use of A Coated Carbide Cutting Insert: An Experimental Study

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ABSTRACT: This study investigates the effects of cutting parameters on turning AISI 5115 steel in both dry and MQL environments using a coated carbide insert. The cutting parameters are determined using a full factorial design. A comprehensive full factorial experimental design was executed in order to investigate the effect of cutting parameters, including cutting speed, feed rate, and depth of cut, on surface roughness, cutting force and cutting temperature. Following the completion of the turning trials, surface roughness measurements were meticulously recorded. Also cutting force and cutting temperature were measured. The results of the study indicated that the most significant influence on surface roughness is exerted by the feed rate. Moreover, the impact of the depth of cut became more significant as the cutting speed decreased. While the surface roughness increased by 23% in the dry environment due to the increased feed rate at low cutting speed, the increase in the MQL environment was 32%. The cutting temperature is influenced by a number of factors, including the cutting parameters and the material properties. The maximum temperature for turning in the MQL environment was 381°C compared with an average cutting temperature of 430°C in dry machining conditions. The application of high-speed cutting in a dry cutting environment was found to result in a 10% increase in cutting temperature. The influence of cutting speed on the outcome was less pronounced in the MQL environment. At high cutting speeds and low parameter values in the MQL environment, the cutting force decreased by 75% in contrast to the low cutting speeds and high cutting parameters in the dry environment. The optimal cutting conditions for minimising cutting force were identified in the MQL environment, characterised by high cutting speeds and low feed rates.

Keywords: 5115 steel, Turning, Dry cutting, MQL, ANOVA

1. INTRODUCTION

In the field of manufacturing, the machinability of metals represents a fundamental aspect, influencing the overall efficiency and quality of machining processes (Kuntoglu, 2022).

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Machinability as a concept refers to how easily a material can be machined using different cutting tools and techniques like milling, turning, drilling, or grinding (Binali, Coşkun, & Neşeli, 2022; Korkmaz & Günay, 2018). Case-hardened steels, are a special group of low-carbon steels for applications requiring a hard, wear-resistant surface with a tough, ductile core. A surface treatment process known as carburisation or cementation achieves this unique combination of properties. The case-hardened steel AISI 5115, also called 16MnCr5, is a low alloy steel. Due to its specific properties and suitability for certain processes, it is widely used in various mechanical components and applications. AISI 5115 is considered a medium strength/toughness steel. Its structure, with a hard outer surface and a softer inner core, enables it to absorb impact. AISI 5115 is used economically in a wide variety of mechanical components such as pulleys, gears, shafts, machine parts, piston rods, washers, chain links, sprockets, extrusions, roller bearings and where shock absorption is required(Selçuk, Ipek, & Karamış, 2003). Conventional surface treatments such as carburisation and nitriding or induction hardening are widely used in 5115 steels for these applications(Selçuk, Ipek, Karamiş, & Kuzucu, 2000). Cementation is a surface hardening process that introduces carbon into the steel surface to form a hard outer layer. Nitriding improves hardness and wear resistance by introducing nitrogen into the surface(Lampman, 1991). This surface provides wear resistance and durability, while the softer core absorbs shocks and impacts, reducing the risk of fracture or failure. AISI 5115 has good mechanical properties including moderate strength and toughness. This makes it suitable for moderate-to-heavy loaded and dynamic stressed components. This grade of steel is generally used for elements where a core tensile strength of 800-1100 Nmm^{-2} is required and a good load bearing capacity is required(Monkova et al., 2019). As well as its importance in industrial applications, the machinability properties of AISI 5115 steel are remarkable due to the material's chemical properties, hardness distribution and surface properties. To increase the machinability of hardened metals, modern cooling techniques that are less harmful to the environment and human health have been the subject of much recent research(Binali, Demirpolat, Kuntoğlu, & Sağlam, 2023; Binali, Demirpolat, Kuntoğlu, & Salur, 2023; Mahapatra, Das, Jena, & Das, 2023). While flood lubrication undoubtedly improves surface quality and tool life, it has a negative impact on human health and the environment due to the use of harmful chemicals (Aslan, Salur, & Kuntoğlu, 2022). Production costs are also significantly increased by the flood lubrication system(Ghosh & Rao, 2015). Cryogenic cooling is becoming increasingly important as an environmentally friendly and sustainable alternative to the use of liquid-based mineral/synthetic cutting fluids in metal cutting(Mia, Gupta, Singh, Królczyk, & Pimenov, 2018). Nano-fluid-based processing methods, which are less harmful to the environment, are also being considered to improve processing performance by creating a film layer on the surface by improving the heat transfer properties of the fluid (Ben Said, Kolsi, Ghachem, Almeshaal, & Maatki, 2023). The use of CNC nano powders was found to improve the machinability of high-strength structural steel with effective lubrication and cooling by Usca (Usca, 2023). Although dry machining is a traditional method of machining without the use of hazardous cutting fluids, it is also a preferred method in modern production systems (Asiltürk, Kuntoğlu, Binali, Akkuş, & Salur, 2023). However, because of very high temperatures during machining on tool wear and surface quality, minimum quantity lubrication (MQL) is accepted as an alternative to the dry environment in sustainable machining (Makhesana & Patel, 2022; Ross et al., 2022; Sen, Mia, Krolczyk, Mandal, & Mondal, 2021).. The efficiency of MQL in machining operations has been investigated in many studies in recent years. They include several studies using different optimization techniques. Response surface methodology and Taguchi's signal-to-noise (S/N) ratio are two prominent methods often used for parameter optimisation. Recently, the Taguchi method has emerged as the most widely referenced approach (Salur, Kuntoğlu, Aslan, & Pimenov, 2021). Mia et al. (Mia, 2018) investigated several sustainability issues in machining by looking at cutting energy, surface finish and using MQL. This study focuses on the mathematic modelling of specific cutting energies (Esp) and average roughness (Ra) during end milling of hardened AISI 4140 steel by MQL. Amini et al. (Amini, Khakbaz, & Barani, 2015) studied tool wear when turning AISI 4142 alloy steel in the MQL cutting environment and found that tool life was significantly extended compared to dry machining. Sampaio et al. (Sampaio, Machado, Laurindo, Torres, & Amorim, 2018) evaluated the MQL lubrication in turning SAE 1045. They found that cutting in an MQL environment not only required lower cutting forces at lower wear rates, but also reduced white film formation.

The cutting conditions and the condition of the tool are directly related to the cutting force during machining. The interaction between the geometry of the cutting tool and the depth of cut has a direct effect on the dominant cutting force (Mikolajczyk, Paczkowski, Kuntoglu, Patange, & Binali, 2022; Yallese, Chaoui, Zeghib, Boulanouar, & Rigal, 2009). Mondal et al. (Mondal, Das, Mandal, & Sarkar, 2016) evaluated different cutting tool tip options to determine the effect of cutting speed and feed on turning of hardened 16MnCrS5. When compared to dry machining, TiC coated flat and wide channel carbide inserts have shown superior performance in wet conditions at high cutting speeds. Grzesik et al. (Grzesik, Denkena, Żak, Grove, & Bergmann, 2016)investigated the power consumption in turning of AISI 5115 steel with CBN tools at different cutting parameters. At low undeformed chip thickness values, power consumption was also low at low cutting parameters, while at higher cutting parameter values it was in the characteristic high undeformed chip thickness carbon steel machining range. Agarwal et al.(Agarwal et al., 2022) studied the variation of the surface roughness as a function of the cutting parameters in the CNC turning of 16MnCr5 steel materials. Analysis of variance with orthogonal array, signal-to-noise ratio and ANOVA were used in experimental studies using the Taguchi method. Feed rate was the most important parameter in changing surface roughness. However, higher MRR values were obtained with depth of cut.

The objective of this study is to investigate the turning machinability of AISI 5115 steel using experimental methods. The experiments were designed using a full factorial approach. In particular, the effects of cutting parameters such as: cutting speed, feed, depth of cut on surface finish, cutting temperature and cutting forces during turning are evaluated. Understanding AISI 5115's machinability will provide valuable information to help optimise machining processes and increase productivity in manufacturing environments.

2. MATERIALS AND METHODS

2.1 Experimental Design

A sample of hardened AISI 5115 steel with dimensions of 50 mm in diameter and 400 mm in length, the chemical composition of which is given in Table 1, was used in the turning experiment. The experimental setup consisted of a universal lathe (De Lorenzo S547-8899), AISI 5115 workpiece, TiN coated carbide cutting tool (CCMT-09T308-304), perthometer (Mahr), InGaAs (Telc) radiation sensors seen in Figure 1. TiN coated carbide inserts inscribed circle diameter is 9.525mm and corner radius 0.8mm. Turning tests were performed according to ISO 3685, with tool changes after each dry and MQL cutting environment trial period. The STN 15 MQL system was used at 6 bar pressure with a 45° nozzle angle. Vegetable based lubricating oil was sprayed on the cutting zone from 20 mm. A full factorial design of experiments was used for two levels of 3 factors each as well as for two conditions of the cutting environment as given in Table 2. In total, 16 cutting experiments were performed. Recommendations from industry representatives and tool manufacturers, as well as the results of our previous experimental studies, were used in the determination of the cutting parameters. The cutting parameters were limited to two levels to simplify the experimental design and focus on the most important factors affecting the cutting process. A more manageable number of experiments, essential for maintaining precision and control over the variables, was achieved by limiting the levels. This allows a clearer understanding of how each parameter affects the results obtained. Limiting the parameters to two levels also helps to reduce the complexity and resources required for the study. Previous research and preliminary experiments suggested that these two levels would provide sufficient variation to observe meaningful differences in outcomes, and this limitation was also guided by this research. Surface roughness values were determined by taking the arithmetic mean of 3 different roughness measurements taken from different parts of the cylindrical samples. The ISO 4288:1996 standard was applied in this experimental study to determine the rules and procedures for the evaluation of surface roughness. Ra, or arithmetic mean roughness, is a key parameter in the quantification of surface roughness. It represents the average absolute value of surface profile deviations from the mean line over a specified length. In essence, it measures the average variation in the height of the peaks and valleys of the surface relative to the mean line. Ra is the most used surface roughness parameter because it provides a simple and reliable indication of overall surface texture and smoothness.

Table 1. Chemical composition of workpiece

wt%	%C	%Si	%Mn	%Cr	%P	%Fe
AISI 5115 (sample)	0.16	0.40	1.20	1.10	0,02	Bal.

Orthogonal array, signal/noise (S/N) ratio and analysis of variance (ANOVA) were used to determine the effects and contributions of cutting speed, feed rate and depth of cut on the response variable turning of AISI 5115 operations. To determine the percentage contribution of the factors, statistical analysis was performed on the results of the full factorial experiment.

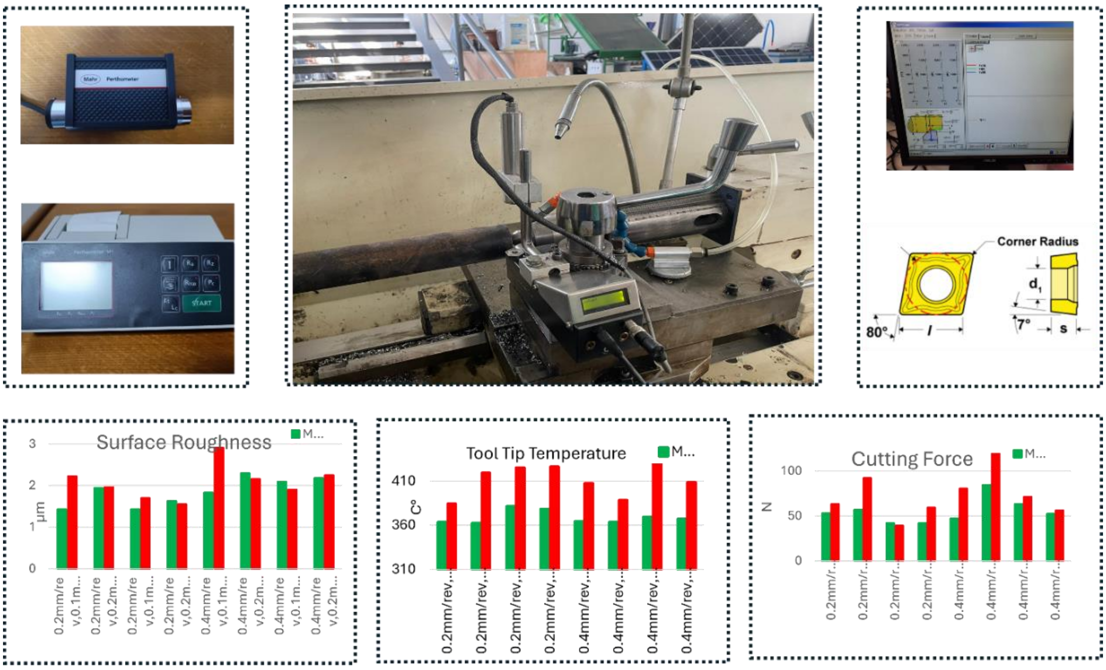


Figure 1. The experimental setup

Table 2. Parameters and levels of machining

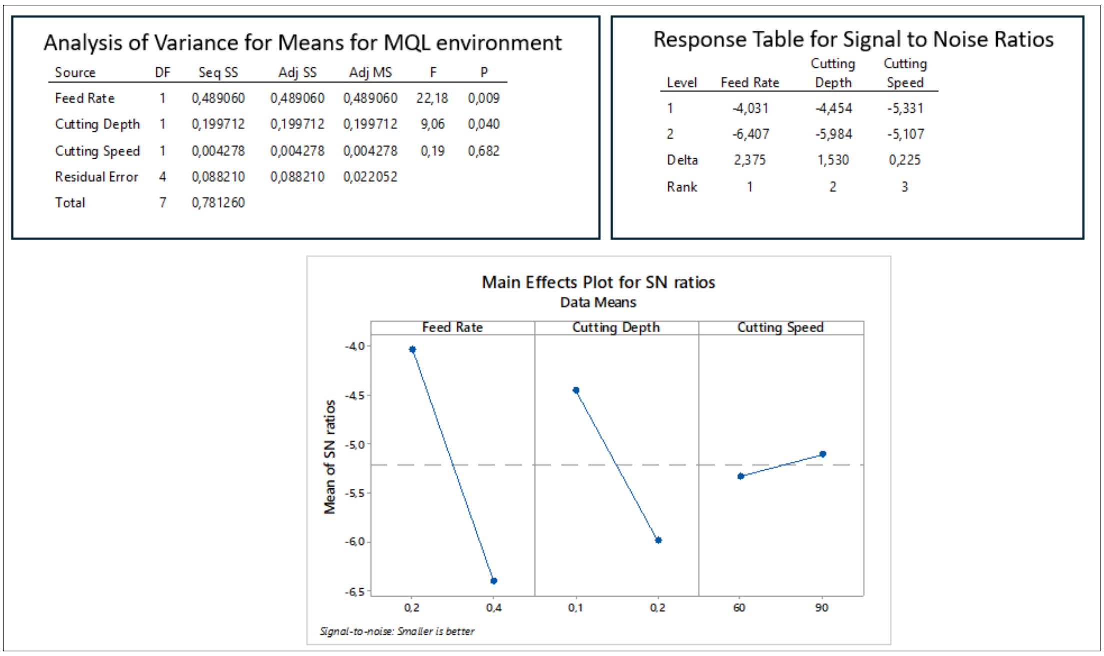
Factor	Level I	Level II
V	60	90
f	0.2	0.4
a	0.1	0.2
Environment	DRY	MQL

3. RESULTS AND DISCUSSION

This study evaluates the effects of machining parameters and cutting environment on surface roughness, cutting force and tool tip temperature of AISI 5115 steel.

3.1 Surface Roughness

This study utilises a one-way ANOVA to investigate the influence of distinct cutting parameters (namely feed rate, cutting depth, and cutting speed) on the response variable, which can reasonably be presumed to relate to a signal-to-noise ratio. It can be hypothesised that smaller values of this ratio are preferable. The experimental context is that of MQL given in Figure 2. It can be observed that the feed rate and depth of cut exert a considerable influence on the performance of the process (signal-to-noise ratio) in the MQL cutting environment. It is therefore recommended that lower values for both parameters be employed. Regarding cutting speed, it can be stated that this does not exert a significant effect on surface quality within the specified range of values.



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Analysis of Variance for Means for MQL environment
Source          DF  Seq SS    Adj SS    Adj MS    F      P
Feed Rate       1   0,489060  0,489060  0,489060  22,18  0,009
Cutting Depth   1   0,199712  0,199712  0,199712  9,06   0,040
Cutting Speed   1   0,004278  0,004278  0,004278  0,19   0,682
Residual Error  4   0,088210  0,088210  0,022052
Total           7   0,781260
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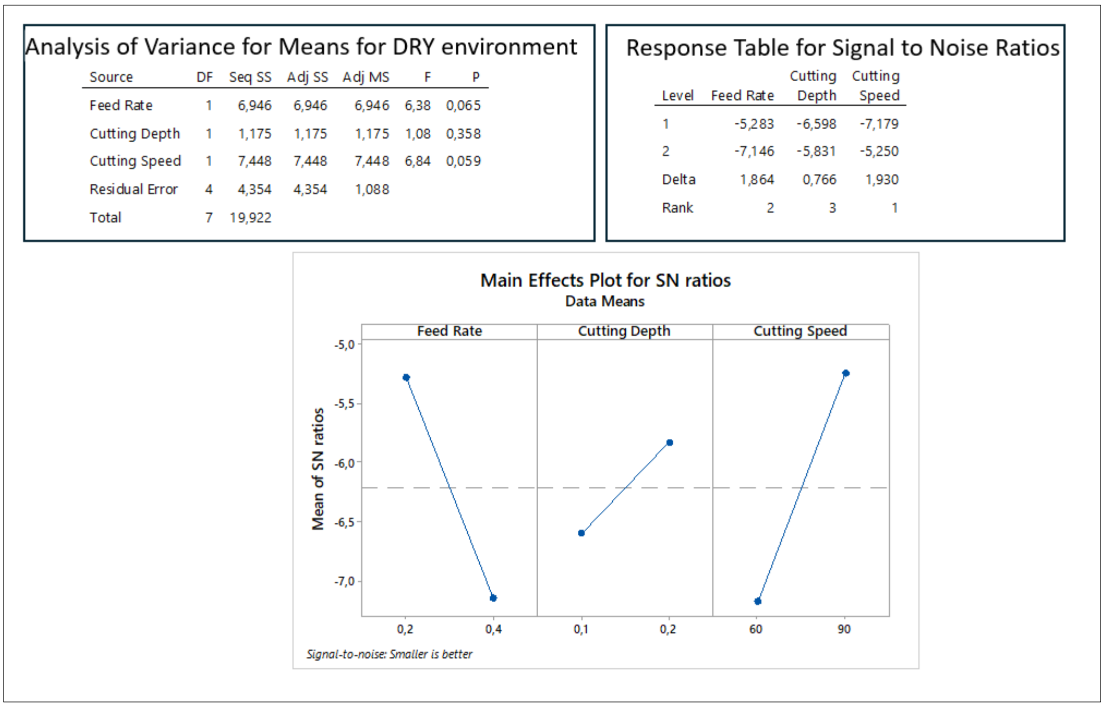
Response Table for Signal to Noise Ratios
                        Cutting  Cutting
Level   Feed Rate       Depth    Speed
1       -4,031          -4,454   -5,331
2       -6,407          -5,984   -5,107
Delta   2,375           1,530    0,225
Rank    1               2        3
```

Figure 2. Analysis of ANOVA (Surface Roughness under MQL cutting environment)

Under dry conditions, a trend toward significance can be identified in the results for the feed rate, though the observed values do not reach conventional levels of statistical significance, as determined by a p-value of less than 0.05 as seen in Figure 3. This indicates that the feed rate may exert some influence on the response (signal-to-noise ratio) in the dry cutting environment, although the effect is not definitive based on this analysis. Cutting speed also exhibits a tendency towards significance, although it fails to attain the conventional levels of statistical significance ($P < 0.05$). This implies that cutting speed might exert an influence on the response (signal-to-noise ratio) in the context of dry cutting, although further investigation or the inclusion of a larger range of cutting parameters may be necessary to confirm this effect. It was observed that the cutting depth had no significant effect on the response (signal-to-noise ratio) in the dry cutting environment. It is more probable that the observed variation in the response is due to random factors rather than the cutting depth parameter.

To ensure the quality of machined components, it is essential to achieve better surface quality. Surface roughness not only defines the topography of a workpiece, but also reflects changes in microstructure that have an impact on mechanical properties. The achievement of the required surface finish is the result of careful attention to several machining factors. Valuable information for optimising machining conditions can be obtained by analysing roughness profiles(Benardos & Vosniakos, 2003; Yurtkuran, Korkmaz, & Günay, 2016).



Analysis of Variance for Means for DRY environment

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	1	6,946	6,946	6,946	6,38	0,065
Cutting Depth	1	1,175	1,175	1,175	1,08	0,358
Cutting Speed	1	7,448	7,448	7,448	6,84	0,059
Residual Error	4	4,354	4,354	1,088		
Total	7	19,922				

Response Table for Signal to Noise Ratios

Level	Feed Rate	Cutting Depth	Cutting Speed
1	-5,283	-6,598	-7,179
2	-7,146	-5,831	-5,250
Delta	1,864	0,766	1,930
Rank	2	3	1

Figure 3. Analysis of ANOVA (Surface Roughness under DRY cutting environment)

A full factorial experimental design was implemented to investigate the effects of cutting parameters such as cutting speed, feed rate and depth of cut on surface roughness. Surface roughness measurements were recorded after turning trials. In this study, Ra was a key factor in modelling cutting conditions to optimise surface characteristics and the results were evaluated graphically to measure effectiveness. From the investigation it was found that the feed rate had the greatest effect on surface roughness. The effect of depth of cut became more pronounced and the surface quality of this combination decreased at low values of cutting speed. The poorest surface quality was observed in dry machining with a low cutting speed, high feed rate, and a low cutting depth value combination, as evidenced by the results. The lowest surface roughness values were observed when machining under MQL conditions, with the combination of high cutting speed and low feed rate exhibiting the greatest reduction in surface roughness. It can be observed that MQL cutting environment conditions offer a considerable benefit in terms of surface roughness when compared to dry conditions. MQL improves surface lubrication between the cutting tool and the workpiece, whereas the dry cutting environment is characterised by pronounced crests and troughs (E. Şap et al., 2024). It can be observed that MQL cutting environment conditions offer a considerable benefit in terms of surface roughness when compared to dry conditions.

The results of this study indicate that the feed rate and cutting speed may have an impact on the performance of the cutting process in a dry environment. When both high cutting speeds and low feed rates are used together, they have a synergistic effect to minimise surface roughness (Usca, Şap, Uzun, & Değirmenci, 2024). This suggests that further investigation or refinement of the experimental conditions may be necessary to gain a deeper understanding of the effects of these parameters.

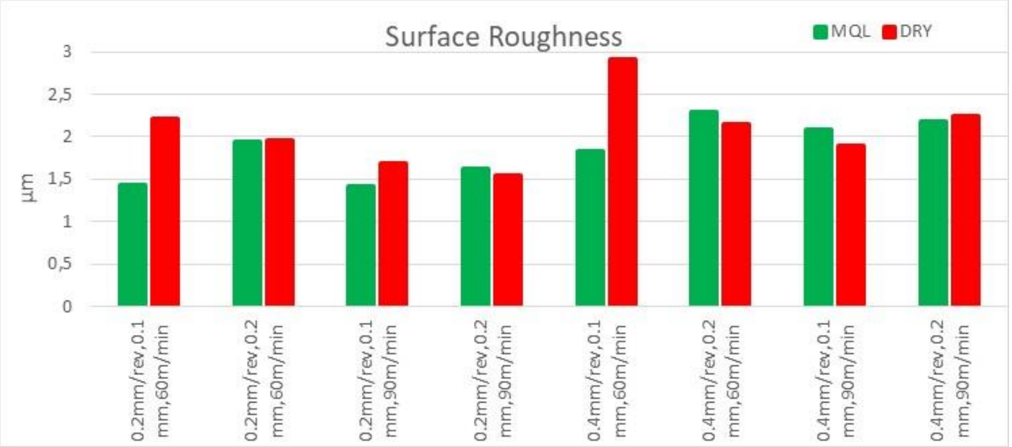
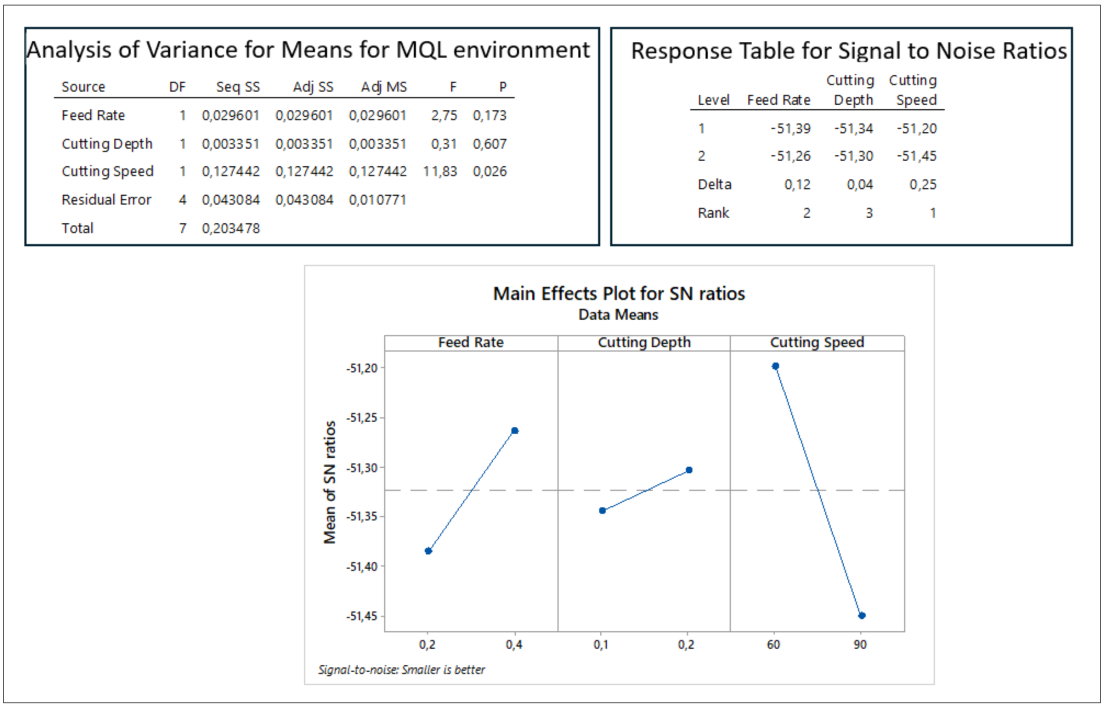


Figure 4. Surface Roughness variation with dry and lubri-cooling environment

3.2 Cutting Temperature

During machining, a significant amount of mechanical energy is converted into heat due to friction in the cutting zone, leading to inevitable temperature increases (Gupta et al., 2023; Mutlu, Binali, Demirsöz, & Yaşar, 2022). The specific heat capacity of the AISI 5115 steel, which is 452 J/kgK, and its thermal conductivity, which is 44 W/mK(Harichand & Sharma, 2012), play a decisive role in determining the temperature changes during the turning operation, especially when machining 16MnCr5(Agarwal et al., 2022). It's worth noting that cutting temperatures can rise to around 410°C as seen in Figure 7. This is close to the tempering threshold of AISI 5115. Cutting speed, as a primary parameter, strongly influences the temperature rise (S. Şap et al., 2024). In addition, in MQL environments, feed rate is closely correlated with temperature changes, affecting heat dissipation and machining efficiency. These factors highlight the complex relationship between cutting conditions, material properties and resulting temperatures in AISI 5115 machining. The process of dry machining, a traditional approach that is environmentally friendly in principle, nevertheless frequently encounters difficulties when it comes to controlling temperature during the cutting process, particularly in zones where chips are retained on the workpiece. While most of the thermal energy produced during machining is dissipated through the chips, the retention of certain chips on the surface of the workpiece remains a critical factor contributing to elevated temperatures. Furthermore, the specific heat capacity value and conduction effects, in conjunction with the retention of chips, contribute to an elevation of surface temperatures during the dry machining of AISI 5115 Steel.



Analysis of Variance for Means for MQL environment

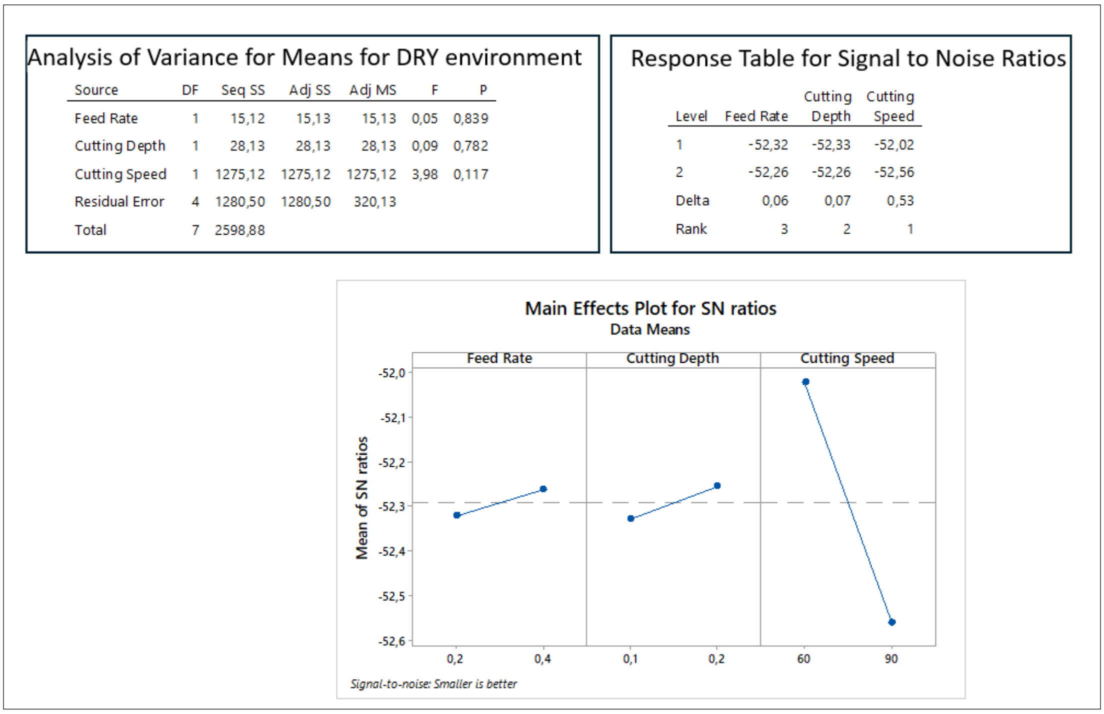
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	1	0,029601	0,029601	0,029601	2,75	0,173
Cutting Depth	1	0,003351	0,003351	0,003351	0,31	0,607
Cutting Speed	1	0,127442	0,127442	0,127442	11,83	0,026
Residual Error	4	0,043084	0,043084	0,010771		
Total	7	0,203478				

Response Table for Signal to Noise Ratios

Level	Feed Rate	Cutting Depth	Cutting Speed
1	-51,39	-51,34	-51,20
2	-51,26	-51,30	-51,45
Delta	0,12	0,04	0,25
Rank	2	3	1

Figure 5. Analysis of ANOVA (Cutting temperature under MQL cutting environment)

The cutting speed significantly influences the cutting temperature (signal-to-noise ratio) in the MQL cutting environment. Higher cutting speeds are associated with lower cutting temperatures, suggesting an improved performance given in Figure 5.



Analysis of Variance for Means for DRY environment

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	1	15,12	15,13	15,13	0,05	0,839
Cutting Depth	1	28,13	28,13	28,13	0,09	0,782
Cutting Speed	1	1275,12	1275,12	1275,12	3,98	0,117
Residual Error	4	1280,50	1280,50	320,13		
Total	7	2598,88				

Response Table for Signal to Noise Ratios

Level	Feed Rate	Cutting Depth	Cutting Speed
1	-52,32	-52,33	-52,02
2	-52,26	-52,26	-52,56
Delta	0,06	0,07	0,53
Rank	3	2	1

Figure 6. Analysis of ANOVA (Cutting temperature under DRY cutting environment)

It can be concluded that the feed rate has no significant effect on cutting temperature (signal-to-noise ratio) within the MQL cutting environment. Furthermore, changes in feed rate do not have a strong association with variations in cutting temperature. Additionally, cutting depth does not significantly influence cutting temperature within the MQL cutting environment. Therefore, it can be stated that variations in cutting depth do not have a meaningful contribution to changes in cutting temperature.

Cutting speed shows a trend towards significance but does not reach conventional levels of statistical significance ($P < 0.05$). This suggests that cutting speed may have a moderate influence on cutting temperature in the dry cutting environment, but further investigation or larger range of turning parameters may be needed to confirm this effect given in Figure 6. The results of the study indicated that the feed rate did not have a statistically significant effect on cutting temperature (signal-to-noise ratio) when the cutting was performed in a dry environment. It can be concluded that changes in feed rate are not associated with variations in cutting temperature. Similarly, cutting depth does not significantly influence cutting temperature in the dry cutting environment. It is not the case that variations in the cutting depth are meaningful contributors to changes in cutting temperature.

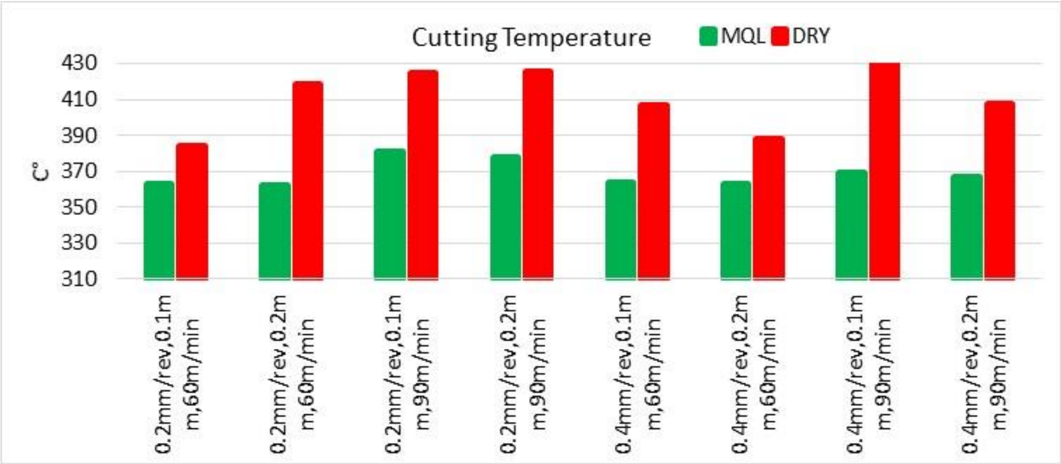


Figure 7. Cutting temperature variation with dry and lubri-cooling environment

3.3 Cutting Force

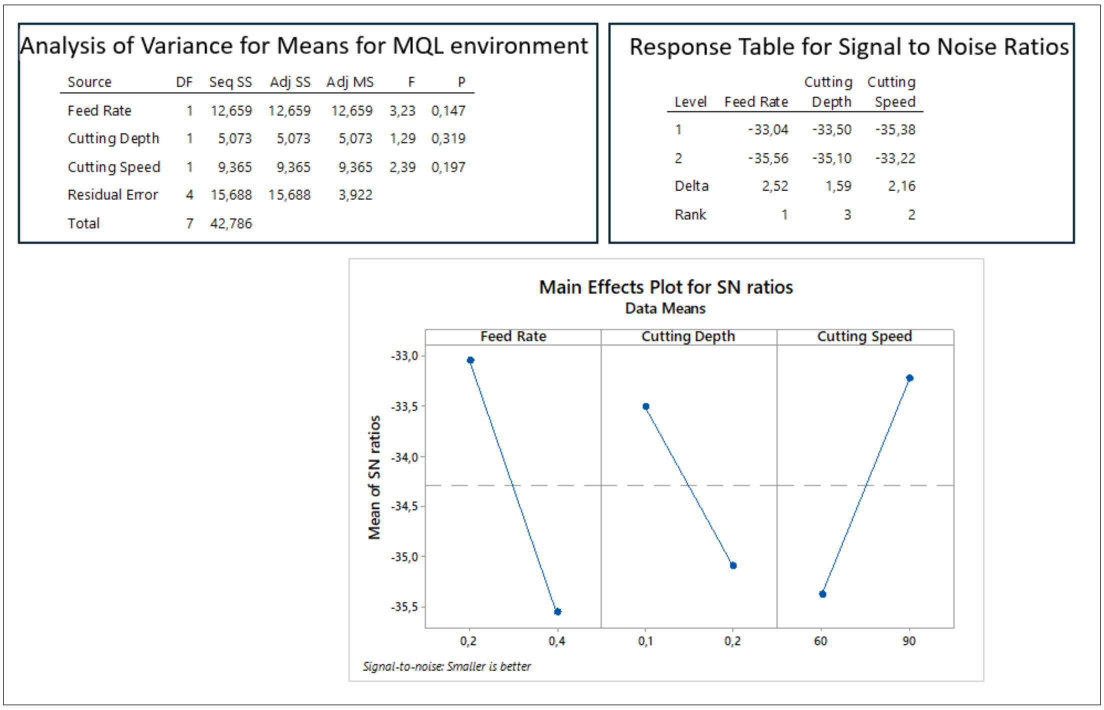
The AISI 5115 case hardening steel has moderate mechanical properties and strength, which results in a relatively low cutting force and power requirement during the machining process. The cutting force plays a critical role in determining the energy efficiency and the effectiveness of the machining process. The impact of extended cutting operations on sustainable manufacturing goals was investigated. It was found that machining accounts for a significant proportion of the energy consumed in manufacturing processes. Increased cutting force directly correlates with increased energy consumed (Pimenov et al., 2024).

In particular, the maximum cutting force occurs under conditions of low cutting speed and increased feed rate and depth of cut in dry machining environments (Binali, Patange, Kuntoğlu, Mikolajczyk, & Salur, 2022). This is illustrated in Figure 10. Among these factors, feed rate emerges as the primary driver for escalating cutting force. This observation implies that higher feed rates and deeper cutting depths create greater resistance during cutting, requiring increased force to remove material. To optimise machining parameters and minimise energy consumption when machining AISI

5115 steels, it is essential to understand these dynamics. It can be observed that at lower cutting parameters, both low cutting force and reduced power consumption are evident. However, under both conditions, cutting force increases significantly with higher feed rates. It is noteworthy that in dry machining environments, an increase in the depth of cut at lower cutting speeds led to a 32% rise in cutting force. Specifically, under dry machining conditions with low cutting speeds and increased cutting depths, the maximum cutting force reached a peak of 119 N.

Conversely, the lowest cutting force of 32 N was achieved in MQL environments with a combination of high cutting speeds, low feed rates, and shallow cutting depths. An increase of over 100% in cutting force was observed due to higher feed rates. These findings emphasise the pivotal role of optimising cutting parameters in reducing power consumption and achieving sustainable production goals.

The optimal cutting conditions for minimising cutting force in AISI 5115 steel were identified in the MQL environment with high cutting speeds and low feed rates. These findings emphasise the significance of selecting optimal cutting parameters to enhance efficiency and sustainability in machining processes.



Analysis of Variance for Means for MQL environment

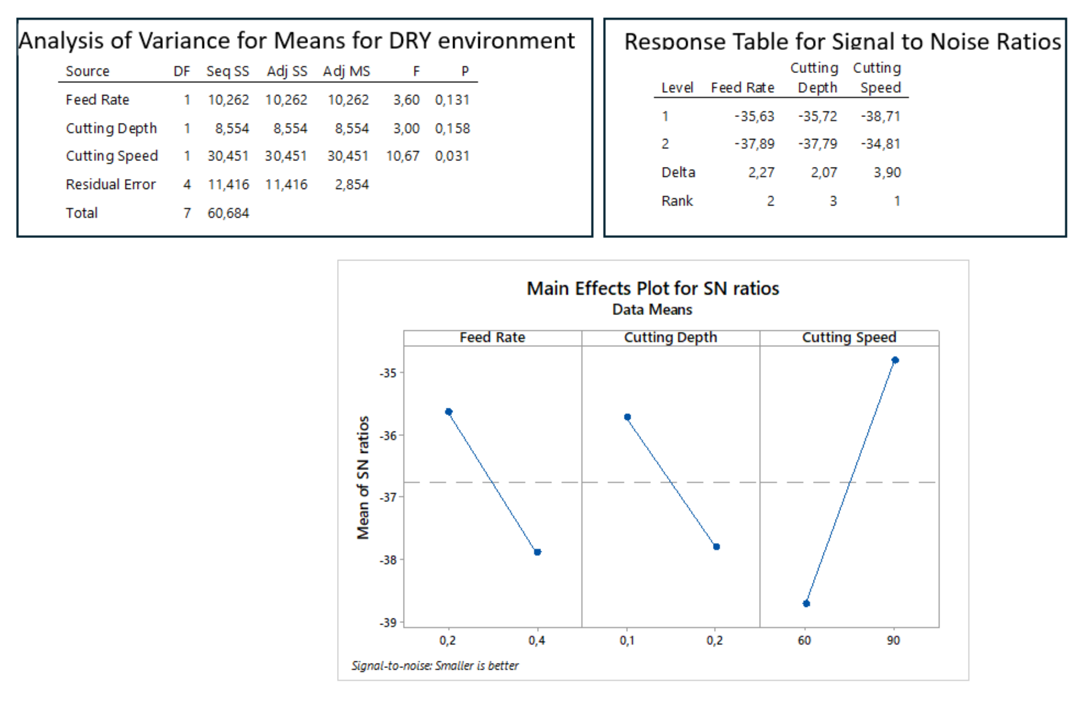
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	1	12,659	12,659	12,659	3,23	0,147
Cutting Depth	1	5,073	5,073	5,073	1,29	0,319
Cutting Speed	1	9,365	9,365	9,365	2,39	0,197
Residual Error	4	15,688	15,688	3,922		
Total	7	42,786				

Response Table for Signal to Noise Ratios

Level	Feed Rate	Cutting Depth	Cutting Speed
1	-33,04	-33,50	-35,38
2	-35,56	-35,10	-33,22
Delta	2,52	1,59	2,16
Rank	1	3	2

Figure 8. Analysis of ANOVA (Cutting force under MQL cutting environment)

The results of this study indicate that other factors or interactions may be more influential in determining cutting force in MQL cutting operations. It is not possible to observe the individual contributions of changes in cutting parameters to changes in cutting force in Figure 8. Nevertheless, it can be posited that the interactions between the parameters and tool wear mechanisms exert a significant influence on the cutting force. However, it was demonstrated that cutting speed exerts a statistically significant influence on cutting force in the dry cutting environment. A positive correlation exists between the cutting speed and the cutting force seen in Figure 9. It can be demonstrated that variations in cutting depth and feed rate do not contribute to meaningful changes in cutting force.



Analysis of Variance for Means for DRY environment

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	1	10,262	10,262	10,262	3,60	0,131
Cutting Depth	1	8,554	8,554	8,554	3,00	0,158
Cutting Speed	1	30,451	30,451	30,451	10,67	0,031
Residual Error	4	11,416	11,416	2,854		
Total	7	60,684				

Response Table for Signal to Noise Ratios

Level	Feed Rate	Cutting Depth	Cutting Speed
1	-35,63	-35,72	-38,71
2	-37,89	-37,79	-34,81
Delta	2,27	2,07	3,90
Rank	2	3	1

Figure 9. Analysis of ANOVA (Cutting force under DRY cutting environment)

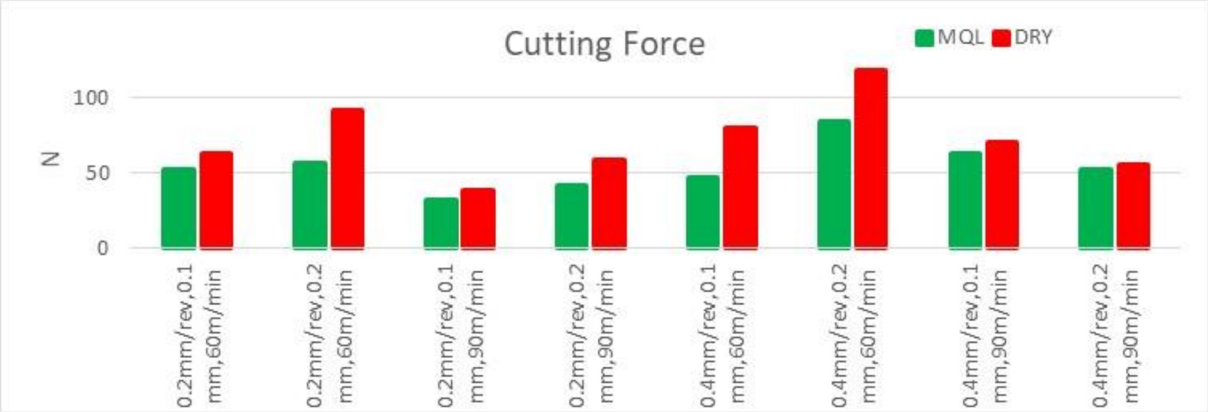


Figure 10. Cutting force variation with dry and lubri-cooling environment

4. CONCLUSION

Achievement of superior surface finishes on machinable components is essential to ensure optimum mechanical performance. This study has highlighted the intricate relationship between machining parameters, material properties and the resulting surface characteristics when machining AISI 5115 steels. A full factorial design was employed to investigate the effects of cutting speed, feed and depth of cut on surface roughness (Ra). The findings demonstrate the critical role of these parameters in optimising surface characteristics. The results demonstrated that feed rate had a profound impact on surface roughness, exhibiting the greatest influence among all the variables examined. Furthermore, the impact of depth of cut became more pronounced, particularly at lower cutting speeds.

In dry machining conditions, the surface roughness increased by 23% due to the higher feed rate at low cutting speeds, while in the MQL environment the increase was 32%. The increase in surface roughness resulting from machining in a dry environment under the same conditions was approximately 40%. Cutting temperature is influenced by several factors, including cutting parameters and material properties. In the MQL environment, the maximum cutting temperature reached 381°C, compared to an average of 430°C in dry machining conditions. Cutting speed is a primary factor influencing temperature rise, especially in MQL environments. Dry machining presents challenges for temperature control due to chip retention and material properties. Additionally, in the MQL environment, cutting forces decreased by 75% at high cutting speeds with low parameter values, in comparison to the high cutting forces observed at low cutting speeds and high parameter values in the dry environment. Dry machining poses a challenge for temperature control due to the retention of chips and the properties of the material.

During the turning operation of AISI 5115 steel, a substantial amount of mechanical energy is converted into heat due to friction in the cutting zone. The specific heat capacity (452 J/kg K) and thermal conductivity (44 W/m K) of AISI 5115 steel serve as key determinants of the resulting temperature changes. Cutting temperatures can reach levels close to the tempering threshold of AISI 5115, particularly under high cutting speeds. In Minimum Quantity Lubrication (MQL) environments, the feed rate exerts a pivotal influence on temperature fluctuations, influencing heat dissipation and machining efficacy. Furthermore, the moderate mechanical characteristics and resilience of the AISI 5115 steel result in relatively low cutting forces and power requirements throughout machining. However, extended cutting operations lead to augmented energy consumption, with cutting force escalating under conditions of low cutting speeds and elevated feed rates and depths of cut.

In order to optimize the parameters used during machining of AISI 5115 steels and to reduce energy consumption, it is crucial to consider the interactions between cutting conditions, material properties and the resulting surface quality. This research offers valuable insights into the optimization of machining processes, with the aim of improving surface finish and enhancing manufacturing efficiency.

Future research should investigate the specific interactions between cutting conditions and material properties, develop advanced predictive models for temperature and force outcomes, and explore sustainable machining practices. It will also be important to investigate the long-term effects of optimised parameters on tool wear and product durability.

5. CONFLICT OF INTEREST

Author(s) approves that to the best of their knowledge, there is not any conflict of interest or common interest with an institution/organization or a person that may affect the review process of the paper.

6. AUTHOR CONTRIBUTION

Havva DEMİRPOLAT has the full responsibility of the paper about determining the concept of the research, data collection, data analysis and interpretation of the results, preparation of the manuscript and critical analysis of the intellectual content with the final approval.

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