European Journal of Technique

journal homepage: https://dergipark.org.tr/en/pub/ejt

Vol.14, No.2, 2024

Research Article

Effect of Cutting Parameters in Turning of AISI 1015 Steel: Comparison of Dry and MQL Conditions

Bahar Sayin Kul[1*]

[1*]Selçuk University, Mechanical Engineering Department, Konya, Turkey. (e-mail: bsayin@selcuk.edu.tr).

ARTICLE INFO

Received: June, 05. 2024
Revised: July, 20. 2024
Accepted: July, 20. 2024

Keywords:
AISI 1015 Steel
Machinability
Turning
MQL

Corresponding author: *Bahar Sayın Kul*

ISSN: *2536-5010* | e-ISSN: *2536-5134*

DOI:https://doi.org/10.36222/ejt.1496244

ABSTRACT

This study is about turning AISI 1015 steel with coated carbide inserts in dry and MQL environments. In the experimental procedure built according to the full factorial experimental design, cutting parameters such as cutting speed (90,135 m/min), feed rate (0.2, 0.40 mm/rev) and cutting depth (0.1, 0.2 mm) on surface roughness, cutting force and cutting temperature were investigated. The experiments were carried out in two different environmental conditions, aiming to compare the machining performances in both environments and to determine the cutting parameters that make the biggest contribution to each output parameter. The main findings of the study are as follows: In turning operations performed under dry and MQL conditions, the worst surface quality (with surface roughness values of 2.509 µm and 2.114 µm respectively) was obtained at the lowest cutting speed, feed and depth of cut values. Increasing the cutting speed was manifested by the average 20.1% decrease in surface roughness for both environmental conditions. While cutting temperature and cutting force increased as the cutting speed increased at low feed rates, both decreased at high feed rates. Increasing the cutting depth caused an average 40% increase in cutting forces. Moreover, the surface roughness, cutting temperature, and cutting force data obtained under MQL conditions were on average 16.9%, 2%, and 29.8% lower than those obtained under dry conditions, respectively.

1. INTRODUCTION

The machinability is a multifaceted process that is affected by both the composition, microstructure and strength of the material being processed, and operational factors such as cutting speed, feed rate, cutting dept, cutting fluid and cutting tool material. Making the appropriate selection for operational factors is important to avoid consequences such as tool wear and/or breakage, workpiece deterioration, and the process resulting in a poor-quality surface [1-4].

In engineering processes, where the bar is raised with the development of technology, the term quality, which is reduced to surface quality when evaluating the processing of the material, continues to be a critical feature that cannot be compromised.

It is possible to talk about the simultaneous effect of many factors on roughness during processing. While this is the case subjecting different cutting parameters, material and cutting tool combinations, to experimental studies is a necessary procedure to better understand the parameters affecting surface roughness and optimize the process [5-7].

To date, various studies have been carried out on the machinability of many materials, one of which is steel, and academic outputs have been obtained [8-15] can be given as examples of machinability studies carried out in recent years and these examples can be multiplied. Within the scope of this paper, studies on AISI 1015 steel have been exemplified below and it has aimed to give readers an idea about the place of this material in the literature. Then, studies on the machinability of it were discussed in some more detail. Apay and Gulenc [16] have coated AISI 1015 steel with an alloy welding wire by micro laser, and microstructure of the samples was examined by being evaluated in terms of microhardness and wear tests, SEM and XRD analysis. Gnanamoorthy and Reddy [17] carried out a study on the plain and fretting fatigue of AISI 1015. The study, Makhatha, et al. [18] carried out, the variation on corrosion, hardness and wear properties of laser alloyed Al-Sn dual coatings on AISI 1015 steel were reported. Namdev, et al. [19] developed dual phase steel by inter-critical heat treatment followed by water quenching using AISI 1015 to analyze its mechanical properties such as tensile and hardness behavior and wear properties by comparing that of with other varieties of plain low carbon steel properties. During CNC turning of AISI 1015 steel with cathodic arc evaporation coated TiAlN/WC-C tungsten carbide cutting tool, cutting parameters, namely cutting depth, feed rate, spindle speed, cutting fluid flow rate and number of layers accumulated on the surface, on roughness and flank wear were examined in the study belongs to Moganapriya, et al. [20]. Gökkaya and Nalbant [21] have examined the variation in surface quality using four different cemented carbide cutting tools in the turning process of AISI 1015 steel. Experiments carried out for 5 different cutting speeds and 2 different feed rates, the most positive effect on surface roughness was obtained with 3-layer coated tool coated outermost with TiN. Increasing the cutting speed and keeping the feed rate low resulted in better surface quality. Sahu, et al. [22] investigated the effects of cutting parameters such as spindle speed, feed rate, cutting depth and air pressure on surface roughness, cutting temperature and metal removal rate during hard machining of AISI 1015 steel using carbide insert in dry and spray impact cooling environment. Moganapriya, et al. [23] evaluated coated carbide inserts for surface roughness and flank wear during turning of AISI 1015 steel and determined optimum levels of five parameters, for which three levels of each were tested. It was concluded that the most optimum combination was the speed of 500 rpm, cutting depth of 1 mm, the feed rate of 0.05 mm/rev, the cutting fluid flow rate at a high level, and the use of a TiAlN/WC-C coated insert.

The main motivation for the preparation of this study is that when the literature is examined, it is seen that studies on turning AISI 1015 steel are limited and there is no sufficient and satisfactory information about the material/process. This situation has revealed the need for a study investigating the effects of machining parameters on turning. Therefore, in the study carried out by turning AISI 1015 steel with a TiAl coated carbide insert under different cutting parameters/levels, it was aimed to investigate the effect of cutting speed, feed rate, cutting depth on the variation in cutting temperature, surface roughness and cutting force. Traditional machining processes, especially those conducted under dry conditions, can lead to high surface roughness, increased cutting forces, and elevated cutting temperatures. These factors not only affect the quality of the machined parts but also lead to increased tool wear and energy consumption. Although dry cutting conditions are considered the cheapest and cleanest process for chip removal, it is necessary to test more environmental methods, due to the difficulty of removing chip under these conditions and the difficulty of controlling the heat occurring during the process. The study aims to explore the potential benefits of using Minimum Quantity Lubrication (MQL) as an alternative to dry machining and to compare machining performances in both environments and identify cutting parameters that make greater contributions to each output parameter compared to others. At the same time, it aims to lay the foundation for future studies on the machinability of AISI 1015 and to contribute to the existing literature.

2. MATERIALS AND METHODS

In this study, AISI 1015 steel with a machining length of 100 mm and a diameter of 70 mm was used as the sample, while TiAl-coated carbide insert was preferred as the cutting edge. Chemical composition of it has presented in Table 1. The machining parameters in the form of cutting speed, feed rate and cutting depth, which were prepared according to the full factorial experimental design and each consisted of two different levels, are detailed in Table 2. Full factorial experimental design is an experimental method used to examine the effects of combinations of multiple factors (independent variables) and all possible levels (values) of each factor [24, 25]. The reason why this design method is preferred is that it ensures that the experimental results are more comprehensive and reliable since it includes all possible combinations. Machining parameters were selected by examining the studies in the existing literature and according to the hypothesis established in accordance with the purpose of the experiment, taking into account both material properties and the recommendations of the cutting tool company. The schematic view of the experimental setup, in which the entire experimental study was carried out and consisting of elements such as a universal lathe (De Lorenzo S547-8899), AISI 5115 workpiece, TiN coated carbide cutting tool, a type of cutting tool commonly used in high-performance machining applications (CCMT-09T308-304), perthometer (Mahr), InGaAs (Telc) radiation sensors, is presented in Figure 1. Following the experiments carried out under dry conditions, all were repeated in an MQL environment with the lubrication support of oil-based (olive oil) cutting fluid. In the experiments where measurements were repeated 3 times, temperature and force data were also taken. Statistical analysis was applied to see the contribution of the cutting parameters on each of the output factors, such that signal to noise ratio and variance analysis were used for evaluation.

TABLE 1.
CHEMICAL COMPOSITION OF AISI 1015 STEEL [19]

	% C	% Mn	% P	%S
wt.%	0.15	0.3-0.6	0.04	0.05

TABLE 2. Machining parameters for experiments.

Machining Parameters/Levels	Cutting speed (m/min)	Feed rate (mm/dev)
	90-135	0.2-0.4
	Cutting depth (mm)	Regime
	0.1-0.2	Dry-MQL

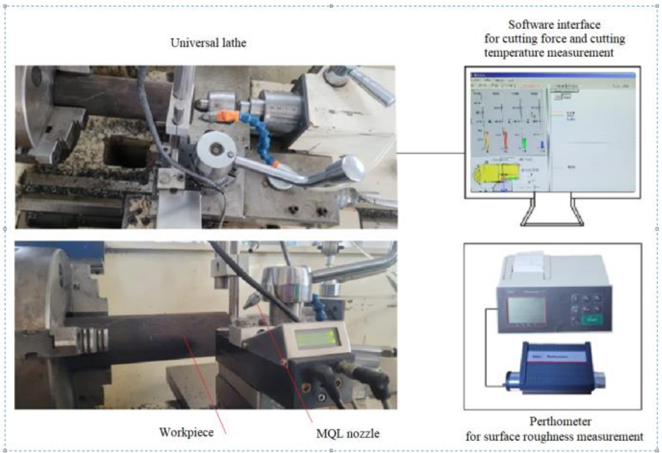

Figure 1. The schematic view of the experimental setup.

3. RESULTS AND DISCUSSION

This study provides an evaluation of the effects of both cutting parameters and cutting environment (regime) on the surface roughness, cutting force and cutting temperature of AISI 1015 steel. Below, the effects of cutting parameters on each output parameter are examined under separate headings.

3.1. Surface Roughness

As can be seen from figure 2, during the turning process performed both in dry conditions and in the MQL environment, the worst surface quality was obtained in the experimental conditions where the cutting speed, feed rate and cutting depth had the lowest values. In dry conditions, increasing the cutting speed at both cutting depth levels, both at low feed speed and high feed speed, resulted in a decrease in surface roughness. Namely higher cutting speeds (90 m/min) generally produce better surface roughness to lower speeds (60 m/min) under both dry and MQL conditions. The range where this decrease is more pronounced (with a difference of 0.785 (µm) is where the cutting speed increases from 90 to 135 for low feed rate and cutting dept. It is reported in the literature that cutting speed is an effective parameter on surface roughness and causes changes in the mechanical properties of the workpiece and chip formation [26-28]. It is possible to make similar evaluations in the case of MQL. This can be explained by the decrease in the hardness of the material with increasing cutting speeds [5]. For the same combination of cutting speed, feed rate and cutting depth, in terms of surface roughness, those obtained under dry conditions always had higher values than those obtained under MQL conditions. This difference varies between 6.1 % (for 90/04/02 experiment) and 31.5% for 135/04/02 experiment). Thus, it can be said that MQL cutting environment conditions are better in terms of surface roughness compared to dry conditions.

To sum up, regardless of the feed rate and cutting depth, increasing the cutting speed caused the surface roughness to decrease. Study belongs to Gökkaya and Nalbant [21] is an example of studies in which the relationship between cutting speed and surface roughness is similar to the one here. The decrease in surface roughness as the cutting speed increases is associated with the removal of less material from the sample surface as a result of the increase in the volume of the cutting edge in relation to the amount of sample removed per unit time in the literature [29-31]. In addition, the decrease in surface roughness with the increase of cutting speed can be attributed to the fact that the increase in cutting speed causes the temperature to increase and subsequently causes the workpiece to be easily deformed.

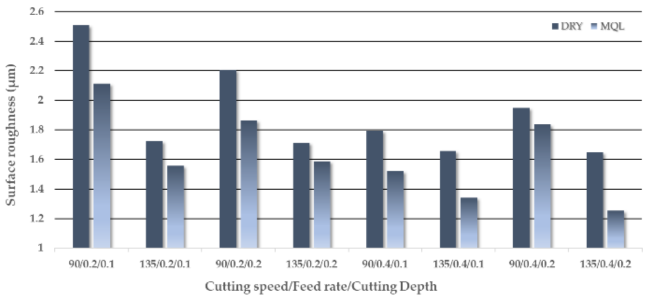

Figure 2. Variation of surface roughness versus cutting parameters.

Env.	Exp.	Surface Roughness (µm)	SR vs CS	Exp.	Surface Roughness (µm)	SR vs CD	Exp.	Surface Roughness (µm)	SR vs FR
DRY	**90**/0.2/0.1	2.509	↘	90/0.2/**0.1**	2.509	↘	90/**0.2**/0.1	2.509	↘
	135/0.2/0.1	1.724		90/0.2/**0.2**	2.206		90/**0.4**/0.1	1.795	
	90/0.2/0.2	2.206	↘	90/0.4/**0.1**	1.795	↗	90/**0.2**/0.2	2.206	↘
	135/0.2/0.2	1.711		90/0.4/**0.2**	1.948		90/**0.4**/0.2	1.948	
	90/0.4/0.1	1.795	↘	135/0.2/**0.1**	1.724	↘	135/**0.2**/0.1	1.724	↘
	135/0.4/0.1	1.659		135/0.2/**0.2**	1.711		135/**0.4**/0.1	1.659	
	90/0.4/0.2	1.948	↘	135/0.4/**0.1**	1.659	↘	135/**0.2**/0.2	1.711	↘
	135/0.4/0.2	1.65		135/0.4/**0.2**	1.65		135/**0.4**/0.2	1.65	
MQL	**90**/0.2/0.1	2.114	↘	90/0.2/**0.1**	2.114	↘	90/**0.2**/0.1	2.114	↘
	135/0.2/0.1	1.556		90/0.2/**0.2**	1.863		90/**0.4**/0.1	1.521	
	90/0.2/0.2	1.863	↘	90/0.4/**0.1**	1.521	↗	90/**0.2**/0.2	1.863	↘
	135/0.2/0.2	1.587		90/0.4/**0.2**	1.836		90/**0.4**/0.2	1.836	
	90/0.4/0.1	1.521	↘	135/0.2/**0.1**	1.556	↗	135/**0.2**/0.1	1.556	↘
	135/0.4/0.1	1.343		135/0.2/**0.2**	1.587		135/**0.4**/0.1	1.343	
	90/0.4/0.2	1.836	↘	135/0.4/**0.1**	1.343	↘	135/**0.2**/0.2	1.587	↘
	135/0.4/0.2	1.255		135/0.4/**0.2**	1.255		135/**0.4**/0.2	1.255	
SR:Surface roughness CS:Cutting speed CD: Cutting Depth FR:Feed Rate									

Figure 3. An additional figure for variation of surface roughness.

It cannot be said that the effect of feed rate on surface roughness is affected much by the variation in cutting speed and cutting depth, either in dry conditions or in MQL conditions. This situation is thought to be due to keeping the difference between the levels of the parameters small. In other words, increasing the feed rate reduced the surface roughness in both dry and MQL cases. Reducing the feed rate mentioned as a well-known practice for improving surface roughness makes the results here reasonable [21, 32-36].

Although increasing the cutting depth mostly has a decreasing effect on the surface roughness, it is not possible to make a generalization. When the 90/04/01 experiment is compared with the 90/04/02 experiment in both dry and MQL cases, it is seen that the decreasing trend is disrupted. Under MQL conditions, the same effect is also seen between the 135/02/01 experiment and the 135/02/02 experiment. In other words, the effect of low cutting speed combined with high feed rate and similarly the effect of high cutting speed combined with low feed rate resulted in an increase in surface roughness.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	1	2,6891	2,68911	2,68911	4,80	0,094
Cutting Depth	1	0,0339	0,03385	0,03385	0,06	0,818
Cutting Speed	1	7,2064	7,20640	7,20640	12,86	0,023
Residual Error	4	2,2411	2,24106	0,56026		
Total	7	12,1704				

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	1	0,169653	0,169653	0,169653	7,88	0,048
Cutting Depth	1	0,000006	0,000006	0,000006	0,00	0,987
Cutting Speed	1	0,317206	0,317206	0,317206	14,73	0,018
Residual Error	4	0,086162	0,086162	0,021541		
Total	7	0,573028				

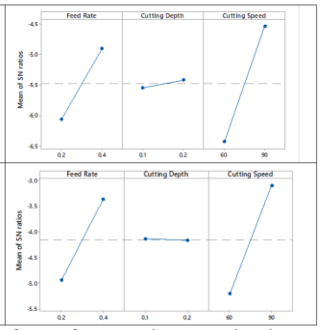

Figure 4. Anova tables and S/N ratios for surface roughness under dry and MQL cases respectively.

The value of $p < 0.05$, which indicates the significance level of each parameter in Figure 4a), shows that cutting speed has a significant effect on surface roughness in dry conditions. In MQL conditions, two parameters, cutting speed and feed rate, have a significant effect on the surface roughness. The order of importance of cutting parameters on surface roughness is as follows; cutting speed > feed rate > cutting depth.

Signal-to-noise ratio symbolizes the ratio of the signal (S) to the background noise factor (N), which are exemplified by ambient temperature and humidity, and are the source of variability in responses [37, 38]. As can be seen from Figure 4 b), the cutting depth has almost no effect on the S/N ratio, while high levels of cutting speed and feed rate serve to reduce surface roughness. These results are also compatible with ANOVA tables.

3.2. Cutting Temperature

In Figure 5 and Figure 6, where the effect of cutting parameters on the cutting temperature is seen, a trend is observed between the experiments conducted in dry and MQL environments for the same cutting parameters/levels, where the cutting temperature obtained in the MQL condition is lower than that obtained in the other. This decrease is approximately 2% on average and the inherent cooling effect of oil-based lubrication.

While the increase in cutting speed causes an effect that increases the cutting temperature at low feed rates, the opposite trend is observed at high feed rates. In experiments carried out under MQL conditions, increasing the shear rate has a relatively similar effect to that in dry conditions. Again, increasing the cutting depth decreased the cutting temperature at low feed speeds and caused it to increase at high feed speeds. This situation is similar for MQL conditions, ignoring the change between 90/04/01 and 90/04/02. The increasing effect of feed rate generally increased the cutting temperature regardless of cutting speed and cutting depth.

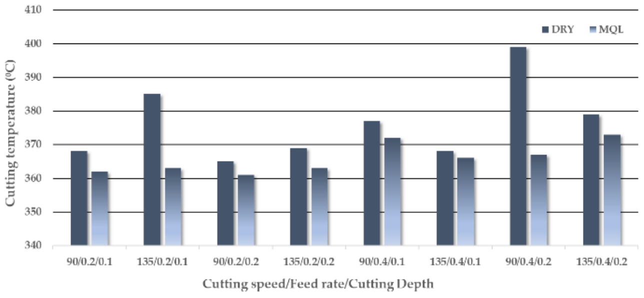

Figure 5. Variation of cutting temperature versus cutting parameters.

Env.	Exp.	Cutting Temperature (ºC)	CT vs CS	Exp.	Cutting Temperature (ºC)	CT vs CD	Exp.	Cutting Temperature (ºC)	CT vs FR
DRY	90/0.2/0.1	368	↗	90/0.2/0.1	368	↘	90/0.2/0.1	368	↗
	135/0.2/0.1	385		90/0.2/0.2	365		90/0.4/0.1	377	
	90/0.2/0.2	365	↗	90/0.4/0.1	377	↗	90/0.2/0.2	365	↗
	135/0.2/0.2	369		90/0.4/0.2	399		90/0.4/0.2	399	
	90/0.4/0.1	377	↘	135/0.2/0.1	385	↘	135/0.2/0.1	385	↘
	135/0.4/0.1	368		135/0.2/0.2	369		135/0.4/0.1	368	
	90/0.4/0.2	399	↘	135/0.4/0.1	368	↗	135/0.2/0.2	369	↗
	135/0.4/0.2	379		135/0.4/0.2	379		135/0.4/0.2	379	
MQL	90/0.2/0.1	362	↗	90/0.2/0.1	362	↘	90/0.2/0.1	362	↗
	135/0.2/0.1	363		90/0.2/0.2	361		90/0.4/0.1	372	
	90/0.2/0.2	361	↗	90/0.4/0.1	372	↘	90/0.2/0.2	361	↗
	135/0.2/0.2	362		90/0.4/0.2	367		90/0.4/0.2	367	
	90/0.4/0.1	372	↘	135/0.2/0.1	363	↘	135/0.2/0.1	363	↗
	135/0.4/0.1	366		135/0.2/0.2	362		135/0.4/0.1	366	
	90/0.4/0.2	367	↗	135/0.4/0.1	366	↗	135/0.2/0.2	362	↗
	135/0.4/0.2	373		135/0.4/0.2	373		135/0.4/0.2	373	

CT:Cutting temperature CS:Cutting speed CD: Cutting Depth FR:Feed Rate

Figure 6. An additional figure for variation of cutting temperature.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	1	162,000	162,000	162,000	0,90	0,397
Cutting Depth	1	24,500	24,500	24,500	0,14	0,731
Cutting Speed	1	8,000	8,000	8,000	0,04	0,844
Residual Error	4	723,000	723,000	180,750		
Total	7	917,500				

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	1	0,059064	0,059064	0,059064	11,08	0,029
Cutting Depth	1	0,000066	0,000066	0,000066	0,01	0,917
Cutting Speed	1	0,000640	0,000640	0,000640	0,12	0,746
Residual Error	4	0,021323	0,021323	0,005331		

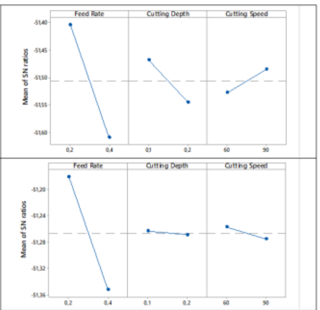

Figure 7. Anova tables and S/N ratios for cutting temperature under dry and MQL cases respectively.

Considering the statistical evaluation for cutting temperature given in Figure 7, the fact that p values of all variables are greater than 0.05 in dry conditions shows that the effect of cutting parameters on cutting temperature is not statistically significant. In the MQL condition, only the feed rate has a significant effect on the cutting temperature. This situation reveals the necessity of making new experimental designs by changing the parameter levels and perhaps even the parameters. It can also be seen from the graph that the lower feed rate, corresponding to the higher value of the S/N ratio, serves to minimizing the cutting temperature.

3.3. Cutting Forces

Low cutting forces are a desired condition for high machining performance and efficiency [23]. Figures 8 and 9 show how cutting forces, another output parameter, are affected by variation in cutting conditions. The cutting force had its lowest value at 50 N in dry conditions and 44 N in MQL conditions for the lowest levels of all cutting parameters. The cutting force peaked at 156 N in dry conditions and 120 in MQL conditions with low cutting speed and high feed rate and cutting depth. For the same combinations of cutting speed, feed rate and cutting depth, there is an average difference of 29.8% between the test results under dry conditions and those under MQL conditions. The difference in force data obtained in experiments performed at a high level of feed rate is more evident than in those performed at a low level of feed rate.

At low feed rates and for both levels of cutting depth, the increase in cutting speed resulted in an increase in cutting force. This trend is like this for both dry and MQL conditions.

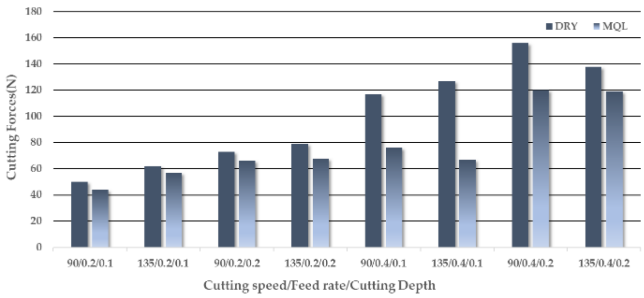

Figure 8. Variation of cutting temperature versus cutting forces.

Env.	Exp.	Cutting Forces (N)	CF vs CS	Exp.	Cutting Forces (N)	CF vs CD	Exp.	Cutting Forces (N)	CF vs FR
DRY	90/0.2/0.1	50	↗	90/0.2/0.1	50	↗	90/0.2/0.1	50	↗
	135/0.2/0.1	62		90/0.2/0.2	73		90/0.4/0.1	117	
	90/0.2/0.2	73	↗	90/0.4/0.1	117	↗	90/0.2/0.2	73	↗
	135/0.2/0.2	79		90/0.4/0.2	156		90/0.4/0.2	156	
	90/0.4/0.1	117	↗	135/0.2/0.1	62	↗	135/0.2/0.1	62	↗
	135/0.4/0.1	127		135/0.2/0.2	79		135/0.4/0.1	127	
	90/0.4/0.2	156	↘	135/0.4/0.1	127	↗	135/0.2/0.2	79	↗
	135/0.4/0.2	138		135/0.4/0.2	138		135/0.4/0.2	138	
MQL	90/0.2/0.1	44	↗	90/0.2/0.1	44	↗	90/0.2/0.1	44	↗
	135/0.2/0.1	57		90/0.2/0.2	66		90/0.4/0.1	76	
	90/0.2/0.2	66	↗	90/0.4/0.1	76	↗	90/0.2/0.2	66	↗
	135/0.2/0.2	68		90/0.4/0.2	120		90/0.4/0.2	120	
	90/0.4/0.1	76	↘	135/0.2/0.1	57	↗	135/0.2/0.1	57	↗
	135/0.4/0.1	67		135/0.2/0.2	68		135/0.4/0.1	67	
	90/0.4/0.2	120	↘	135/0.4/0.1	67	↗	135/0.2/0.2	68	↗
	135/0.4/0.2	119		135/0.4/0.2	119		135/0.4/0.2	119	

CF:Cutting force CS:Cutting speed CD: Cutting Depth FR:Feed Rate

Figure 9. An additional figure for variation of cutting forces

Among the combinations where high feed rate is combined with high cutting depth, the effect of increasing cutting speed on reducing cutting force stands out. It is seen that increasing the cutting depth increases cutting forces, regardless of changes in cutting speed and feed rate. This effect is similar and stable for both cutting media. Again, it is seen that the increase in feed rate increases the cutting forces, regardless of the cutting speed and cutting depth. Although this increase seems to be independent of the cutting conditions in terms of quality, the difference is evident in terms of quantity, so that, as stated at the beginning, an average difference of 1 in 3 is observed between the cutting forces by assuming the other conditions are constant and changing the cutting environment only.

The ANOVA table in Figure 10 shows that feed rate and cutting depth are significant factors affecting the S/N ratio, with feed rate being the most significant. Cutting speed, on the other hand, does not significantly affect the S/N ratio in both cases. This conclusion is supported by the high F-statistics and low p-values for feed Rate and cutting depth, indicating their strong influence on the response variable. Considering the S/N ratios, it was observed that lower cutting forces occurred when the sample was turned with a low feed rate and low cutting depth.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	1	78,4606	78,4606	78,4606	112,69	0,000
Cutting Depth	1	9,2709	9,2709	9,2709	13,32	0,022
Cutting Speed	1	0,6061	0,6061	0,6061	0,87	0,404
Residual Error	4	2,7850	2,7850	0,6962		
Total	7	91,1225				

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	1	32,8241	32,8241	32,8241	27,11	0,006
Cutting Depth	1	24,5396	24,5396	24,5396	20,27	0,011
Cutting Speed	1	0,2245	0,2245	0,2245	0,19	0,689
Residual Error	4	4,8422	4,8422	1,2106		
Total	7	62,4305				

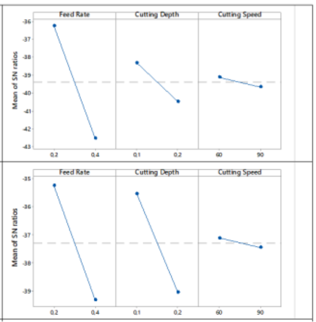

Figure 10. Anova tables and S/N ratios for cutting force under dry and MQL cases respectively.

4. CONCLUSION

This study, which experimentally demonstrates the positive effects of the minimum quantity lubrication (MQL) method on performance compared to dry cutting conditions, serves the purpose of using more environmentally friendly and efficient methods in manufacturing processes. The findings of this study, which investigated the relationship between cutting parameters and output parameters such as surface roughness, cutting temperature and cutting force during the machining of AISI 1015 steels, are summarized below.

Surface roughness;

- In turning operations performed under dry and MQL conditions, the worst surface quality was obtained at the lowest cutting speed, feed rate and depth of cut values.
- As the cutting speed increased, the surface roughness decreased in both conditions.
- Surface roughness values obtained under MQL conditions were between 6.1% and 31.5% lower than those obtained under dry conditions.
- According to ANOVA analysis, cutting speed has a significant effect on surface roughness in dry conditions, and both cutting speed and feed rate have a significant effect on surface roughness in MQL conditions.

Cutting Temperature;

- Cutting temperature was on average 2% lower under MQL conditions than under dry conditions.
- As the cutting speed increased at low feed rates, the cutting temperature increased, and at high feed rates it decreased.
- According to ANOVA analysis, cutting parameters have no significant effect on cutting temperature in dry conditions, while only feed rate has a significant effect in MQL conditions.
- When the signal-to-noise ratio was evaluated, it was seen that low feed rate minimized the cutting temperature.

Cutting Forces;

- Cutting forces were on average 29.8% higher in dry conditions than in MQL conditions.
- As the cutting speed increased at low feed rates, the cutting force increased, and at high feed rates it decreased.
- According to ANOVA analysis, feed rate and depth of cut have a significant effect on cutting forces, while cutting speed has no significant effect.
- When signal-to-noise was evaluated, it was seen that low feed rate and depth of cut resulted in lower cutting forces.
- This study, which experimentally demonstrates the positive effects of the minimum quantity lubrication (MQL) method on performance compared to dry cutting conditions, serves the purpose of using more environmentally friendly and efficient methods in manufacturing processes.

In line with these findings, the following recommendations can be made for future studies: In addition to diversifying the input parameters (such as cooled/uncooled machining conditions) or output parameters (such as tool wear, vibration), examining the parameters in a wider range to detail the simultaneous effects of the parameters can be help obtain more comprehensive results. The environmental impacts and cost effectiveness of the MQL method can be evaluated in terms of sustainable production, and the machinability of the material can also be tested in different cutting environments.

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BIOGRAPHIES

Bahar Sayın Kul obtained his BSc degree in Atatürk University, Mathematics / Mechanical Engineering Department in 2010/2012. In 2014 and 2020, she received her Master's and PhD degrees, respectively, from Selçuk University, Institute of Science, Department of Mechanical Engineering. Commencing her academic journey as a research assistant in 2012, she now holds the position of assistant professor in the Mechanical Engineering Department at the Faculty of Technology, Selcuk University.