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Experimental and Statistical Investigation of the Effect of Nanoparticle Minimum Quantity Lubrication (nano-MQL) Method on Cutting Performance

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ABSTRACT

In this study, two distinc cutting tools, coated carbide and cermet, were used in turning 20NiCrMo2 case-hardened steel. Turning experiments were carried out with these tools at three distinc cooling methods (dry, MQL, nano-MQL), three distinc cutting speeds (80, 120, 160 m/min) and three distinc feed rates (0.125, 0.167, 0.2 mm/rev) has been carried out. As a result of the experiments, the effects of cutting parameters, cutting tool type and cooling method type on the average surface roughness (Ra) and cutting zone temperature (Ctemp) were examined. In the study, the Taguchi optimization method was also applied to the experimental Ra and Ctemp results. As a result of Taguchi optimization, the most effective cutting parameters on Ra and Ctemp were determined. This result was confirmed by ANOVA analysis. Optimum parameters for Ra; cermet cutting tool, nano-MQL cooling method, 160 m/min cutting speed and 0.12 mm/rev feed rate. Optimum parameters for Ctemp; carbide cutting tool, nano-MQL cooling method, 80 m/min cutting speed and 0.12 mm/rev feed rate. Ideal numbers for both Ra and Ctemp were not found in the 18 turning experiments performed. Therefore, the 19th experiment was conducted for both output parameters. The average surface roughness value for optimum parameters was measured as 1.08 μm.

Keywords: ANOVA, Cutting temperature, MQL, nano-MQL, Surface roughness, Taguchi analyses

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Nanopartikül Takviyeli Minimum Miktarda Yağlama (MMY) Yönteminin Kesme Performansına Etkisinin Deneysel ve İstatistiki Araştırılması

ÖZ

Bu çalışmada, 20NiCrMo2 çeliğinin tornalanmasında kaplamalı karbür ve sermet olmak üzere iki farklı kesici takım kullanılmıştır. Bu takımlar ile üç farklı soğutma yöntemi (kuru, MQL, nano-MQL) üç farklı kesme hızı (80, 120, 160 m/dak) ve üç farklı ilerleme hızı (0,125, 0,167, 0,2 mm/dev) değerlerinde tornalama deneyleri gerçekleştirilmiştir. Deneyler sonucunda ortalama yüzey pürüzlülüğü (Ra) ve kesme bölgesi sıcaklığı (Ctemp) üzerinde kesme parametrelerinin, kesici takım türünün ve soğtma yöntemi türünün etkileri incelenmiştir. Çalışmada ayrıca deneysel Ra ve Ctemp sonuçlarına Taguchi optimizasyon metodu uygulanmıştır. Taguchi optimizasyonu sonucunda Ra ve Ctemp üzerinde en etkili kesme parametreleri tespit edilmiştir. ANOVA analizi ile bu sonuç doğrulanmıştır. Ra için optimum parametreler; sermet kesici takım, nano-mql soğutma yöntemi, 160 m/dak kesme hızı ve 0,12 mm/dev ilerleme hızı olarak bulunmuştur. Ctemp için optimum parametreler; karbür kesici takım, nano-mql soğutma yöntemi, 80 m/dak kesme hızı ve 0,12 mm/dev ilerleme hızı olarak bulunmuştur. Yapılan 18 tornalama deneyi içerisinde optimum parametrelere ait deneyler yer almadığı için hem Ra hem de Ctemp için 19. deneyler yapılmıştır. Optimum parametreler için ortalama yüzey pürüzlülük değeri 1,08 μm olarak ölçülmüştür.

Anahtar Kelimeler: Kesme sıcaklığı, MQL, nano-MQL, Taguchi analizi, Yüzey pürüzlülüğü

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1. Introduction

Machining is an important process in production and is one of the issues that should be given special attention in terms of sustainability, as it has a direct impact affect the lifespan and functionality of numerous critical components as well as the cost of production [1,2]. Cutting fluids are used because of their primary roles in cooling and lubricating metal goods, which guarantee high production speed throughout the machining process. Cutting force and temperature rise during machining as a result of friction produced by the chip moving across the cutting tool's surface and the metal workpiece cutting directly in front of the tool. Cutting fluids can help minimize cutting forces at lower cutting speeds, enabling machining at relatively higher cutting speeds. They can also lessen or completely remove the heat created, which has the potential to harm high-speed cutting tools [3]. As a result, machining time can be reduced by using higher cutting speeds, resulting in increased production rate. Numerous researchers agree that MQL can be considered a better alternative to the traditional cooling technique for use in a variety of machining operations, including milling, turning, grinding, and drilling [4-7]. According to Najiha et al. [2], MQL is regarded as a workable approach for a cleaner production process since it is an affordable way to apply cutting fluid and ensures worker and environmental safety. Since very little cutting fluid was used, other researchers have also backed up this assertion [5,8]. Makhesana et al. [9] were investigated to influence of MoS2 and graphite-reinforced nanofluid-MQL on surface roughness, tool wear, cutting temperature and microhardness in machining of Inconel 625. The turning tests are conducted under dry, MQL, and nanofluid-MQL (nMQL) environments, and the findings are compared considering surface roughness, chip morphology, tool wear, cutting temperature, power consumption, and microhardness. The sunflower oil blended with MoS2 resulted in 56%, 42%, and 22% improved surface quality compared to dry, MQL, and nMQL (Graphite) conditions. Also, the efficacy of nMQL with graphite and MoS2 is seen in the form of slower tool wear progression. Also, MQL, nMQL with MoS2, and nMQL (Graphite) resulted in lower cutting temperatures by 18%, 35%, and 25%, respectively, compared to dry turning [9].

Rooprai et al. [10] implemented MQL for distinc injection rates in milling En 31 steel. Two distinc cutting depths, three distinct feed rates and three distinct cutting speeds and three distinc MQL oil flow rates were used in the experiments. The number of experiments was minimized by performing 18 experiments with Taguchi analysis instead of 54 experiments with these parameters. In this way, both time and cost were saved. As output parameters, surface roughness and micro hardness values were examined. ANOVA analysis was also performed on the experimental results. The most ideal processing conditions were determined by Taguchi analysis [10]. Özbek and Saruhan [11] tested tool steel on a lathe under dry and MQL conditions with two distinc cutting tools with PVD and CVD coating at a constant cutting depth (1 mm) and three distinc feed rates (60, 90 and 120 m/min). They examined the tool wear, cutting temperature and surface roughness of the part as a result of machining. As a result of the study, an 88% improvement in Ra values was achieved during processing with MQL. It has been observed that machining with MQL extends tool life by 267% with CVD-coated cutting tools and 200% with PVD-coated cutting tools in contrast to dry machining. Cutting temperatures were reduced using PVD-coated tools compared to CVD-coated tools. Better surface roughness values were displayed by PVD-coated tools in all cutting circumstances. Likewise, in terms of tool wear, PVD coated tools exhibited superior wear performance over CVD coated tools at all cutting speeds. They observed that in dry machining, tool life for PVD-coated tools was four times greater than tool life for CVD-coated tools. They stated that under MQL machining, PVD-coated tools exhibited three times longer tool life than CVD-coated tools [11].

Most of the mechanical load and friction used to remove chip from the workpiece is converted into heat energy. Therefore, one of the most important factors to be considered during machining is the heat generation and post-heat temperature formation in the cutting zone [12]. The heat generated during the metal cutting process and the heat removed from the environment determines the temperature increase. The temperature increase due to the heat generated affects the tool performance and workpiece quality [13]. A product's surface roughness is a measurement of its surface texture, profile, irregularities or protrusions that determine the quality of that product and its compliance with design standards and specifications. The measurement of a product's surface roughness is so critical that mating parts may not fit properly if their roughness exceeds allowable limits; therefore such a situation may require rework or disposal as scrap. The probability of a product functioning well in service is a function of its quality, which is primarily dictated by the level of accuracy and precision in obtaining the perfect surface. Furthermore, tolerances and surface roughness place a crucial restriction on the choice of cutting parameter when developing a machining process [14]. Fatigue, corrosion, wear, warping, and poor dimensional and geometric precision are all encouraged by poor surface quality, and results in reduced functionality and lifespan of the product [15]. Chips formed at high temperatures on the surface of the metal can cause surface roughness if not cleaned intermittently. In addition, if left uncontrolled, the nature and thickness of the chips formed may reduce the surface integrity of the product [16]. Determining the ideal processing parameter values that will result in a smooth cutting action and, as a result, permissible surface roughness is necessary since certain cutters can badly break or fail when exposed to an intermittent rather than continuous operation mode. Past scholars have estimated surface roughness ratings using a variety of methodologies [17-22]. One of these techniques is the Taguchi optimization method. The Taguchi method is an acceptable method that can replace traditional methods, leading to a reduction in cost and time. The Taguchi method is one of the important quality strategies that minimizes the number of experiments and at the same time takes into account the effects of all controllable factors. There is a wide range of studies focused on determining the importance of parameters and their contribution percentages, and there are many studies showing that the Taguchi method is a tool suitable for application [23-26]. Gökçe [27] experimentally and statistically examined the cutting force, drill tip temperature and burr height in drilling Custom 450 martensitic stainless steel. Within the scope of the study, Taguchi and Response Surface Methods were applied to the experimental results and the most suitable drilling parameters were determined. They also applied using an analysis of variance to ascertain the effects and percentages of drilling parameters on the outputs. A correlation coefficient of over 94 percent was obtained for both optimization models, thus a successful optimization study was carried out [27].

In this study, the type of cooling method, type of cutting tool, cutting speed and feed rate were investigated in the turning of 20NiCrMo2 case-hardened steel, which is widely used in the manufacturing of machine parts such as shafts, gears, chain links, piston pins, discs, chain sprockets and pulleys, rolling bearings and rollers. Its effects on temperature and surface roughness were evaluated experimentally and statistically, and the most suitable turning conditions were determined for this purpose.

2. Material and Methods

The 20NiCrMo2 steel used in the experiments was prepared with a diameter of 50 mm and a length of 500 mm. The chemical composition of the test sample is presented in Table 1. Turning experiments were carried out on a ZMM BULGARIA CU500 brand universal lathe with 7.5 KW engine power. In the turning experiments, Taegutec TT8125B coded CVD coated carbide cutting tool and CT 3000 coded cermet turning inserts were used with PSBNR 2525M 12 turning bar. In the turning experiments, the STN-40 model device, produced by the Werte Company, was used as the MQL system. The visual of the MQL system used in the experiments is given in Figure 1. 100% biodegradable vegetable-based SAMNOS ZM22W cutting oil was used in turning experiments. Single variety nanopowder and nanoparticle-added MQL cutting fluid was prepared for the turning experiments. Multi-walled carbon nanotubes was used in MQL cutting fluid.

Table 1. Chemical components of 20NiCrMo2 steel

Element	**C**	**Si**	**Mn**	**Cr**	**Mo**	**Nb**
Wt.%	0.17-0.23	Max. 0.40	0.65-0.95	0.35-0.70	0.15-0.25	0.40-0.70

Mahr MarSurf PS 10 model device was used for surface roughness measurements. Surface roughness was measured from three areas of the turned surfaces, namely the beginning, middle and end, and these results were averaged, and the average values of surface roughness (Ra) were found. In the turning experiments, the temperature data occurring in the cutting zone on the cutting tool was measured with an OPTRIS PI 450 thermal camera. The camera was mounted in a way to see the interaction between the workpiece and the cutting tool on the universal lathe, and during all turning experiments, the temperature signals were transferred to the computer with the manufacturer's software and the highest cutting temperature (Ctemp) was determined. In order to provide the most ideal outputs in experimental studies, optimum design is necessary. In this study, Taguchi technique was preferred for experimental design and optimization. In this technique, statistical performance criterions called utilizing the signal-to-noise ratio analyze the outputs and the resulting experimental results. Surface roughness and cutting zone temperature values acquired as a consequence of the turning process are converted into S/N ratios. When calculating noise rates; Depending on the type of characteristic, there are three approaches used: largest is best, nominal is best and smallest is best [28, 29]. The study's formula for the "smallest is best" tenet, as stated in Equation 1, was preferred for S/N values.

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (1)$$

In the formula; The measured average surface roughness and cutting zone temperature values are expressed as yi, and the number of experiments performed is expressed as n. Cutting parameters in this study; cutting tool type (Ct), cooling method type (Cm), feed rate (f), and cutting speed (V). The control factors and control levels used when turning 20NiCrMo2 steel are given in Table 2. Using Analysis of Variance (ANOVA) and a 95% confidence interval, the factors' levels of impact on Ra and Ctemp were ascertained. Minitab 18 software was employed in the design of the experiment and Taguchi technique statistical analyses.

Table 2. Turning parameters and levels

Turning parameters	**Level 1**	**Level 2**	**Level 3**
Cutting tools (Ct)	TT8125B	CT3000	
Cooling method (Cm)	Dry	MQL	Nano-MQL
Cutting speed - V (m/min)	80	120	160
Feed rate - f (mm/rev)	0.12	0.16	0.20

3. Findings and Discussion

3.1. Optimization of experimental results

The orthogonal array experimental design, which was put forth by Taguchi, can be used to investigate the impact of numerous variables on the performance characteristic in a concentrated experimental group. Upon identifying the variables impacting a controllable process, it is important to ascertain the thresholds at which these parameters ought to be adjusted. A thorough understanding of the procedure, including the parameter's lowest, maximum, and current values, is necessary to decide which levels of a variable to test. The tested values may be farther apart or more values may be evaluated if there is a significant discrepancy between the parameter's minimum and maximum values. If the range of a parameter is small, fewer values may be tested or the tested values may be closer to each other [30, 31]. The average Ra and Ctemp values acquired as a consequence of the turning experiments carried out on case-hardened steel based on the Taguchi L18 experimental design, and the S/N ratios computed are given in Table 3.

Table 3. The experimental results and S/N ratios values

Exp. no.	**Cutting tools (Ct)**	**Cooling method (Cm)**	**V (m/min)**	**f (mm/rev)**	**Ra (µm)**	**Ra - S/N ratio (dB)**	**Ctemp (°C)**	**Ctemp - S/N ratio (dB)**
1	TT8125B	Dry	80	0.12	4.78	-13.5886	161.2	-44.1473
2	TT8125B	Dry	120	0.16	3.95	-11.9319	176.6	-44.9398
3	TT8125B	Dry	160	0.20	3.86	-11.7317	224.2	-47.0127

4	TT8125B	Mql	80	0.12	4.18	-12.4235	135.0	-42.6067
5	TT8125B	Mql	120	0.16	3.75	-11.4806	174.9	-44.8558
6	TT8125B	Mql	160	0.20	3.64	-11.2220	224.2	-47.0127
7	TT8125B	Nano-Mql	80	0.12	3.71	-11.3875	138.0	-42.7976
8	TT8125B	Nano-Mql	120	0.16	3.10	-9.8272	165.1	-44.3549
9	TT8125B	Nano-Mql	160	0.20	3.20	-10.1030	131.0	-42.3454
10	Cermet	Dry	80	0.12	2.70	-8.6273	206.1	-46.2816
11	Cermet	Dry	120	0.16	2.20	-6.8485	222.1	-46.9310
12	Cermet	Dry	160	0.20	1.94	-5.7560	230.0	-47.2346
13	Cermet	Mql	80	0.12	2.66	-8.4976	176.9	-44.9546
14	Cermet	Mql	120	0.16	1.92	-5.6660	189.7	-45.5613
15	Cermet	Mql	160	0.20	1.23	-1.7981	224.4	-47.0205
16	Cermet	Nano-Mql	80	0.12	2.36	-7.4582	166.8	-44.4439
17	Cermet	Nano-Mql	120	0.16	1.34	-2.5421	154.9	-43.8010
18	Cermet	Nano-Mql	160	0.20	1.11	-0.9065	176.0	-44.9103

The S/N response table acquired as a consequence of Taguchi optimization gives the turning parameters that provide the optimum values of cutting zone temperature and surface roughness and the order of influence of these parameters. The largest values in the response table show the ideal value for that parameter. The S/N response table created the outcome of the Taguchi analysis is displayed in Table 4.

Table 4. S/N response tables

Levels	**Ra**				**Ctemp**			
	Turning parameters							
	Ct	**Cm**	**V**	**f**	**Ct**	**Cm**	**V**	**f**
Level 1	-11.522	-9.747	-10.330	-7.884	-44.45	-46.09	-44.21	-44.48
Level 2	-5.344	-8.515	-8.049	-8.327	-45.68	-45.34	-45.07	-44.95
Level 3		-7.037	-6.920	-9.089		-43.78	-45.92	-45.78
Delta	6.177	2.710	3.411	1.205	1.23	2.32	1.72	1.30
Rank	1	3	2	4	4	1	2	3

According to Table 4's S/N response table, the optimum parameters for Ra are; Cermet cutting tool, which is the second kind of cutting tools, nano-mql, which is the third level of cooling method type, 160 m/min, which is the third level of cutting speed, and 0.12 mm/rev, which is the first level of feed rate. The optimum parameters for Ctemp are; The first level of the cutting tool type, coated carbide cutting tool, the third level of the cooling method type, nano-mql, the first level of the cutting speed, 80 m/min, and the first level, the feed rate, were determined as 0.12 mm/rev. The order in the bottom row of the table corresponds to the order of effect of the parameters on the outputs. Effect order of parameters for Ra according to response values; cutting tool type, cutting speed, cooling method type and feed rate. For Ctemp; cooling method type, cutting speed, feed rate and cutting tool type. According to Table 4, the most effective turning parameter on Ra is the cutting tool type, while the type of cooling method is the most effective parameter on Ctemp.

Primary effect diagrams displaying the ideal control factor values, that is, cutting parameters are presented in Figures 1 and 2. Similar to the results in the response table for S/N in Table 4, the primary effect graph's largest S/N values show the parameter's ideal level. As a result, the ideal Ra values for feed rate, cutting speed, cooling technique, and cutting tool type, respectively; cermet cutting tool, nano-mql cooling method, 160 m/min and 0.12 mm/rev. For the cutting zone temperature; coated carbide cutting tool, nano-mql cooling, cutting speed of 80 m/min and feed rate of 0.12 mm/rev. When Table 4 and Figure 1-2 are evaluated together, it is noteworthy that the optimum parameters for Ra and the optimum turning parameters for Ctemp vary. While the cermet tool gave the lowest value for Ra, the carbide cutting tool gave the lowest temperature value for Ctemp. Similarly, while the ideal result was obtained for Ra at the fastest possible cutting speed value of 160 m/min, the lowest value for Ctemp was found at 80 m/min. The reason for this difference is; Ra values tend to decrease as the cutting zone's temperature rises to a certain level. Therefore, as the cutting speed increased from 80 m/min to 160 m/min, the cutting zone temperature increased and due to this increase, thermal softening occurred at the chip-cutting tool-workpiece interface. Due to this thermal softening, the cutting process becomes easier. As a result, since the cutting tool shapes the material more easily, the roughness of the processed surface is better [32,33].

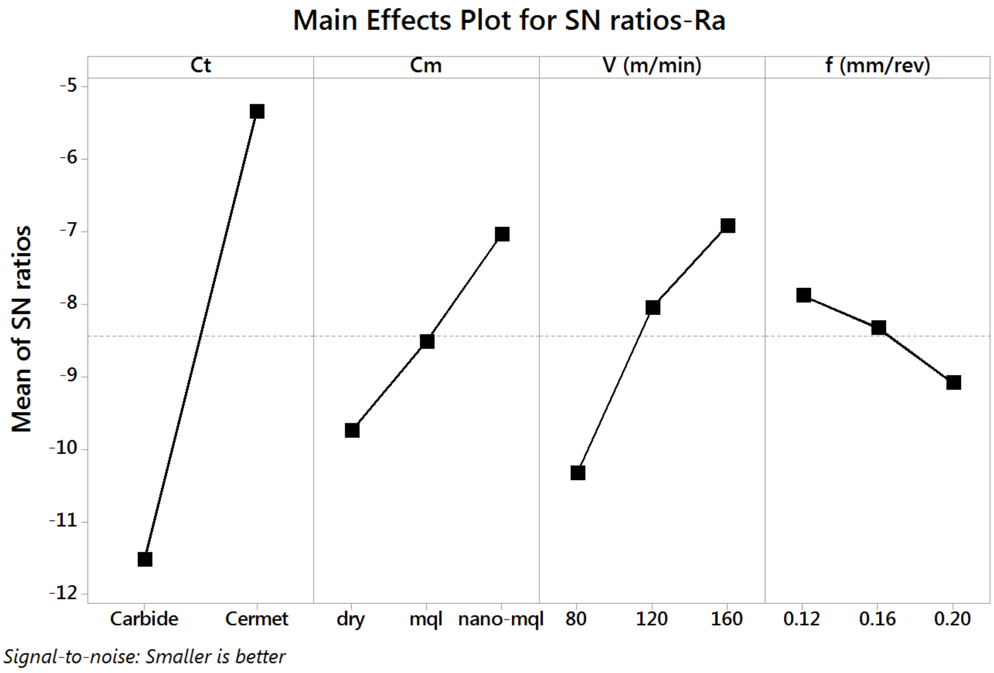

Figure 1. Main effects plot of S/N ratios for Ra

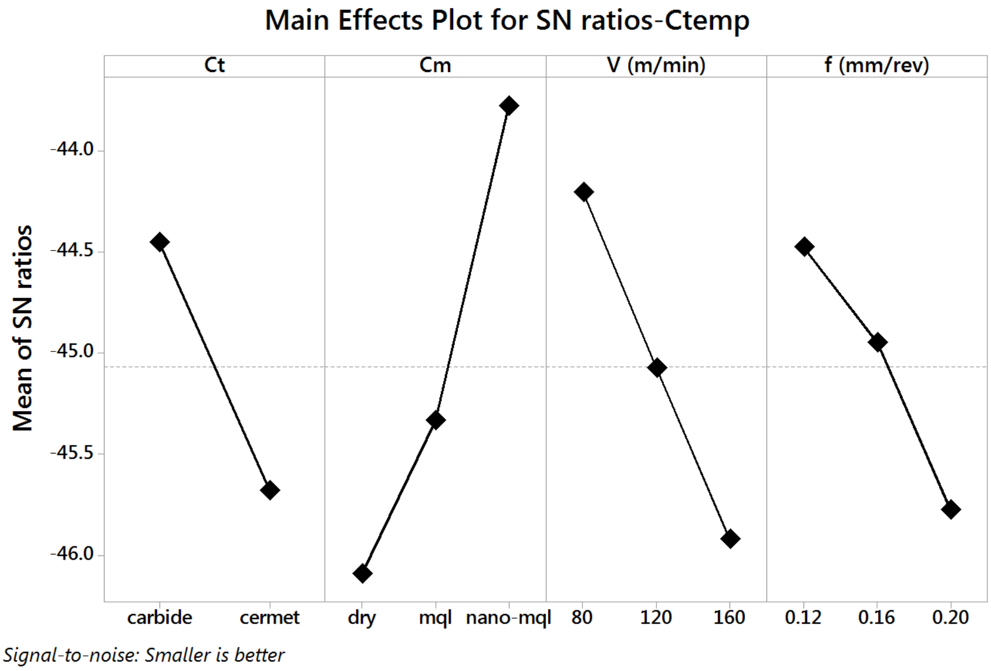

Figure 2. Main effects plot of S/N ratios for Ctemp

Ideal numbers for both Ra and Ctemp were not found in the 18 turning experiments performed. Therefore, the 19th experiment was conducted for both output parameters. The average surface roughness value for optimum parameters was measured as 1.08 µm. For optimum parameters, the cutting zone temperature was measured as 122 °C.

3.2. Variance analyses for experimental results

An experiment's variability can be divided into distinguishable causes of variance as well as the corresponding degrees of freedom using the analysis of variance technique. The analysis of the significant effects of the parameters comprising the quality features is done in statistics using the frequency test (F-test) [34]. Table 5 displays the findings of the variance analysis that was done to ascertain the rates at which turning parameters (type of cutting tool, feed rate, cutting speed, and cooling technique) affected the average surface roughness and temperature of the cutting zone. In the table; DF, SS, MS, F and PCR correspond to degrees of freedom, sum of squares, mean of squares, significance level and percentage effect ratio, respectively. ANOVA analysis was carried out using 5% significant levels and 95% confidence. F values are of great importance to ascertain the impact of control factors. The effect of turning parameters on the output parameters Ra and Ctemp is ascertained by contrasting F values. As a result, the cutting parameter with the largest F value is the parameter that affects the experimental result the most.

Table 5. Ra and Ctemp's ANOVA table

Source	DF	SS	MS	F ratio	P	PCR (%)
Ra						
Ct	1	15.5124	15.5124	360.50	0.000	75.96
Cm	2	1.7782	0.8891	20.66	0.000	8.71
V	2	2.6646	1.3323	30.96	0.000	13.05
f	2	0.0372	0.0186	0.43	0.660	0.18
Error	10	0.4303	0.0430			2.11
Total	17	20.4228				100.00
Vb						
Ct	1	2609	2608.8	10.47	0.009	14.11
Cm	2	7199	3599.5	14.44	0.001	38.95
V	2	4269	2134.7	8.56	0.007	23.10
f	2	1913	956.3	3.84	0.058	10.35
Error	10	2493	249.3			13.49
Total	17	18483				100.00

According to the ANOVA results in Table 5, it was seen that the primary influencing turning parameter Ra was the kind of cutting tools with a rate of 75.96%. Then comes the rate of cutting speed of 13.05%, the type of cooling method with a rate of 8.71% and finally the feed speed with a rate of 0.18%. The turning parameter that had the most impact on the cutting zone temperature was the cooling method type with a rate of 38.95%. Then comes cutting speed with 23.10%, cutting tool type with 14.11% and feed rate with 10.35%, respectively. Within the scope of this study, it was noted that the type of cutting tool was more effective on surface roughness than the type of cooling method, cutting speed and feed rate parameters. It has been established that the cooling method has a more significant effect on the cutting zone temperature than other turning parameters. If an evaluation is made between a cermet cutting tool and a coated carbide cutting tool in turning case-hardened steel, it is seen that the cermet cutting tool provides lower Ra values. Cutting speed, which is one of the most effective cutting parameters on Ra, was evaluated as the second effective parameter for both Ra and Ctemp in this study. It is clearly seen that the feed rate does not have a noteworthy impact on either output parameter.

3.3. Regression analyses for experimental results

Multiple regression analysis was performed for Ra and Ctemp values obtained after turning experiments.

Graphs of the regression analysis (Normal Probability Plot, Versus Fits, Histogram, and Versus Order) are given in Figure 3 and Figure 4.

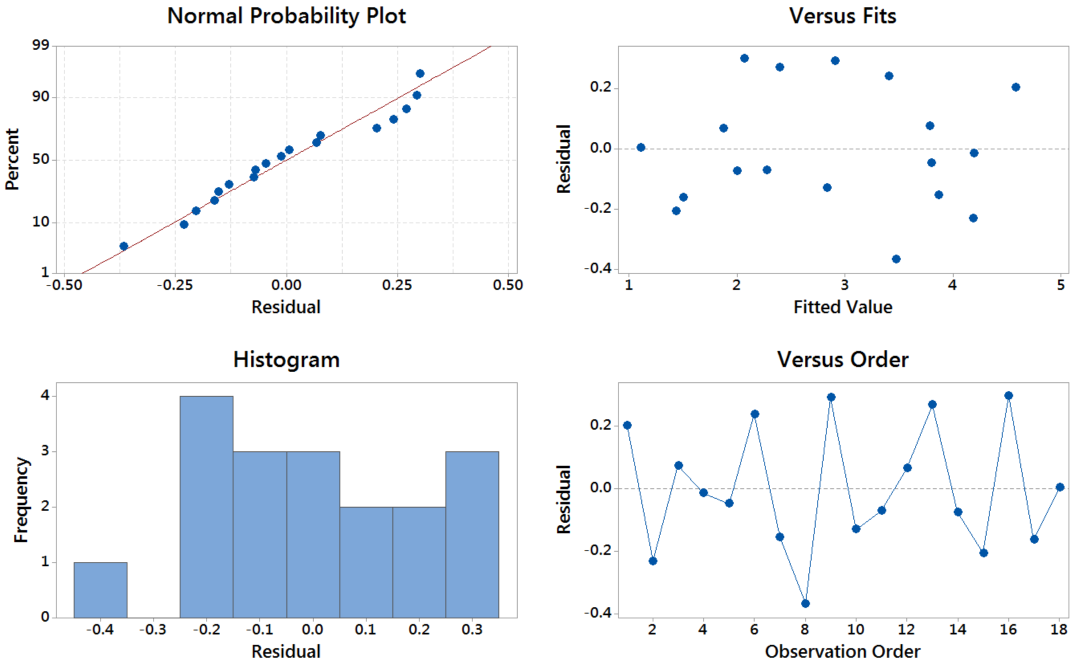

Figure 3. Residual plots for Ra

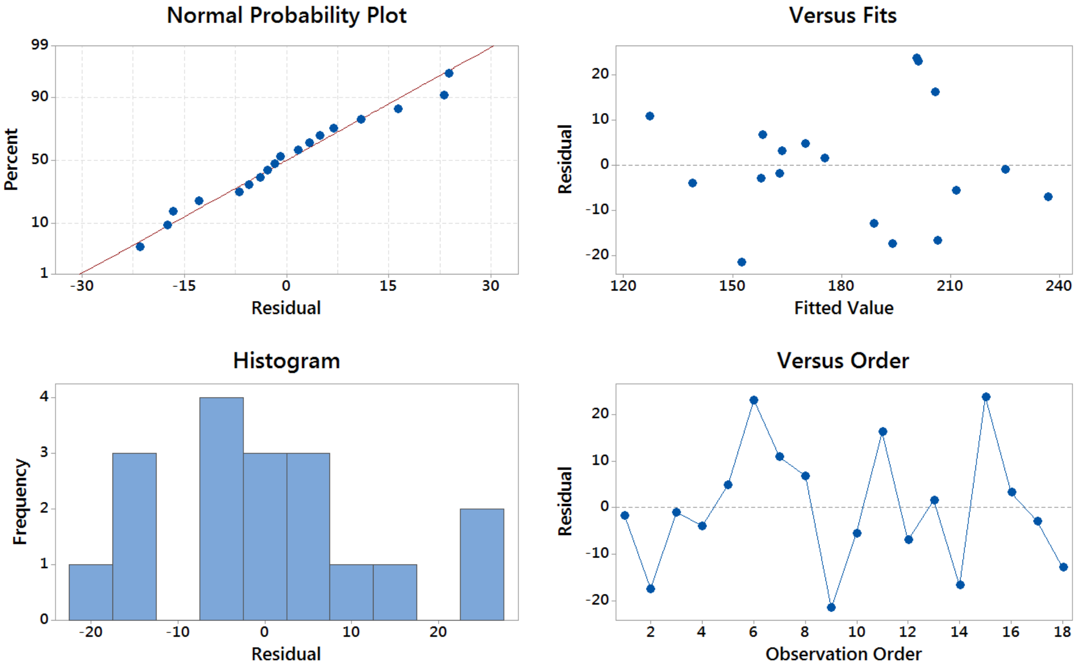

Figure 4. Residual plots for Ctemp

In Figures 3 and 4 statistical results for Ra and Ctemp are given. In Figure 3 and 4, showing the normal probability plot vs the residuals of the linearquadratic models, it can be seen that the residuals are arranged in a relatively straight line. This denoted a normal distribution of errors and signified that the terms stated in the model were significant. Moreover, a good correlation was found between the experimental vs predicted Ra and Ctemp values and their close similarity was noted. Multiple regression analysis was used to obtain the predictive equations (for linear regression model) for Ra and Ctemp, as seen in equations (2) and (3), respectively:

$$Ra\ (\mu m) = 7.557 - 1.857\ Ct - 0.3842\ Cm - 0.01127\ V\ (m/min) + 1.35\ f\ (mm/rev) \quad (2)$$

$$Ctemp\ (°C) = 88.4 + 24.08\ Ct - 24.03\ Cm + 0.470\ V\ (m/min) + 307\ f\ (mm/rev) \quad (3)$$

The R^2 values of the equations obtained by the linear regression model for Ra and Ctemp were found to be 0.96 and 0.84, respectively. For reliable statistical analyses, the error values must be less than 20 per cent [28].

4. Conclusions

In this study, 20NiCrMo2 steel was subjected to turning process with distinc cutting tools, distinc cooling methods and distinc cutting parameters. Coated carbide and cermet cutting tools were preferred as the cutting tool type. Three distinc cooling methods were used: dry, mql and nano-mql. As turning parameters, three distinc cutting speeds (80, 120, 160 m/min) and three distinc feed rates (0.12, 0.16, 0.20 mm/rev) were used. Taguchi L18 orthogonal array was preferred for experimental design. In addition, analysis of variance was performed to determine the impact ratios of turning parameters on Ra and Ctemp. The results of the study are listed below.

- As a result of Taguchi analysis, average surface roughness was determined at the second level of the cutting tool type (cermet cutting tool), at the third level of the cooling method type (nano-mql), at the third level of the cutting speed of 160 m/min and at the first level of the feed rate of 0.12 mm/rev parameters. The lowest Ra values were reached.
- The average surface roughness value for optimum parameters was measured as 1.08 µm.
- Optimum result for cutting zone temperature; It was obtained at the first level of the cutting tool type (coated carbide cutting tool), at the third level of the cooling method type (nano-mql), at the first level of the cutting speed of 80 m/min and at the first level of the feed rate of 0.12 mm/rev.
- For optimum parameters, the cutting zone temperature was measured as 122 °C.
- The type of cutting tool is the most useful parameter for Ra, based on ANOVA data (75.96%), followed by cutting speed (13.05%), cooling method type (8.71%) and feed rate (0.18%) has been seen.
- The turning parameter that had the most impact on the cutting zone temperature was the type of cooling method with a rate of 38.95%. Then comes cutting speed with 23.10%, cutting tool type with 14.11% and feed rate with 10.35%, respectively.

When all the outcomes are assessed, it can be seen that the most suitable cutting parameters and cooling method type have been successfully determined for intermediate and finish turning conditions of 20NiCrMo2 steel. We can say that cermet cutting tools should be preferred for low Ra value when material with a hardness of approximately 30 Brinell is subjected to turning at a cutting speed of 80 to 160 m/min and a feed rate of 0.12 to 0.20 mm/rev. For low Ctemp values, coated carbide cutting tools should be preferred instead of hardmet tools. The nano-mql method provided the lowest values for both Ra and Ctemp. This result once again demonstrated the unique value of the study. According to the Taguchi analysis results, it is clearly seen that a valid optimization has been made for the lowest Ra and Ctemp values. According to all these results, it can be stated that the study successfully achieved its objectives. In addition to these results, the following recommendations can be made for future studies.

- Turning experiments can be performed with the same cutting parameters for higher hardness values of the workpiece sample.
- Tests can be performed on ceramic and uncoated carbide cutting tools as well as cermet and carbide cutting tools.
- Differences between dry cutting, mql and nano-mql can be detected with boron oil, which is the

traditional cooling method.
- Cutting experiments can be performed for distinc nanoparticle particles.
- Experiments can be performed for distinc outputs such as tool wear and vibration, as well as cutting zone temperature and surface roughness.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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