Techno-Science 3:3 (2020) 103-109

Techno-Science
Scientific Journal of Mehmet Akif Ersoy University
www.dergipark.gov.tr/sjmakeu

Original Research Article

hosted by Turkish JournalPark ACADEMIC

EFFECTS OF ALLOY 718 (INCONEL) SUPER ALLOY CUTTING PARAMETERS ON SURFACE ROUGHNESS

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ARTICLE INFO

Article History

Received	:	17/10/2020
Revised	:	14/12/2020
Accepted	:	29/12/2020
Available online	:	31/12/2020

Keywords
Alloy 718, Surface roughness, Cutting parameters, RSM, ANOVA

ABSTRACT

Alloy 718, alias INCONEL, is a high-strength, corrosion-resistant nickel chromium material used at -252° to 705°C. It is an austenitic nickel-base super alloy which is used in applications requiring high strength to approximately 760°C and oxidation resistance to approximately 982°C. In addition, the alloy exhibits excellent tensile and impact strength even at cryogenic temperatures. In this study, Alloy 718 was processed at various cutting speeds (100-220 rpm) and using three different cooling techniques (dry cut, MQL and CO2) and the factors affecting surface roughness were analysed using Taguchi, RSM and ANOVA methods. Moreover, the interaction of the factors affecting the surface roughness is also shown graphically. The results of measurements and analysis show that the cutting parameters that minimize surface roughness are obtained with high cutting speed and high MQL values.

1. INTRODUCTION

Development of superalloys began in United States in the 1930s. There has been an intense demand for turbine engines for high power performance in military, commercial aircraft, and industrial turbines, starting in the middle of the second world war, focusing on the search for new materials. In order to produce jet engines, higher temperature resistant material is needed. This requirement accelerated the development of alloys [1].

Inconel 718 (2.4668) or other commonly used alloy 718 is one of the most commonly used materials among nickel alloy materials. Inconel 718 quality material is also called Alloy 718. It is a nickel-chromium alloy capable of precipitation hardening, because it contains substantially iron, niobium, and molybdenum and with a small amount of aluminum and titanium. This combination has high corrosion resistance and high strength as well as excellent weldability with weld crack resistance. This material, which corresponds to 2.4668 according to DIN standard, also corresponds to UNS N07718 standard. This nickel alloy material with a chemical expansion of NiCr19Fe19Nb5Mo3 has an extremely high resistance to corrosion.

The alloy has excellent creep-breaking strength up to 700°C (1300°F). It can be used in gas turbines, rocket engines, nuclear reactors, pumps and tools. This quality material, which can be hardened by aging, can maintain its mechanical properties even at very different temperatures. This nickel alloy material has a very high tensile strength. Inconel 718 material is very high material breaking resistance, fracture resistance. At the same time, this material, which can withstand high temperatures, has an even harder structure.

Inconel 718, is the most widely used commercial material among super alloys especially in aircraft and space industry. The Inconel 718 superalloy is generally shaped by machining and turning operations cover most of the machining process. In machining, poorly selected cutting parameters cause losses such as rapid wear and breakage of cutting tools, as well as economic losses such as degradation of workpiece or poor surface quality. Cutting speed, cutting depth, cutting tool

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To cite this article: Kırbaş, İ., Basmacı, G., Ay, M., (2020). Effects of Alloy 718 (Inconel) Super Alloy Cutting Parameters on Surface Roughness. Techno-Science, vol. 3, no. 3, p. 103-109.

geometry and cooling type are the most important parameters in terms of the machinability. Inconel 718 can be machined with cemented carbide tools at low cutting speeds, but with ceramic cutting tools at higher cutting speeds.

When the literature is examined, detailed studies on processing and mathematical modeling of superalloys are included [1-7]. During the CNC turning cycle for microalloyed 30MnVS6 steel, Özlü et al. focused on mathematical modeling of surface roughness and cutting force parameters [8]. In Gökkaya's study, the effects of different cutting and feeding rates on the main cutting force and average surface roughness of the aluminum alloy series AA5052 with cemented carbide uncoated tool were investigated [9]. Taşliyan et al. investigated the effects of cutting speed, feed rate and cutting depth on the actual cutting force of the cutting parameters for the Inconel 718 superalloy [10]. A.Güllü et al. Inconel 718 concentrated on the development of the chip breaker to extract the chip when turning the product. A dynamic chip breaker mechanism was designed for this purpose, which can be used with positive and negative tool holders [11].

In this study, Alloy 718 was processed at various cutting speeds (100-220 rpm) and using three different cooling techniques (dry cut, MQL and CO2) and the factors affecting surface roughness were analyzed using Taguchi, RSM and ANOVA methods.

2. MATERIAL AND METHODS

The structure of a machined surface is one of the most important criteria for quality. Each parameter used at the time of processing affects the surface accuracy. Surface roughness is a parameter that determines the surface quality. Surface irregularities resulting from the cutting tool or other problems in the manufacturing process are defined as roughness [12]. Roughness covers other irregularities with traces of cross progress. The purpose of the chip removal process is not only to shape the parts, also manufacture them to a certain degree of accuracy in terms of geometry, size and surface as shown in the Figure 1. The surface quality, including the surface accuracy of the part, is the most important feature that guides the determination of the chip removal process. In chip removal processes, multiple parameters affect the cutting forces. The component contents and quantities of the alloy 718 as a superalloy are given in Table 1.

Table 1. Limiting chemical composition for Inconel alloy 718

Compound	Composition (%)
Nickel	50-55
Ferrum	19.03
Chromium	17-21
Niobium (plus Tantalum)	4.75-5.5
Molybdenum	2.8-3.3
Titanium	0.65-1.15
Aluminum	0.2-0.8
Cobalt	1 max.
Carbon	0.08 max.
Manganese	0.35 max.
Silicon	0.35 max.
Phosphorus	0.015 max
Sulfur	0.015 max.
Boron	0.006 max.
Copper	0.30 max

Alloy 718 was processed with two different techniques: conventional and wiper. For cutting speed, the range of 100-220 rpm was tested and three different cooling techniques (dry cut, MQL and CO_2) was applied. Two different sizes of 20ml and 40ml were used for MQL cooling method.

First, the experiment sheet was prepared to perform factor analysis for the specified intervals. The Taguchi method was used to reduce the number of experiments and thus the cost and total number of experiments was determined as 24. After the measurements, ANOVA analysis was performed for factor analysis. Response surface methodology (RSM) was used to mathematically model the obtained surface roughness values and their relationship with cutting parameters [13-14]. The relationship between dependent and independent variables was determined by regression analysis [15].

Mathematical model is one of the most effective methods of expressing a study. This method is based on experimentally obtained data. The model is based on specific parameters and is generated from the data obtained from the experiments using these parameters. Curve fitting algorithms are used to create the most appropriate mathematical model based on a limited number of data. The formation of the model facilitates the subsequent experimental studies. That is, it is possible to calculate previously unknown values with the created model [8]. In our study, for the method parameter, 1 represents conventional processing and 2 represents wiper method. A value of 0 for MQL and CO_2 parameter refers to dry cut in RSM model. Figure 1 shows the experimental setup and devices used in the measurements.

Fig 1. Experimental setup for Alloy 718

When the response surface regression is performed for surface roughness (Ra), the data obtained are presented in Table 2.

Table 2. Analysis of variance for Alloy 718

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	13	7.7640	0.59723	2.02	0.084
Linear	5	3.1113	0.62226	2.10	0.112
Cutting Speed	1	0.0272	0.02722	0.09	0.765
CO2	1	1.8458	1.84584	6.24	0.022
MQL	2	0.0666	0.03330	0.11	0.894
Method	1	0.3753	0.37530	1.27	0.275
Square	1	1.3878	1.38782	4.69	0.044
Cutting Speed*Cutting Speed	1	1.3878	1.38782	4.69	0.044
2-Way Interaction	7	2.6319	0.37599	1.27	0.319
Cutting Speed*CO2	1	0.7054	0.70538	2.38	0.140
Cutting Speed*MQL	2	0.4701	0.23504	0.79	0.467
Cutting Speed*Method	1	0.0006	0.00061	0.00	0.964
CO2*Method	1	0.1866	0.18664	0.63	0.438
MQL*Method	2	1.3964	0.69822	2.36	0.123
Error	18	5.3279	0.29600		
Lack-of-Fit	16	4.1927	0.26204	0.46	0.853
Pure Error	2	1.1352	0.56762		
Total	31	13.0919			

Coded coefficients values obtained using RSM technique are presented in Table 3.

Table 3. Coded coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.948	0.197	4.82	0.000	
Cutting Speed	0.063	0.208	0.30	0.765	2.60
CO2					
0	-0.393	0.158	-2.50	0.022	2.01
MQL					
0	0.072	0.157	0.46	0.650	1.83
20	-0.021	0.157	-0.13	0.895	1.33
Method					
1	0.188	0.167	1.13	0.275	2.98
Cutting Speed*Cutting Speed	0.469	0.217	2.17	0.044	1.00
Cutting Speed*CO2					
0	-0.321	0.208	-1.54	0.140	2.60
Cutting Speed*MQL					
0	-0.114	0.211	-0.54	0.595	2.00
20	0.265	0.211	1.26	0.225	1.33
Cutting Speed*Method					
1	-0.007	0.145	-0.05	0.964	1.24
CO2*Method					
0 1	-0.133	0.167	-0.79	0.438	2.98
MQL*Method					
0 1	-0.015	0.157	-0.10	0.923	1.96
20 1	0.303	0.157	1.93	0.070	1.33

The uncoded units and their coefficients calculated for the Ra response are reported in Table 4.

Table 4. Regression equation in uncoded units

CO2	MQL	Method				
0	0	1	Ra	=	5.02 + 0.000130 Cutting Speed*Cutting Speed	- 0.0480 Cutting Speed
1	0	1	Ra	=	4.36 + 0.000130 Cutting Speed*Cutting Speed	- 0.0373 Cutting Speed
0	20	1	Ra	=	4.23 + 0.000130 Cutting Speed*Cutting Speed	- 0.0417 Cutting Speed
1	20	1	Ra	=	3.57 + 0.000130 Cutting Speed*Cutting Speed	- 0.0310 Cutting Speed
0	40	1	Ra	=	4.72 + 0.000130 Cutting Speed*Cutting Speed	- 0.0487 Cutting Speed
1	40	1	Ra	=	4.06 + 0.000130 Cutting Speed*Cutting Speed	- 0.0380 Cutting Speed
0	0	2	Ra	=	4.90 + 0.000130 Cutting Speed*Cutting Speed	- 0.0478 Cutting Speed
1	0	2	Ra	=	3.71 + 0.000130 Cutting Speed*Cutting Speed	- 0.0371 Cutting Speed
0	20	2	Ra	=	3.48 + 0.000130 Cutting Speed*Cutting Speed	- 0.0415 Cutting Speed
1	20	2	Ra	=	2.29 + 0.000130 Cutting Speed*Cutting Speed	- 0.0308 Cutting Speed
0	40	2	Ra	=	5.15 + 0.000130 Cutting Speed*Cutting Speed	- 0.0484 Cutting Speed
1	40	2	Ra	=	3.95 + 0.000130 Cutting Speed*Cutting Speed	- 0.0377 Cutting Speed

According to the results obtained from the response surface methodology, standardized factors are presented as pareto graph in Fig 2.

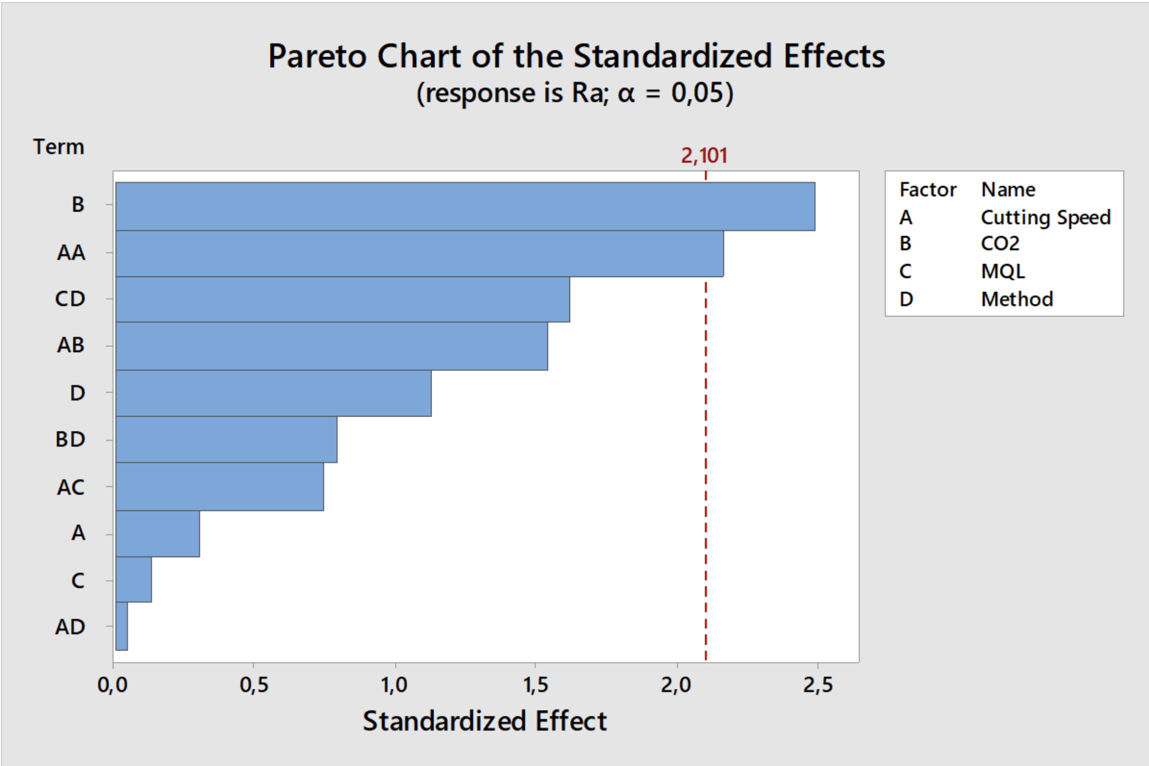

Fig 2. Experimental setup for Alloy 718

According to the graphical comparison given in Figure 2, the biggest standardized factor is the CO_2 cooling method. CO_2 cooling is also the most important factor that affects surface roughness alone. Again, according to the same pareto graph, the dual factor that could exceed the 2.101 limits was determined as the cutting speed.

3. RESULTS AND DISCUSSIONS

In this study; alloy 718 for turning superalloys; the effects of cutting speed and cooling type and cutting method on surface roughness have been demonstrated. In addition, RSM technique was used for mathematical modeling of the relationship between surface roughness and these parameters. The main factors affecting the Ra parameter and the effective levels of these factors are shown in Fig 3.

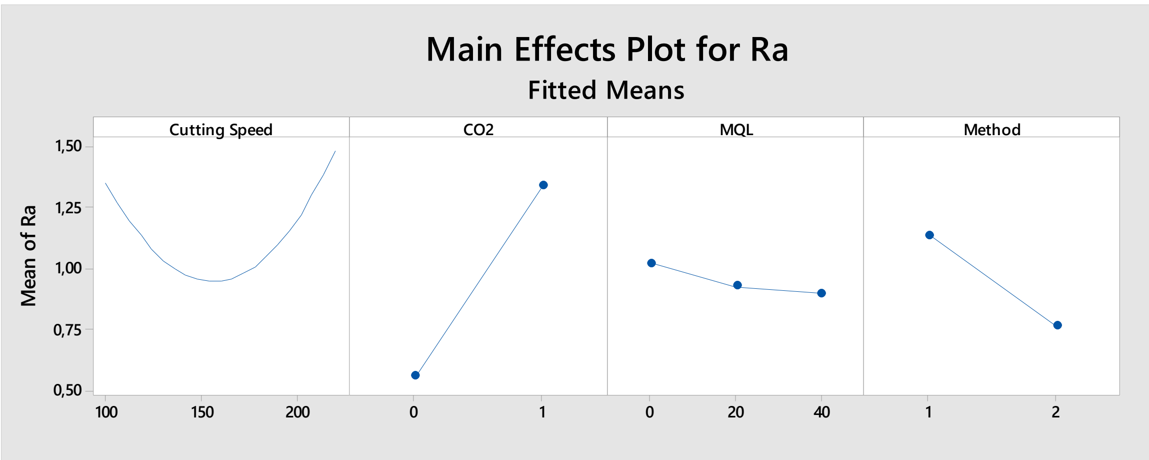

Fig 3. Experimental setup for Alloy 718

When the effect of cutting speed is examined, a nonlinear relationship is observed. When carbon dioxide cooling is considered, the use of carbon dioxide in terms of surface roughness has produced negative results. When the effect of MQL method and amount on surface roughness is examined, it is seen that the cooling with 40ml is more successful although there is no striking difference between 20ml and 40ml uses. When the effect of machining methods on surface roughness is examined, it is seen that wiper method achieves much more successful results than conventional machining method.

Finally, the parameters and values that should be selected in order to minimize surface roughness were studied. For this purpose, multiple response optimization was performed for Ra parameter and the results were expressed as curves in Figure 4.

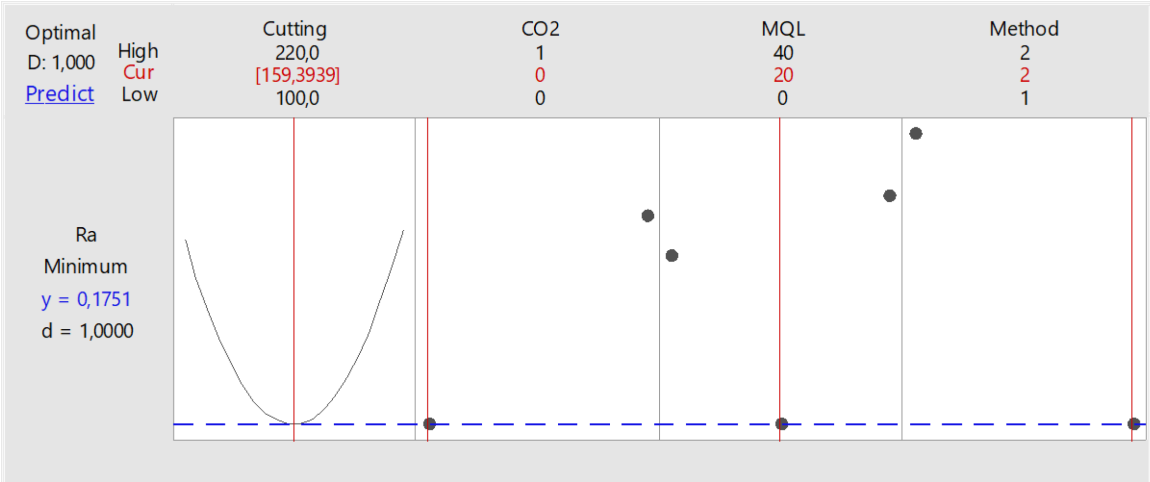

Fig 4. Experimental setup for Alloy 718

When Figure 4 is examined, it is seen that operating parameters reducing Ra value to 0.1751 are approximately 160 rpm for cutting speed factor, MQL 20ml as cooling method and wiper as machining method.

As a result of the experiments and measurements carried out within the scope of the study, it was clearly determined by using statistical approaches that cooling method should be used in which amount to obtain the lowest surface roughness for Alloy 718. That was the ideal level of the cutting speed and which of the cutting methods were more successful. Thus, more successful results can be obtained by spending less material, time and energy in processing Alloy 718 alloy.

For further studies, creating a mathematical model of the alloy by using artificial intelligence methods will be useful in terms of reducing the number of experiments and measurement costs.

4. CONCLUSIONS

This study, Alloy 718 was processed at various cutting speeds (100-220 rpm) and using three different cooling techniques (dry cut, MQL and CO2) and the factors affecting surface roughness were analysed using Taguchi, RSM and ANOVA methods.

- The measurements and analysis results show that the cutting parameters that minimize surface roughness are obtained with high cutting speed and high MQL values.
- Results can be obtained by spending less material, time and energy in processing Alloy 718 alloy.

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Techno-Science *Paper ID: 812055*