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(Research Article)

A study on effects of cutting parameters on surface roughness in milling of Hastelloy C276 under pure MQL and nanofluid MQL modes

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Abstract

The main objective of this paper is to investigate the influence of parameters including lubrication/cooling conditions (MQL and MQL using nano cutting oil), cutting speed, and feed rate on the surface roughness value R_a during the milling process of Hastelloy C276. The influence of input parameters was studied by using the factorial experimental design. Experimental results show that feed rate has the greatest influence on surface roughness, while cutting speed and lubrication/cooling modes have little influence. Furthermore, the interaction between lubrication/cooling conditions and cutting speed has a significant impact on surface roughness R_a. Based on the obtained experimental results, MQL condition using nano cutting oil brings out the better results when compared to pure MQL method. The cutting speed v = 70 m/min, and feed rate f = 0.08 mm/tooth is a reasonable set of parameters and should be selected to achieve the smaller values of surface roughness R_a under Al_2O_3 nanofluid MQL environment.

Keywords: Milling; Nanofluid; Al_2O_3 Nanoparticle; MQL; Cutting Speed; Feed Rate; Surface Roughness

1. Introduction

In recent years, the materials industry has developed rapidly and brought out many special alloys that possess many good mechanical, physical, and chemical properties to meet the increasing demand in industrial applications [1]. Nickel alloys are metallic materials formed when nickel combines with one or more other elements such as Chromium, Iron, Copper, or Aluminum. These alloys usually have high mechanical strength, good heat resistance, wear resistance, and corrosion resistance, so they are widely used in industries such as chemical industry, aerospace, machine manufacturing, and heat-resistant material production [2,3]. Hastelloy is a typical Ni-based alloy in this group. This material has a high yield strength and low thermal conductivity, so it is classified as a difficult-to-machine material [4]. When machining this alloy, tool wear is observed to be more severe than when machining soft materials. This is because this alloy has high strength, high ductility, and the ability to harden upon deformation, so during the cutting process, it easily increases the cutting force and temperature in the contact zone [5]. In addition, Ni alloys have poor thermal conductivity, causing heat to concentrate at the tool tip, accelerating tool wear. During the cutting process, materials also easily adhere to the tool surface (BUE phenomenon), causing wear and reducing tool life [3]. Therefore, in order to effectively machine Ni alloys, cutting tools need to possess high hardness and heat resistance [6], and the lower cutting speed and cooling lubrication conditions are needed to reduce heat and friction in the cutting zone [1,7]. Flood coolant is a traditional method and has been widely used in the metal cutting industry. However, due to the low spraying pressure, the ability to deliver cutting oil deeply into the cutting zone is limited and a large amount of cutting oil is used [7]. The high cost of processing the used cutting oils has become a major problem, increasing machining costs and making this technology unsuitable for green and sustainable development trends [8]. To overcome this problem, several

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advanced cooling and lubrication technologies have been researched and developed such as minimum quantity cooling (MQC), minimum quantity lubrication (MQL), MQL using nano cutting oil, and so on.

In particular, the use of nano cutting oil as the based cutting oil for MQL technology has become a new technological solution, attracting much attention of researchers worldwide. The additives of nanoparticles into base cutting oil has improved the lubricating and cooling properties of the base cutting oil [9]. This helps improve the hard machining efficiency of the AISI D2 tool steel [10]. Directly introducing cutting oil containing nanoparticles into the cutting zone not only improves the lubricating efficiency resulted from the properties of the cutting oil but also the lubricating/cooling properties from the nanoparticles [11]. Tool wear and cutting force reduction during the milling process were noted in the studies [8,12]. At the same time, surface quality was improved in machining with MQL mode using nano cutting oil when compared to dry and MQL conditions [8]. However, there is little information on the milling performance of Hastelloy C276 alloy under MQL condition using nano cutting oil, so the authors conducted the study on the effect of cutting parameters on surface roughness R_a under MQL and MQL environment using Al_2O_3 nano cutting oil.

2. Material and Method

The experimental setup is shown in Figure 1. Smart 530C vertical milling center (Mazak, Japan) was used to conduct the milling experiments. The chemical composition and mechanical properties of Hastelloy C276 alloy samples are presented in Tables 1 and 2. Surface roughness R_a was measured three times after each cutting trial by using Mitutoyo SJ-210 surface roughness tester and the average value was taken. The factorial experimental design was used to study the influence of input machining parameters (lubrication/cooling mode, cutting speed and feed rate) on the surface roughness R_a values. The input variables and investigated values are presented in Table 3. The experimental trials were conducted according to the run order in the experimental matrix.

Table 1 Chemical composition of Hastelloy C276

Ni	Co	Cr	Mo	Fe	W	Mn	Mo	V	Si	C
57 balance	2.5 max	16	16	5	4	1.0 max	0.6	0.35 max	0.08 max	0.01 max

Table 2 Mechanical properties of Hastelloy C276

Yield strength (Mpa)	Tensile strength, (Mpa)	Elongation (%)	Hardness range (HRB)	Modulus of Elasticity (Gpa)	Poison's ratio
355	760	40	88	200	0.32

Figure 1 Setup for milling experiments

Table 3 Input variables and their levels

Input parameters	Low level	High level	Output parameter
Cooling lubricating mode	MQL	NF MQL	Surface roughness R_a (µm)
Cutting speed (m/min)	30	70	
Feed rate (mm/tooth)	0.08	0.16	

3. Results and discussion

The Pareto plot in Figure 2 shows the influence of each parameter and the interaction of input parameters on the surface roughness R_a. The factors with a significant influence on the output variable are located to the right of the reference line with a value of 0.02258, while those to the left of the reference line have negligible influence. In Figure 2, it can be seen that feed rate has the strongest influence on the surface roughness R_a, while cutting speed and lubrication/cooling mode are located to the left of the reference line. In addition, the interaction of input variables has little influence on the surface roughness R_a.

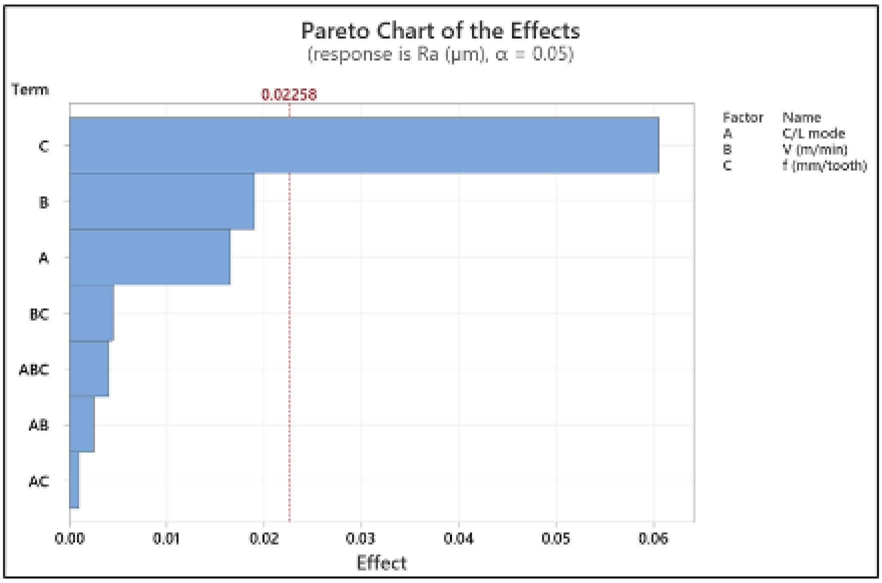

Figure 2 Pareto chart of the effects of input parameters on surface roughness R_a

The main effects of each surveyed factor are shown in Figure 3. Due to the increased cutting layer [13], the R_a values increased rapidly when the feed rate increased from 0.08 mm/tooth to 0.16 mm/tooth. At the same time, the declining rate of surface roughness R_a was observed when the cutting speed grew up. The increase of the cutting speed from 30 m/min to 70 m/min contributed to reducing the surface roughness R_a, which can be explained by the reduction in cutting forces and cutting heat [13]. In addition, under MQL condition using nano cutting oil, the R_a values were smaller than in MQL with the based cutting oil without nanoparticles, which reflects that the Al_2O_3 nano cutting oil improved the lubrication and cooling efficiency of the based cutting oil [8,14].

Figure 4 illustrates the interaction effects of input machining parameters on the response, surface roughness R_a. The interaction between lubrication/cooling mode and cutting speed has a greater impact on the surface roughness R_a than other factors. Based on the results obtained, a suitable set of input parameters was selected with MQL technique using nano cutting oil, a cutting speed of 70 m/min, and a feed rate of 0.08 mm/tooth to achieve the smaller surface roughness R_a values.

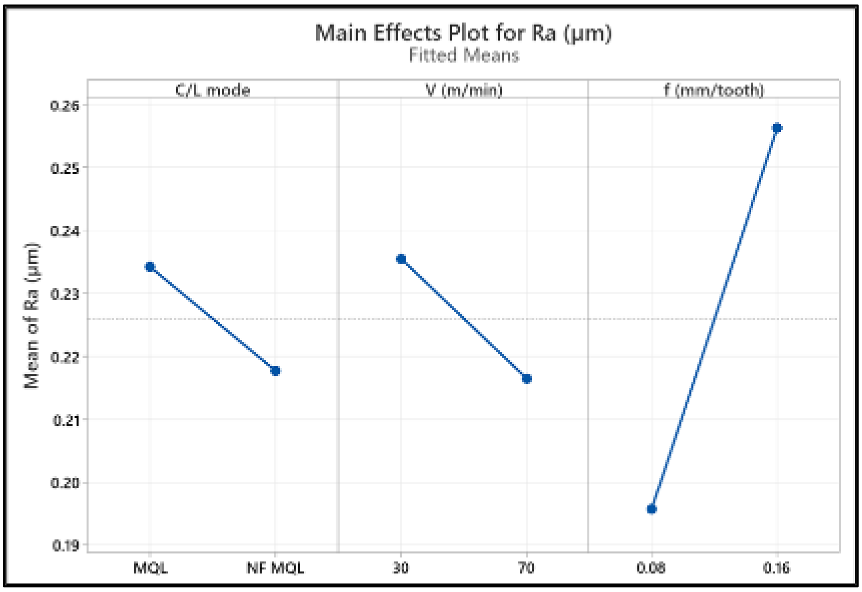

Figure 3 Main effects of input parameters on surface roughness R_a

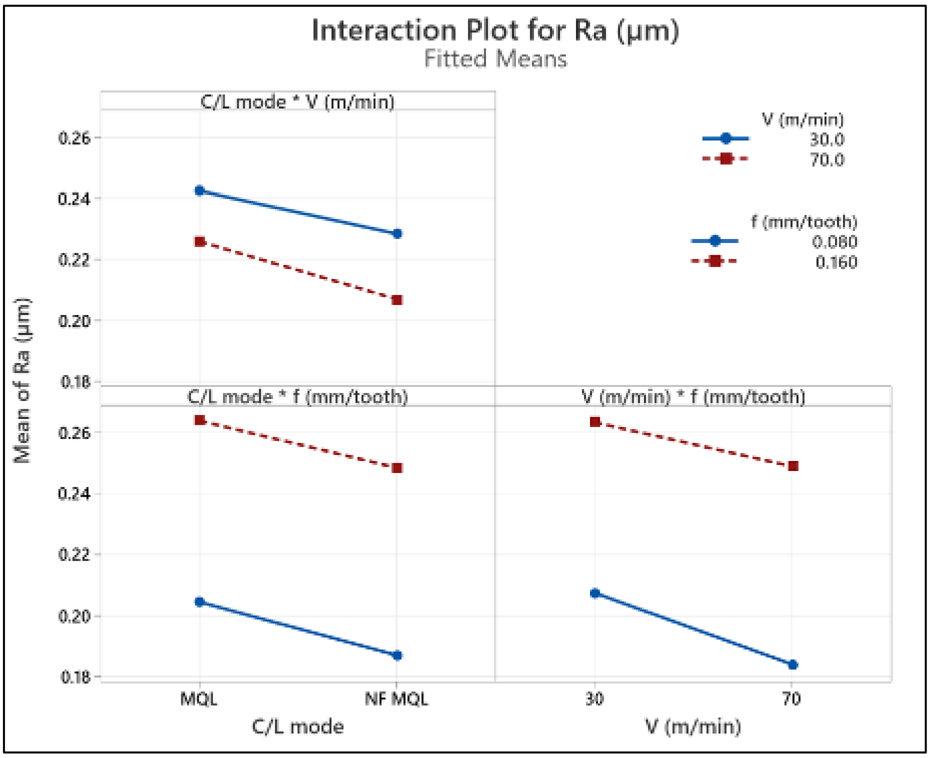

Figure 4 Interaction effects of input parameters on surface roughness R_a

4. Conclusion

In this paper the influence of parameters including lubrication/cooling regime, cutting speed, and feed rate on surface roughness during the milling process of Hastelloy C276 alloy were investigated. The application of the factorial experimental design with the support of Minitab software helped construct an experimental matrix and investigate the influence of each input parameter and the interaction between these variables. The analysis results show that the feed rate has the greatest influence on the surface roughness R_a values. At the same time, the MQL condition using nano cutting oil resulted in better surface quality when compared to MQL using the based cutting oil without nanoparticles, demonstrating the improvement in lubricating performance of nano cutting oil. Furthermore, the increase of the cutting speed contributed to a reduction in surface roughness due to the reduced cutting force and cutting heat. Regarding the interaction between parameters, the influence between lubrication/cooling mode and cutting speed was more significant than other interactions. Under MQL environment using nano-cutting oil, the cutting speed v = 70 m/min and feed rate f = 0.08 mm/tooth should be selected to achieve the smaller surface roughness R_a.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Danil Yu. Pimenov, Leonardo Rosa Ribeiro da Silva, Alisson Rocha Machado, Pedro Henrique Pires França, Giuseppe Pintaude, Deepak Rajendra Unune, Mustafa Kuntoglu, Grzegorz M. Krolczyk. A comprehensive review of machinability of difficult-to-machine alloys with advanced lubricating and cooling techniques, Tribology International 196 (2024) 109677, https://doi.org/10.1016/j.triboint.2024.109677

[2] Liu J, Chen G, Zhao L, Yu Z, Jia X. Research status and development trend of cutting surface integrity of aerospace alloy materials, Int. J. Adv. Manuf. Technol. 127 (2023), 45–63. https://doi.org/10.1007/S00170-023-11558-Z.

[3] Ezugwu EO. Key improvements in the machining of difficult-to-cut aerospace superalloys, Int. J. Mach. Tools Manuf. 45 (2005), 1353–67. https://doi.org/10.1016/J.IJMACHTOOLS.2005.02.003.

[4] Sinha MK, Pal A, Kishore K, Singh A, Archana, Sansanwal H, et al. Applications of sustainable techniques in machinability improvement of superalloys: a comprehensive review, Int. J. Interact. Des. Manuf. (IJIDeM) 17 (2022), 473–98. https://doi.org/10.1007/S12008-022-01053-2.

[5] Zhu T, Cai M, Gong Y, Gao X, Yu N, Gong Q. Research progress of eco-friendly grinding technology for aviation nickel-based superalloys, Int. J. Adv. Manuf. Technol. 126 (2023), 2863–86. https://doi.org/10.1007/S00170-023-11336-X.

[6] Oleksandr Gutnichenko, Sandra Gordon Pozuelo, Luis Llanes, Volodymyr Bushlya. Analysis and Monitoring the Initial Tool Damage and Coating Failure when Hard Milling Vanadis 4E with TiAlN Coated PcBN, 20th CIRP Conference on Modeling of Machining Operations, Procedia CIRP 133 (2025) 322–327, doi:10.1016/j.procir.2025.02.056.

[7] Pil-Ho Lee, Jung Soo Nam, Chengjun Li and Sang Won Lee. An Experimental Study on Micro-Grinding Process with Nanofluid Minimum Quantity Lubrication (MQL). International Journal of Precision Engineering and Manufacturing 13 (2012). 331-338

[8] Duc, T.M., Long, T.T., Ngoc, T.B. Performance of Al2O3 nanofluids in minimum quantity lubrication in hard milling of 60Si2Mn steel using cemented carbide tools. Advances in Mechanical Engineering. 2017;9(7). doi:10.1177/1687814017710618.

[9] Ben Wang, Tie Chen, Biling Wang, Qi Zhang, Chang Song. Lubrication mechanism of nanofluid at the grinding interface in SiCf/SiC composite materials and diamond abrasive: Atomic-scale insights and experiment, Diamond and Related Materials, 159, Part B, 2025, 112927, https://doi.org/10.1016/j.diamond.2025.112927.

[10] Dong, P.Q.; Duc, T.M.; Tuan, N.M.; Long, T.T.; Thanh, D.V.; Truong, N.V. Improvement in the Hard Milling of AISI D2 Steel under the MQCL Condition Using Emulsion-Dispersed MoS2 Nanosheets. Lubricants 2020, 8, 62. https://doi.org/10.3390/lubricants8060062

[11] Sharma AK, Tiwari AK, Dixit AR. Effects of minimum quantity lubrication (MQL) in machining processes using conventional and nanofluid based cutting fluids: a review. J Clean Prod 2016; 127: 1–18, https://doi.org/10.1016/j.jclepro.2016.03.146.

[12] Hamed Hassanpour, Mohammad H. Sadeghi, Amir Rasti, Shaghayegh Shajari. Investigation of Surface Roughness, Microhardness and White Layer Thickness in Hard Milling of AISI 4340 Using Minimum Quantity Lubrication. Journal of Cleaner Production (2016), doi: 10.1016/j.jclepro.2015.12.091.

[13] Said, Z., Gupta, M., Hegab, H. et al. A comprehensive review on minimum quantity lubrication (MQL) in machining processes using nano-cutting fluids. Int J Adv Manuf Technol 105, 2057–2086 (2019). https://doi.org/10.1007/s00170-019-04382-x.

[14] J. Paulo Davim. Machining of Hard Materials. Springer-Verlag London Limited 2011.