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Influence of Process Parameters of Surface Grinding on Maraging Steel

TSRV Padmalatha , Madhavi Jalli and Saraswathamma Konapalli*

Department of Mechanical Engineering, University College of Engineering, Osmania University, Hyderabad 500007, Telangana, India.

Abstract

Surface grinding is one of the important metal cutting processes used extensively in the finishing operations. Significant developments have recently been made in the grinding of metals. Surface finish is the important output response in the production with respect to quantity and quality. The aim of the paper is to study the effect of grinding process parameters namely depth of cut & feed on grinding time, material removal rate, surface roughness of Maraging steel 250 which is a high alloy metal possessing superior strength and toughness. Response surface methodology design was used as the approach for the design of experiments. Through the Analysis of Variance (ANOVA) conducted, it was found that depth of cut played vital role on metal removal rate followed by feed rate. In conclusion, the MRR values increased as the number of passes became higher in proportional to depth of cut. The surface roughness also increased

Keywords: Maraging steels, RSM, ANOVA, depth of cut, feed, MRR, surface roughness

1. INTRODUCTION

Aviation and automotive industry requires high-strength materials with sufficient ductility. Conventional low-alloy steels at strengths above 100 ton/in^2 have been successfully used in various aerospace applications, but laboratory test results, service-performance data and problems in production indicated a need for steels which possessed improved mechanical properties, and which were simpler to machine and fabricate. This requirement initiated in development of Maraging and precipitation-hardening stainless steel. The 18% Ni-Co-Mo Maraging steels were developed in 1961 with the aim of fulfilling this need, and since that date several thousand tons of the steels have been produced and used in all common shapes and forms. These steels have certain advantages in making structural components such as hardening without quenching, and the absence of distortion and decarburization. In comparison with low-alloy steels of equivalent strength, 18% nickel Maraging steels have greater resistance to fracture at highly-stressed notches, defects or cracks, and their susceptibility to hydrogen embrittlement /stress-corrosion failure is generally far superior.

Maraging steels ("martensitic" and "aging") are steels (iron alloys) that are known for possessing superior strength and toughness without losing malleability, although they cannot hold a good cutting edge. *Aging* refers to the extended heat-treatment process. These steels are a special class of low-carbon, ultra-high-strength steels that derive their strength not from carbon, but from precipitation of inter-metallic compounds.

The principal alloying element is 15 to 25 wt. % nickel. Secondary alloying elements, which include cobalt, molybdenum, and titanium, are added to produce inter-metallic precipitates. The common, non-stainless grades contain 17–19 wt. % nickel, 8–12 wt. % cobalt, 3–5 wt. % molybdenum, and 0.2–1.6 wt. %titanium. Addition of chromium produces stainless grades resistant to corrosion. This also indirectly increases hardenability as they require less nickel: high-chromium, high-nickel steels are generally austenitic and unable to transform to martensite when heat treated, while lower-nickel steels can transform to martensite.

D.I. Lalwani & N.K. Mehta [1] has made work on the effect of cutting parameters (cutting speed, feed rate and depth of cut) on cutting forces (feed force, thrust force and cutting force) and surface roughness in finish hard turning of MDN250 steel (equivalent to 18Ni (250) Maraging steel) using coated ceramic tool. The machining experiments were conducted based on response surface methodology (RSM) and sequential approach using face centered central composite design. The results show that cutting forces and surface roughness do not vary much with experimental cutting speed. Depth of cut is the dominant contributor to the feed force.

Based on phase transformation and surface roughness analyses, in micro-grinding of maraging steel 3J33 Beizhi Li et al. [2] provided some suggestions on the combination range of process parameters. They suggested that the high quality of grinding surface can be obtained by choosing a moderate wheel rotation speed combined with the appropriate range of effective wheel revolution and also using these parameters, micro-grinding tools dynamic performance can be reduced.

Ding et al. [3] investigated the phase transformation and residual stress distribution in the grinding of Maraging C250 steel. Phase transformation is reduced while the residual stress is improved with the increase of effective wheel revolution. These results indicate that the reduction of grinding-induced phase transformation cannot decrease the magnitude of residual stress on the surface layer. The improvement of surface quality without enlargement of residual stress or phase transformation can be realized at the middle range of effective wheel revolution.

Aslan et al. [4] developed a thermo-mechanical model to predict the forces and surface roughness in grinding with circumferentially grooved and regular (non-grooved) wheels. These models can be effectively used in predicting the cutting forces and surface roughness, once the wheel topography and sliding friction coefficient are identified.

A mechanical physics-based modeling considering strain rate effects with a phase transformation kinetics approach for maraging steel grinding process was presented by Zishan Ding et al. [5]. It is implied that temperature is not the only dominating factor for the phase transformation, which can take place at a grinding temperature below the nominal transformed temperature. Strain rate plays a significant role for the phase transformation during the grinding heating process.

The aim of the paper is to study the effect of grinding parameters such as feed (mm/min) & depth of cut (mm) on material removal rate, grinding time, surface roughness & micro hardness of Maraging steel (MDN 250) on horizontal surface grinding machine. Then mathematical i.e. regression model is developed for material removal rate, grinding time, &surface roughness. ANOVA was conducted to evaluate the effect of individual parameter and their interactions on response parameters.

2. EXPERIMENTATION

Two level factorial designs with 5 central runs and 4 axial runs leading to central composite design were used to conduct experiment [6, 7] . Table 1 listed the coded and actual values of different parameters used in surface grinding of MDN250 material. The experimental plan is given in Table 2.

The experiments are conducted on tool & cutter grinder machine. The work piece was loaded on magnetic chuck. The input dimensions of the work piece 31mm X 30mm X 12.7mm .The weight of each work piece before and after grinding is measured in order to calculate material removal rate. After every experiment the grinding wheel has undergone dressing for at least 2 min in order to remove the metal entrapment in the grinding wheel. 1.5 min was taken approximately for truing the tool and setting up the job for all thirteen experiments. Servo-cut-S coolant oil was used as coolant. After conducting the experiments output responses like MRR, Grinding time and Surface roughness was measured. Grinding time is the time taken in removal of metal by the rotating abrasive wheel at a defined feed and depth of cut to abrade or wear away. The grinding time values obtained after carrying out the experiments is given in the Table 2.

Table 1. Coded levels and actual values of process parameters

Machining parameters	Units	Levels				
		-1.414	-1	0	+1	+1.414
Feed	mm/min	0.4	0.317	0.6	0.88	0.8
Depth of cut	mm	0.0034	0.02	0.06	0.117	0.1

Table 2. Plan of experiments and the responses

Std	Run	Coded factors		Actual levels		Total Grinding time (min)	Material removal rate (mm/min)	Surface Roughness (µm)	Micro hardness Hv
		Feed (mm/rev)	Depth of cut (mm)	Feed (mm/rev)	Depth of cut (mm)				
1	4	-1	-1	0.40	0.02	26	7.153	0.19	21.409
2	12	1	-1	0.80	0.02	8.65	21.502	0.36	23.065
3	11	-1	1	0.40	0.09	7	26.571	0.19	22.416
4	13	1	1	0.80	0.09	4.39	42.369	0.25	21.688
5	6	-1.414	0	0.32	0.06	7.15	26.013	0.27	22.459
6	9	1.414	0	0.88	0.06	4.35	42.758	0.31	22.962
7	2	0	-1.414	0.60	0.01	28.75	6.469	0.35	21.688
8	3	0	1.414	0.60	0.10	4.76	39.075	0.17	22.46
9	8	0	0	0.60	0.06	6.03	30.845	0.21	20.789
10	10	0	0	0.60	0.06	5.553	33.495	0.19	22.86
11	7	0	0	0.60	0.06	6.62	28.096	0.15	22.361
12	1	0	0	0.60	0.06	5.34	34.831	0.19	21.782
13	5	0	0	0.60	0.06	6.43	28.926	0.11	21.973

In this sub chapter, the results in terms of material removal rate (MRR), grinding time and surface roughness are discussed. The method RSM is used, is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response. Using RSM, independent parameters are chosen viz. feed (mm/min) and depth of cut (mm). Response surface central composite design analysis is done to evaluate the effect of individual parameter and their interactions on response parameters viz. material removal rate, grinding time and surface roughness using Stat-Ease Design Expert software. The contribution of each term of the model in affecting improvement in response variable was found out through the sum of square method.

To know the significance of regression equation in explaining the relationship between responses and machining parameters, ‘F’ test from the Analysis of Variance (ANOVA) was conducted. The contribution of each term of the model, in affecting percent improvement in material removal rate, grinding time and surface roughness was found out through the sum of squares method. Separate ANOVA was carried out to know contribution of machining parameter on material removal rate, grinding time & surface roughness. Analysis was carried out with the help of Stat-Ease Design-Expert software. It gives the main effect of process parameter on response parameters and these analyses help in design a regression equation for response parameters which helps on calculating the response parameters. Thus the relationship between input and output parameters is obtained through empirical expressions developed by using the output values of response parameters.

Sequential Model sum of Squares were calculated to select the highest order polynomial for MRR where the additional terms are significant and the model is not aliased. **Lack of fit test** for each model was calculated and it is insignificant. On the basis above two, quadratic model was selected A, B, AB, A^2, B^2 were included in the Response Surface Model. The Analysis of Variance (ANOVA) for MRR model is given in Table 3.

Table 3. Analysis of Variance for Material removal rate in machining of Maraging steels

Source	**Sum of Squares**	**DOF**	**Mean Square**	**F Value**	**p-value Prob> F**	
Model	1500.05	5.00	300.01	27.00	0.00	significant
A-feed	362.18	1.00	362.18	32.59	0.00	
B-doc	933.05	1.00	933.05	83.96	< 0.0001	
AB	0.53	1.00	0.53	0.05	0.83	
A^2	1.94	1.00	1.94	0.18	0.69	
B^2	193.81	1.00	193.81	17.44	0.00	
Residual	77.79	7.00	11.11			
Lack of Fit	44.42	3.00	14.81	1.77	0.29	not significant
Pure Error	33.38	4.00	8.34			
Cor Total	1577.84	12.00				

The same procedure is adopted for grinding time and surface roughness. The final regression equation in term of actual values for MRR, grinding time and surface roughness respectively are as follows:

$$\boldsymbol{MRR = -12.488 + 14.943Feed + 751.48depth + 51.75feed * depth + 13.211feed^2 - 4308.81depth\ of\ cut^2}$$

3. RESULTS AND DISCUSSION

3.1 Effect of feed & depth of cut on material removal rate

The increase in feed has led to increase in material removal rate .It was also observed that surface roughness decreased as feed was increasing. Material removal rate was maximum at 70 (mm^3/min) at a feed of 0.88 (mm/min)). Feed has significant effect on material removal rate but as feed increased it was observed the tool wear was higher. As feed increases the chances of grains of wheel material adhering to workpiece increases which leads to shorter tool life and poor surface finish.

The increase in depth of cut led to increase in material removal rate. Maximum material removal rate was observed at 0.09 mm depth of cut. But poor surface finish was observed as depth of cut increased. As depth of cut increases, grinding forces near the contact zone also gets increased and this leads to increase in friction & temperature rise at the contact zone. Using of coolant decreases the friction between grinding wheel and work piece & also reduces the temperature rise near the interface increasing the material removal rate without affecting the surface finish of the work piece. The effect of feed and depth of cut on material removal rate is shown in Figs.5 (a) & (b) respectively.

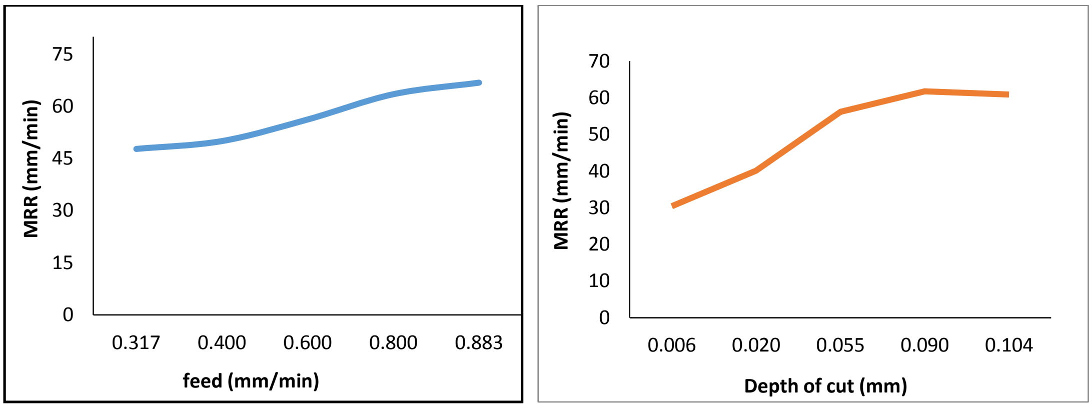

Figure 5: (a) Effect of feed (b) depth of cut on material removal rate

3.2 Effect of feed & depth of cut on grinding time

The grinding time has consistently decreased as the feed is increased. The increase in depth of cut at a constant feed led to decrease in grinding time. But the decrease in grinding time is sharp. It has been observed that grinding time will get affected due to increase in depth of cut and feed. If coolant is used, the grinding time remains consistent because the dressing time required is less. Grinding time reduces because the time taken for wheel dressing is minimum but this leads to shorter grinding wheel life. The effect of grinding time on feed & depth of cut is shown in Figs.6 (a) and (b) respectively.

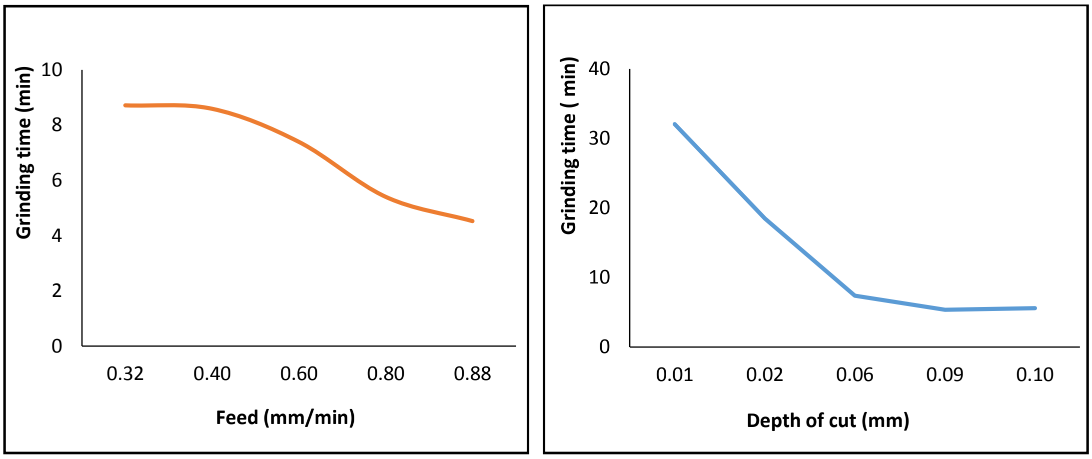

Figure 6: Effect of (a) feed and (b) depth of cut on grinding time

3.3 Effect of feed & depth of cut on surface roughness

As the feed increased surface roughness decreased till certain point and then again increased. At 0.06 feed (mm/min) the surface roughness value was less and beyond 0.06 feed rates till 0.883 mm/min surface roughness increased. Minimum surface roughness value was observed at 0.06 mm depth of cut. As the depth of cut increased surface roughness is decreased. It was observed that surface roughness value was minimum at 0.09 mm depth of cut. The effect of feed & depth of cut on surface roughness in shown in Fig.7 (a) and (b) respectively.

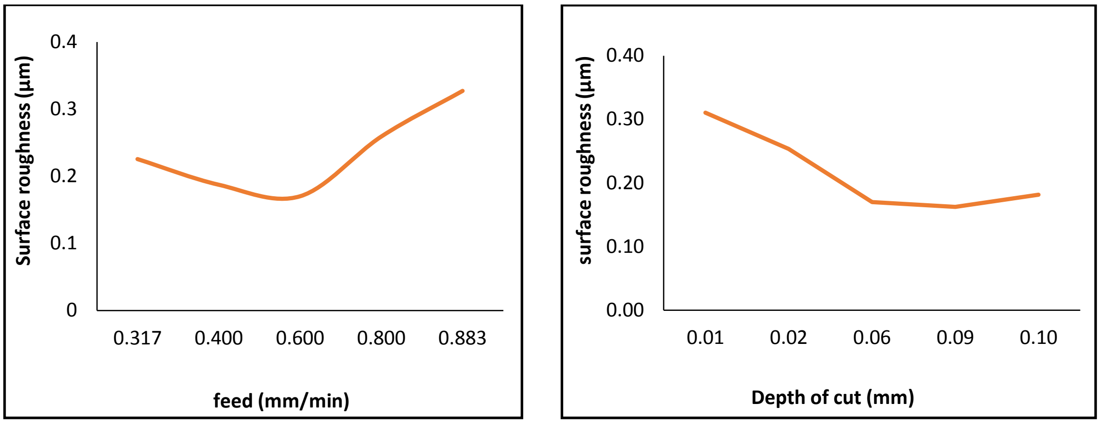

Figure 7: Effect of (a) feed and (b) depth of cut on surface roughness

4. CONCLUSIONS

After analyzing the results of the experiments of Maraging steel with Aluminium oxide grinding wheel and servo oil as a coolant, the following conclusions are arrived at:

- Increase in feed leads to a sharp increase in the material removal rate. At a feed of 0.88 mm/min material removal rate was max at 70 mm^3/min. So, feed was the most significant factor in MRR. The increase in depth of cut leads to an increase in material removal rate. Maximum material removal rate was observed at 0.09 mm depth of cut.
- The increase in feed decreases the grinding time. The increase in depth of cut has led to sharp decrease in grinding time.
- As the feed increased surface roughness decreased till certain point and then again increased. At 0.06 feed (mm/min) the surface roughness value was less and beyond 0.06 till 0.883 feed, roughness's values were increasing. Minimum surface roughness value was observed at 0.06 mm depth of cut.

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