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Optimization of Surface Roughness for hot machining of AISI 4340 steel using DOE method

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Abstract — Material which posses hardness above 45Hrc are difficult to machine with conventional type machining. "Hot Machining" is used for easy machining of these type materials. The Workpiece is preheated or heated during machining operation in hot machining method and it was reported that many advantages have been observed like longer tool life, better surface finish and cost-effective production. In this work, an experimental investigation had been carried out for hot machining of AISI 4340 steel using a tungsten carbide cutting tool. The heating of the work piece was carried out by burning a mixture of oxygen and acetylene gas. The influence of the cutting parameters namely cutting speed (Vs), feed rate (fs) and depth of cut (a_p) at 200°C, 400°C and 600°C hot machining of AISI 4340 steel on surface roughness are studied. Individual and combined effects of cutting parameters i.e. temperature, cutting speed, feed on the surface roughness of the work piece are investigated. The relationship between the parameters and the performance measure is determined using multiple linear regression equation.

Keywords — hot machining, surface roughness, AISI 4340 steel parameters, cutting speed, feed rate, temperature.

I. INTRODUCTION

Materials with resistance to wear are frequently utilized in industry and these materials are notoriously difficult to machine. AISI 4340 steel is one of these wear resistant materials. During the machining process, instead of increasing the quality of the cutter materials, softening of the workpiece is the preferred approach . One of the methods of softening the workpiece is hot machining. In hot machining, a part or the whole of the workpiece is heated. Heating is performed before or during machining. Hot machining prevents cold working hardening by heating the piece above the recrystallisation temperature and this reduces the resistance to cutting and consequently favours the machining. The turning of materials, which have the high strength, wear resistance and toughness exhibit lot of difficulties while doing by conventional machining methods, and yields desirable results only by the selection of optimum machining parameters. Such materials are widely used commonly in aerospace, nuclear industries and food processing industries. AISI 4340 Steel one such material, which posses above mentioned challenges during machining. It is also requires a high strength and robust and costlier cutting tool. The production of super alloys, high hard and smart materials have become extremely essential to satisfy the design requirements for critical equipments, aerospace and defense industries. The machining of such materials has always been a great challenge before the production engineer. These alloys and materials can be machined by cutting tools of vary high hardness and strength but during the machining process, instead of increasing the quality of the cutter materials, softening of the work piece is the preferred approach. The workpiece temperature was chosen above the recrystallisation temperature, where the yield stress of materials decreased rapidly. The yield strength of the structural steel (C355) tend to decrease, when its temperature increasing.Fig.1.

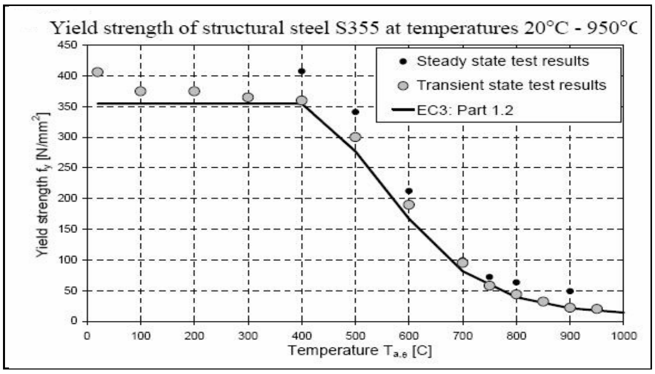

Fig. 1 Effect of Temperature on the yield Stress [3]

II. LITERATURE REVIEW

Pal and Basu carried out hot machining of high manganese steel in shaping operation [11]. Oxyacetylene Torch as heating method was used just ahead of the carbide cutting tool. It was noticed that tool life increased with application of higher temperature (up to 650°C). Tool lifes were 1 min at room temperature, 5-6 mins at 400°C, 7-8 mins at 500 °C and 10 mins at 650°C[1].

N.Tosun and Ozler were used hot machining technique in turning operation. The optimization of the turning operation with multiple performance characteristics, tool life and workpiece surface roughness, was studied using weighted factor to improve the tool life and the workpiece surface roughness. The parameter design method proposed by Taguchi was adopted. Experimental results obtained, when cutting high manganese steel heated with the liquid petroleum gas (LPG) flame, were presented. They improved the approach proposed [2].

Raghuram and Muju reported that tool life has been improved by magnetization and also by a reduction in tool wear was observed due to an external magnetic field in hot machining [3]. Production of hard-to-cut materials with uncoated carbide cutting tools in turning, not only cause tool life reduction but also, impairs the product surface roughness. **M. Davami and M. Zads hakoyan** , in their paper studied the influence of hot machining method and presented in two cases. [4].

Kamdar and Patel machined the EN 36 Steel specimens heated with gas flame on a lathe under different cutting conditions of Surface temperatures, Cutting speeds and Feed rates. Cutting force, feed force and surface roughness were studied under the influence of machining parameter at 200 °C,300 °C, 500 °C,C at constant depth of cut 0.8 mm. The optimum result was achieved in the experimental study by employing Design of experiments With Taguchi. In present study, Analysis found that varying parameters are affected in different way for different response. The ANOVA technique was used to obtain optimum cutting parameters. [5]

Maity and Swain carried out an experimental investigation for hot-machining operation of high manganese steel using a carbide cutting tool. The eating of the work-piece was carried out by burning a mixture of liquid petroleum gas and oxygen. An expression of tool life as a function of cutting speed, feed, depth of cut and temperature was developed using regression analysis. The model adequacy is tested using χ 2 **[5]** test. The tool life is influenced by work-piece temperature, cutting speed, feed and depth of cut in that order. So the effect of temperature of work-piece is found to be the most significant on tool life. However the recrystallisation temperature of work-piece limits the maximum value of temperature. The chip-reduction coefficient decreases with increase in temperature. [6].

III EXPERIMENTAL DETAILS

The experiment was conducted on an auto feed lathe for hot machining operation of AISI 4340 Steel using a Tungsten Carbide cutting tool. The temperature was measured by a infrared thermometer for different condition .Experimental set up is shown in figure-1.Oxi-Acetylene gas flame is used to heat the work piece material

Figure-1 Experimental setup of hot machining

AISI 4340 steel is high-carbon chromium steel, with small quantities of silicon and manganese. AISI 4340 Steel is exceptionally hard and wear-resistant, and is It is widely used for aircraft landing gear, power transmission gear, shaft and other parts. an excellent choice for applications where high operating temperatures is needed. The chemical compositions and physical properties of AISI 4340 steel are given in Table-1. Tungsten carbide was used as a cutting tool during the experiment. The mechanical properties of the cutting tool are shown in Table-2.

Table 1 Chemical composition of AISI4340

Elements	C	Si	Mn	Cr	S	P
%	0.43	0.26	0.65	0.9	0.04	0.03

Table 2 Cutting Tool properties tungsten carbide

Density	15.7g/cm^3
Poisson's ratio	0.28
Hardness	90 HRc
Yield strength	2683 Mpa
Young's modulus	669-696 KN/mm^2

Table 3 Parameter selection range levels

Control Factors	LEVEL-1	LEVEL-2	LEVEL-3
Cutting speed (m/min)	13.84	21.71	32.21
Feed (mm/rev)	0.065	0.102	0.152
Temperature (^{0}C)	200	400	600

In, the experiment result shown in the table 4 and after the machining is performed for all input parameters, the surface roughness is measured using surface roughness tester.

V. RESULTS AND DISCUSSION

Table 4 Result table

Sr. no.	Temp. (^{0}C)	Cutting Speed (m/min)	Feed rate (mm/rev)	Surface Roughness(R_a)μ
1	200	13.84	0.065	1.520
2	200	13.84	0.102	1.450
3	200	13.84	0.152	1.301
4	200	21.71	0.065	1.412

5	200	21.71	0.102	1.234
6	200	21.71	0.152	1.090
7	200	32.21	0.065	1.140
8	200	32.21	0.102	1.023
9	200	32.21	0.152	1.145
10	400	13.84	0.065	1.542
11	400	13.84	0.102	1.427
12	400	13.84	0.152	1.250
13	400	21.71	0.065	1.427
14	400	21.71	0.102	1.190
15	400	21.71	0.152	1.176
16	400	32.21	0.065	1.227
17	400	32.21	0.102	1.139
18	400	32.21	0.152	0.976
19	600	13.84	0.065	0.987
20	600	13.84	0.102	0.923
21	600	13.84	0.152	0.912
22	600	21.71	0.065	1.023
23	600	21.71	0.102	0.896
24	600	21.71	0.152	0.878
25	600	32.21	0.065	0.824
26	600	32.21	0.102	0.792
27	600	32.21	0.152	0.678

Source of variation	**F**	**Sum of squares**	**Variance (mean square) v**	**Variance ratio F**	**Percent contribution P**
Factor A	2	0.867772	0.435	90.73	59.80
Factor B	2	0.31	0.15	32.89	21.68
Factor C	2	0.16	0.08	16.97	11.18
Error (e)	20	0.09	0.004	1	

Table 5 Results of ANOVA for Surface Roughness

Total	26	1.44			

Following is the Minitab 15 window in which ANOVA results for Surface Roughness is shown, which is mostly nearer to the calculated value. Temperature effect more on the surface roughness of the work piece as shown in the table then cutting speed and last feed rate.

Table 6 Analysis of Variance for Surface roughness, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temp	2	0.86724	0.86724	0.43362	90.73	0.000
Cutting Speed	2	0.31443	0.31443	0.15721		
Feed	2	0.16220	0.16220	0.08110	32.89	0.000
Error	20	0.09559	0.09559	0.00478	16.97	0.000
Total	26	1.43946				
S = 0.0691335 R-Sq = 93.36% R-Sq(adj) = 91.37%						

<u>Regression Model Analysis of Surface Roughness:</u>

Weighted analysis using weights in Surface Roughness.

Surface roughness = 2.06 - 0.000945 Temp - 0.00860 Cutting speed - 2.13 Feed

Table 7 Estimated Model Coefficients for Ra

Predictor	Coef	SE Coef	T	P
Constant	2.0606	0.1145	18	0.000
Temp	-	0.0001405	-6.73	0.000
Cutting Speed	-	0.001828	-4.70	0.000
Feed Rate	-2.1273	0.6435	-3.31	0.003
S = 0.119207 R-Sq = 77.3% R-Sq(adj) = 74.3%				

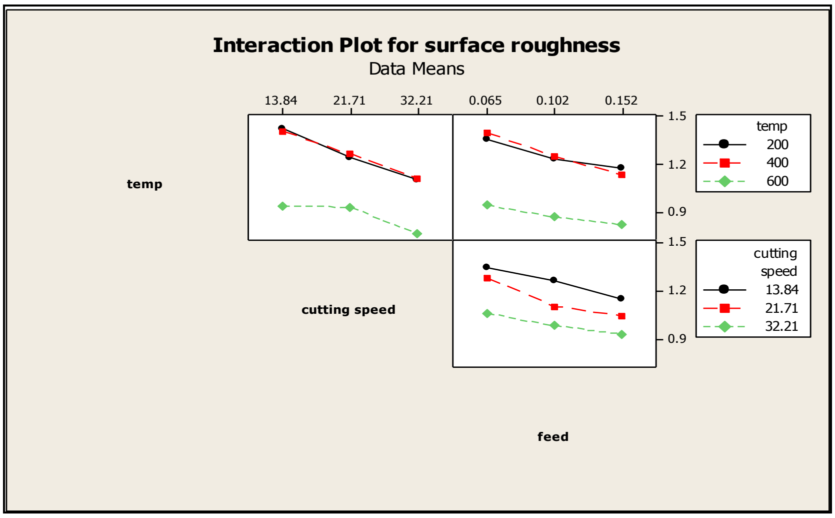

Figure 1 Interaction Plot for Surface Roughness

The coefficients of model for Surf Roughness are shown in Table 7. The parameter R^2 describes the amount of variation observed in Surf Roughness is explained by the input factors. R^2 =77.3 % indicate that the model is able to predict the response with high accuracy. Adjusted R^2 is a modified R^2 that has been adjusted for the number of terms in the model. If unnecessary terms are included in the model, R^2 can be artificially high, but adjusted R^2 (=74.3 %.) may get smaller.

The standard deviation of errors in the modeling, S= 0.119207 Comparing the p-value to a commonly used α-level = 0.05, it is found that if the p-value is less than or equal to α, it can be concluded that all the effects are significant.

VI. CONCLUSION

By hot machining maximum surface roughness obtained 1.52 μm at 200 ^{O}C temperature, 13.84 m/sec cutting speed and 0.065mm/rev feed and minimum surface roughness obtained0.678 μm at600^{O}C temperature, 32.21 m/sec cutting speed and 0.152 mm/rev feed. As shown in table 4 surface roughness decreased from top to bottom means all three cutting parameters are increased this is because of at higher temperature yield strength of work material decreased and it becomes ductile. It is beneficial to increase feed rate and which results in higher production rate.

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