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Performance Evaluation and Parametric Optimization of Hot Machining Process on EN-31 Material

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Abstract- In this study, project work focus on find out optimal process parameter in hot machining of EN-31 steel material. The resultant data was analysed by taguchi method to find out a combination of optimal process parameter. In present research work, an experimental study was conducted to investigate the influence of process parameters in hot machining particularly spindle speed, feed rate and temperature on surface roughness and hardness. Hot machining operation of EN-31steel using a tungsten carbide cutting tool. The heating of the work-piece was carried out by using oxygen and LPG cylinder. Study also includes find out optimum value with the help of main effect plot and ANOVA tables to find out which parameter affect most for surface roughness and hardness.

Key wards: EN-31 Steel Material, Surface Roughness, Hardness, Taguchi Method, ANOVA

I. INTRODUCTION

With advancement in science and technology, there is a need of materials with very high hardness and shear strength in the market. So many materials which satisfy the properties are manufactured. Machining of such materials with conventional method of machining was proved to be very costly as these materials greatly affect the tool life. So to increase tool life, to decrease the power consumption and for improving the machinability an innovative process hot machining came into existence. Here the temperature of the work piece is raised to several hundred or even thousand degree Celsius above ambient, so as to reduce the shear strength of the material. Various heating method has been attempted, for example, bulk heating using furnace, area heating using torch flame, plasma arc heating, induction heating and electric current resistance heating at tool-work interface. The basic of hot machining operation is to first soften the work piece is by preheating and thereby shear strength gets reduced, which results in easier machining of materials with many other added advantages

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 workpiece below the recrystallisation temperature and this reduces the resistance to cutting and consequently favours the machining.

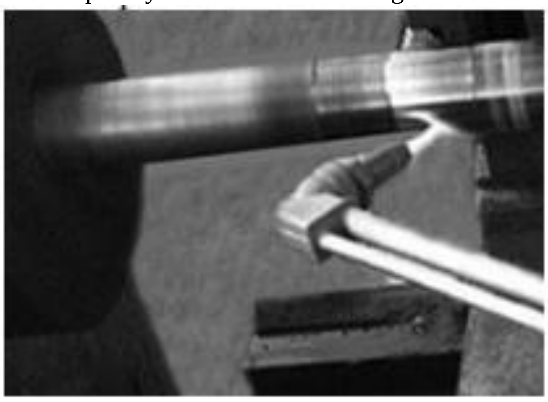

Fig 1.1: Hot machining with flame

II EXPERIMENTAL DETAIL

The experiment was conducted on an lathe machine for hot machining operation of EN-31 steel material using a Tungsten Carbide cutting tool. The thermocouple was used to measure the temperature of the workpiece.

A. Workpiece material and cutting tool:

EN31 is a quality high carbon alloy steel which offers a high degree of hardness with Fabrication and Heat Treatment. EN31 is a high quality alloy steel giving good ductility and shock resisting properties combined with resistance to wear. This steel is basically known as bearing steel and used for gauges, swaging dies, ejector pins, ball and roller bearings production in industrial sector. The EN-31 round bar of 36 mm diameter and 67mm length size has been used as a work piece material for the present experiments. The chemical compositions and mechanical properties of EN-31steel material are given in Table-1 and Table-2.

Tungsten carbide was used as a cutting tool during the experiment. The mechanical properties of the tungsten carbide tool are shown in Table-3.

B. Design of experiment:

Design of experiments (DoE) method are among the most effective and useful statistical quality control technique to investigate the individual and interaction effects of the process parameters. These methods also involve the activity experimental planning, conducting experiments, and fitting models to the outputs. Hence Taguchi based design of experiment method was implemented. In Taguchi method L25 Orthogonal array provides a set of well-balanced experiments, and Taguchi's signal-to-noise (S/N) ratios.
The range of process parameters are shown in Table-4.

Table 1. Chemical composition of work piece material

Constituent	**C**	**Si**	**S**	**P**	**Mn**	**Cr**
% Composition	1.100	0.230	0.033	0.028	0.470	1.220

Table 2. Mechanical properties of work piece material

Properties	**Values**
Hardness	176 HBW
Yield Load	39.39 KN
Ultimate Load	68.22 KN
Ultimate Tensile Stress	690.93 KN
Yield Stess	398.94 Mpa
Elongation	21.78

Table 3. Mechanical properties of tungsten carbide tool

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

Table-4. Process parameters and their levels

Factors	**Parameters**	**Level 1**	**Level2**	**Level3**	**Level4**	**Level5**
A	**Temperature (^{0}C)**	100	200	300	400	500
B	**Speed (m/min)**	60	120	180	240	300
C	**Feed (mm/rev.)**	0.111	0.222	0.333	0.444	0.555

Table-5. Result table for analysis

Test Run No.	**Temperature (^{0}C)**	**Speed (m/min)**	**Feed (mm/rev.)**	**Hardness (BHN)**	**Surface Roughness(μm)**
1	100	60	0.111	174	5.43
2	100	120	0.222	174	5.33
3	100	180	0.333	174	5.21
4	100	240	0.444	174	5.04

5	100	300	0.555	174	4.79
6	200	60	0.222	170	4.71
7	200	120	0.333	170	4.63
8	200	180	0.444	170	4.51
9	200	240	0.555	170	4.34
10	200	300	0.111	170	4.16
11	300	60	0.333	167	4.01
12	300	120	0.444	167	3.92
13	300	180	0.555	167	3.80
14	300	240	0.111	167	3.70
15	300	300	0.222	167	3.45
16	400	60	0.444	165	3.30
17	400	120	0.555	165	3.21
18	400	180	0.111	165	3.17
19	400	240	0.222	165	3.00
20	400	300	0.333	165	2.75
21	500	60	0.555	162	2.59
22	500	120	0.111	162	2.58
23	500	180	0.222	162	2.46
24	500	240	0.333	162	2.29
25	500	300	0.444	162	2.04

III. RESULTS AND DISCUSSION:

A. Effect on hardness:

Main Effects Plot for Mean data and S/N ratio data are shown in fig 2. and fig. 3. that displays effect of speed, feed and temperature on hardness.

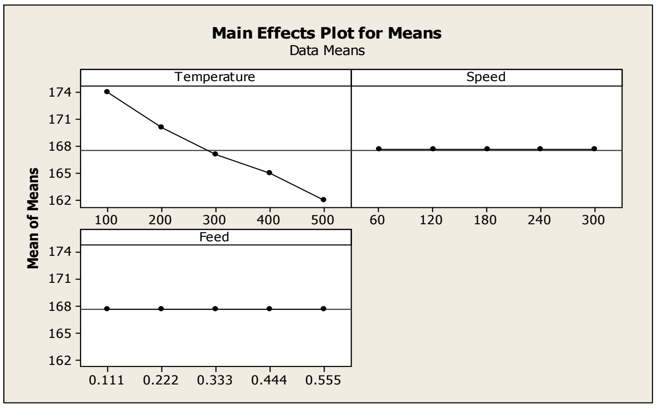

Fig. 2: Main effect plot: Mean for Means

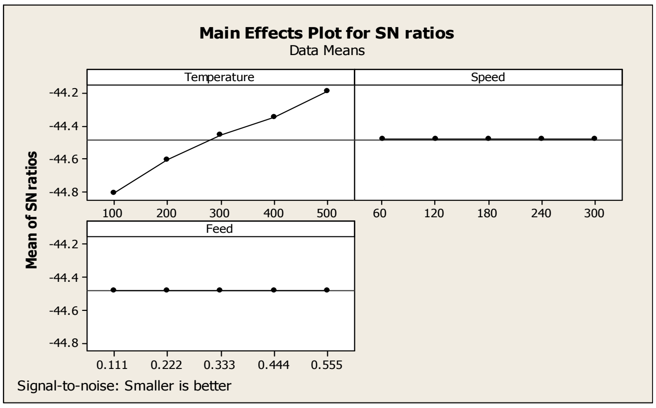

Fig. 3: Main effect plot: Mean of S/N Ratios

Figure-2 shows the main effect plot of hardness at different parameters like temperature, cutting speed and feed rate in hot machining process of EN-31 material. From the figure-2, it can be seen that minimum hardness obtained is at temperature 500 ^{0}C and hardness constant in plot of speed and feed.

B. Effect on surface roughness:

Main Effects Plot for Mean data and S/N ratio data are shown in fig 4. and fig. 5. that displays effect of speed, feed and temperature on surface roughness.

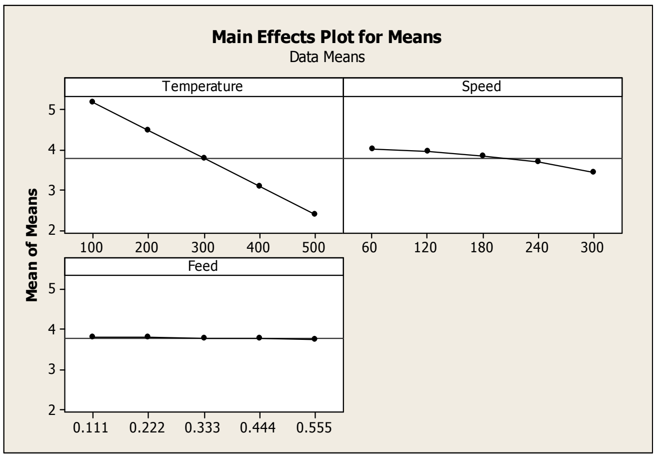

Fig. 4: Main effect plot: Mean of Means

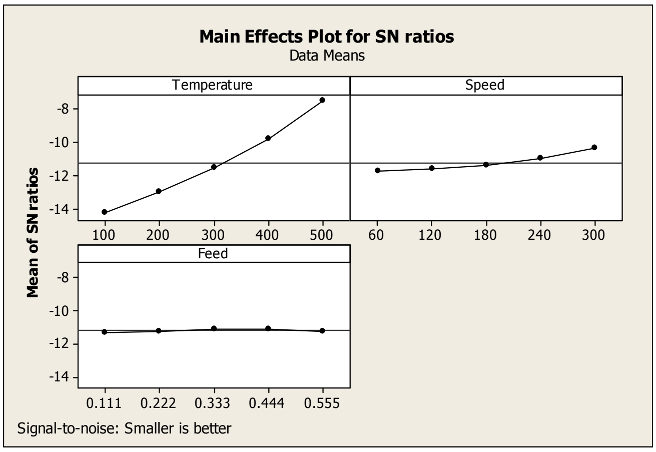

Fig. 5: Main effect plot: Mean of S/N Ratios

Fig.4 shows the main effect plot surface roughness at different parameters like temperature, cutting speed and feed rate in hot machining process of EN-31 material. From the figure, it can be seen that minimum surface roughness obtained is at temperature 500 ^{0}C, cutting speed of 300 m/min and feed rate of 0.555 mm/rev.

C. Regression Model Analysis of Hardness:

The regression equation is
Hardness = 176 - 0.0290 Temperature - 0.00000 Speed - 0.000 Feed

Table-6 Estimated model coefficients for hardness

Predictor	Coef	SE Coef	T	P
Constant	176.300	0.390	452.34	0.000
Temperature	-0.290000	0.0007237	-40.07	0.000
Speed	-0.000000	0.001206	-0.00	1.000
Feed	-0.0000	0.6520	-0.00	1.000
S = 0.511766 R-Sq = 98.7% R-Sq(adj) = 98.5%				

The coefficients of model for S/N ratios for hardness are shown in Table 6. The parameter R2 describes the amount of variation observed in surface roughness is explained by the input factors. R-Sq = 98.7 % indicate that the model is able to predict the response with high accuracy. Adjusted R-Sq is a modified R-Sq that has been adjusted for the number of terms in the model. If unnecessary terms are included in the model, R-Sq can be artificially high, but adjusted R-Sq (=98.5 %.) may get smaller. 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.

D. Regression Model Analysis of Surface Roughness:

The regression equation is
Surface Roughness = 6.32 - 0.00692 Temperature - 0.00233 Speed - 0.137 Feed

Table-7 Estimated model coefficients for surface roughness

Predictor	Coef	SE Coef	T	P
Constant	6.31840	0.03789	166.74	0.000

Temperature	-0.0069200	0.00007037	-98.34	0.000
Speed	-0.0023333	0.0001173	-19.90	0.000
Feed	-0.13694	0.06339	-2.16	0.042
S = 0.0497575 R-Sq = 99.8% R-Sq(adj) = 99.8%				

The coefficients of model for hardness are shown in table 7. The parameter R-Sq describes the amount of variation observed in surface roughness is explained by the input factors. R-Sq = 99.8% indicate that the model is able to predict the response with high accuracy. Adjusted R-Sq is a modified R-Sq that has been adjusted for the number of terms in the model. If necessary terms are included in the model, R-Sq can be artificially high, but adjusted R-Sq (=99.8%) may get smaller.
The standard deviation of errors in the modeling, S= 0.0497575. 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.

E. Comparison of regression model with experimental results for hardness:

Table-8 Comparison of regression model for hardness

Exp. No.	Experimental Value	Predicted Value	Predicted Error
1	174	173.1	0.9
2	174	173.1	0.9
3	174	173.1	0.9
4	174	173.1	0.9
5	174	173.1	0.9
6	170	170.2	-0.2
7	170	170.2	-0.2
8	170	170.2	-0.2
9	170	170.2	-0.2
10	170	170.2	-0.2
11	167	167.3	-0.3
12	167	167.3	-0.3
13	167	167.3	-0.3
14	167	167.3	-0.3
15	167	167.3	-0.3
16	165	164.4	0.6
17	165	164.4	0.6
18	165	164.4	0.6
19	165	164.4	0.6
20	165	164.4	0.6
21	162	161.5	0.5
22	162	161.5	0.5
23	162	161.5	0.5
24	162	161.5	0.5
25	162	161.5	0.5

Table-8 shows the comparison of experimental value of hardness to Predicted values. Error computed is very less so it can be said that prepared Multiple Linear Regression Equation is suitable for estimating hardness values.

F. Comparison of regression model with experimental results for surface roughness:

Table-9 Comparison of regression model for surface roughness

Exp. No.	Experimental Value	Predicted Values	Predicted Error
1	5.43	5.47	-0.04
2	5.33	5.31	0.02
3	5.21	5.16	0.05
4	5.04	5.00	0.04
5	4.79	4.85	-0.06
6	4.71	4.76	-0.05
7	4.63	4.61	0.02
8	4.51	4.45	0.06
9	4.34	4.30	0.04
10	4.16	4.22	-0.06
11	4.01	4.05	-0.04
12	3.92	3.90	0.02
13	3.80	3.74	0.06
14	3.70	3.66	0.04
15	3.45	3.51	-0.06
16	3.30	3.35	-0.05
17	3.21	3.19	0.02
18	3.17	3.11	0.06
19	3.00	2.96	0.04
20	2.75	2.80	-0.05
21	2.59	2.64	-0.05
22	2.58	2.56	0.02
23	2.46	2.41	0.05
24	2.29	2.25	0.04
25	2.04	2.10	-0.06

Table-9 shows the comparison of experimental value of surface roughness to predicted values. Error computed is very less so it can be said that prepared Multiple Linear Regression Equation is suitable for estimating surface roughness values.

IV. CONCLUSIONS:

After completing the experiments and analysis, the following conclusions were derived.

1. Hot machining process gives good surface finish at high temperature, high cutting speed and low feed rate and it is also beneficial in terms of surface roughness.
2. Temperature is the most affecting factor for hardness and with increases in the temperature, hardness decreases significantly. Cutting speed and feed has no effect on hardness.
3. At temperature of 500 ^{0}C during hot machining, workpiece surface color was changed.
4. Finally, the optimum experimental condition for minimum surface roughness value 2.04 µm (500 ^{0}C, 300 m/min, 0.444 mm/rev.) and hardness value 162 BHN (500 ^{0}C, 60 m/min, 0.555 mm/rev.).
5. The predicted values obtained from regression model of hardness and surface roughness were close to the measured value of experimental tests. The results of prediction error indicate that the regression models can be used to predict the hardness and surface roughness.
6. The developed Multiple Linear Regression Model is found very adequate for all the responses because the error is found

in an acceptable range on comparison with the experimental values.

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