Experimental Investigation of Machining Parameters of EN 36 Steel using Tungsten Carbide Cutting Tool during Hot Machining

Nirav M. Kamdar*, Prof. Vipul K. Patel**
*(M.E. MECHANICAL (CAD/CAM) Student, Sankalchand Patel College of Engineering, Visnagar, Mehsana, Gujarat, India)
**(Department of Mechanical Engineering, Sankalchand Patel college of Engineering, Visnagar, Mehsana, Gujarat, India)

ABSTRACT
In this work, the EN 36 Steel specimens heated with gas flame were machined 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, 400 °C, 500 °C and 600 °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 analysis was used to obtain optimum cutting parameters.

*KEYWORDS: **Cutting speed; Feed rate; Depth of cut; Surface roughness; Tool life; Hot machining***

I. INTRODUCTION
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 (S. Ranganathan and T. Senthilevan, 2010). Such materials are widely used commonly in aerospace, nuclear industries and food processing industries. Non-conventional machining techniques such as abrasive jet machining, electro chemical machining and electrical discharge machining processes remove a very small amount of material in every pass, which is very expensive and consuming more time as well. Hence, hot machining process has been developed in industries to remove large amount of materials without compromising machining and quality. In hot machining, a part or whole of work-piece is heated. Heating is performed before or during machining. Hot machining prevents cold working hardening by heating the work-piece above the recrystallization temperature and this reduces the resistance to cutting and consequently favours the machining. Hot machinable materials are classified in four groups according to their composition and properties. These classes are (i) chilled cast iron, (ii) steel with hardness over 50 HRC, (iii) steel whose surface is hardened with cobalt and other additional alloys and (iv) steels hardened by cold working (M. Davami and M. Zadshakoyan, 2008). A selection of improper heating method of the work-piece material will lead to undesirable structural changes, which increases the machining cost. From the past studies, it was understood that for heating the workpiece during hot machining different methods of heating, such as, furnace heating, flame heating, laser heating, friction heating, electric heating and plasma arc heating methods have been employed. One of the primary objectives is to reduce the machining cost without sacrificing the quality of the machined parts (S. Ranganathan and T. Senthilevan, 2010).

Tigham first innovated the process of hot machining in 1989, since then it has created much interest among various investigators. Pal and Basu investigated the tool life during hot machining of Austenitic Manganese Steel and they reported that the tool life is dependent on work piece temperature and relative cutting speed. Chen and Lo presented the experimental investigation of the factors that affect the tool wear in the hot machining of alloy steel. In this study, alloy steels of different harnesses were machined using several grades of carbide tools, over a range of cutting speeds and heating current. Raghuram and Muju reported that tool life has been improved by magnetization and also a reduction in tool wear was observed due to an external magnetic field in hot machining. Hinds and Almedia studied the plasma arc heating for hot machining, which improved the efficiency of heat transfer under high

speed heating of the materials. Kitagawa and Maekawa discussed plasma hot machining for glasses and engineering materials, such as, Pyrex, Mullite, Alumina, Zirconia, Silicon nitride and sintered high speed steel. Tosum and Ozler conducted hot machining experiments up to 600^0 C to optimize the performance characteristics of manganese steel using LPG. Tosum and Ozler computed the tool life during hot machining using artificial neural network (ANN) and regression analysis method (RAM) by considering the cutting speed, feed rate, depth of cut and temperature as machining parameters. Madhavulu and Ahmed compared the metal removal of stainless steel (SS 410), alloy steel and forged stainless steel rotor by hot turning operation with undulations on the surface by applying a plasma arc heating. Maity and Swain investigated the tool life during hot machining by using manganese steel as work piece material. Larin and Martynow discussed the method of heating during machining of steel. Mukherjee and Basu outlined the statistical evaluation of metal cutting parameters during hot machining of nickel-chromium steel. Ranganathan and Senthivalan studied the influence of the cutting parameters on 316 stainless steel using analysis of variance. N.R. modh and K.B. Rahod studied the influence of the cutting parameters of AISI 52100 steel using analysis of variance(ANOVA).

II. EXPERIMENTAL DETAILS

The turning experimental work was conducted in dry cutting condition on an auto feed lathe for Hot machining of EN 36 Steel using Tungsten carbide cutting tool with Flame heating method. In fig. 1 experimental set up for Hot machining is shown.

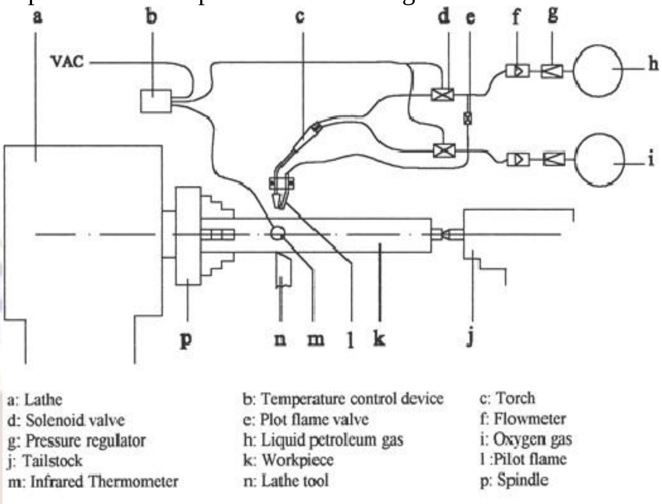

Fig. 1 Experimental Setup of Hot machining

A. Workpiece Material and Cutting Tool

EN 36 Steel is a low carbon and high alloy content alloy steel. Characteristics of steel are toughness arising from the use of nickel and a more uniform hardness produced by the use of chromium. It is specifically designed for carburizing to give a very hard case with strong core. It is widely used for components with large cross section, requiring high toughness and Score strength such as gears, crane shafts and heavy-duty gear shafts in aircraft and truck construction and mechanical engineering. The chemical compositions of EN 36 Steel is given in Table 1.

Elements	Carbon (C)	Nickel (Ni)	Chromium (Cr)	Silicon (Si)	Manganese (Mn)	Sulphar (S)	Phosphorus (P)	Moly (Mb)
%	0.700	3.200	1.050	0.250	0.420	0.010	0.012	0.140
HARDNESS : 55 HRC								

Table 1 Chemical compositions of EN 36 Steel

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 2 Properties of Tungsten Carbide Tool

B. Design of experiment based on Taguchi method

In this investigation carried out by varying three control factors Temperature, Cutting Speed and Feed rate on Hot machining. For experimental work of Hot turning 40 mm diameters EN 36 Steel bar used for constant depth of cut 0.8 mm. Control factors along with their levels are listed in Table 3. 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, which are logarithmic functions of the desired output, serve as objective functions for optimization.

Process Parameters	Level 1	Level 2	Level 3	Level 4	Level 5
Temperature (◦C)	200	300	400	500	600
Cutting Speed (m/min)	21.352	33.912	51.119	78.5	121.204
Feed Rate (mm/rev)	0.245	0.287	0.344	0.382	0.430

Table 3 Control parameters and their levels

III. RESULT AND ANALYSIS

Table 4 Result Table for Analysis

Sr. No	Temperature (°C)	Cutting Speed (m/min)	Feed Rate (rev/min)	Cutting Force (N)	Feed Force (N)	Surface Roughness (µm)	Power Consumption (Kw)
1	200	21.352	0.245	539.55	588.6	3.2	0.63
2	200	33.912	0.287	470.88	470.88	3.147	0.75
3	200	51.119	0.344	421.83	529.74	3.43	0.77
4	200	78.5	0.382	412.02	529.74	3.525	0.88
5	200	121.204	0.43	353.16	421.83	3.425	0.93
6	300	21.352	0.287	235.44	519.93	3.15	0.56
7	300	33.912	0.344	284.49	480.69	3.178	0.63
8	300	51.119	0.382	284.49	421.83	3.251	0.72
9	300	78.5	0.43	304.11	382.59	3.39	0.83
10	300	121.204	0.245	196.2	461.07	2.981	0.8
11	400	21.352	0.344	235.44	441.45	2.81	0.54
12	400	33.912	0.382	245.25	402.21	3.05	0.55
13	400	51.119	0.43	264.87	362.97	3.124	0.68
14	400	78.5	0.245	166.77	412.02	2.39	0.7
15	400	121.204	0.287	176.58	392.4	2.354	0.75
16	500	21.352	0.382	264.87	353.16	2.97	0.52
17	500	33.912	0.43	255.06	333.54	2.794	0.7
18	500	51.119	0.245	137.34	362.97	2.154	0.54
19	500	78.5	0.287	166.77	353.16	2.162	0.66
20	500	121.204	0.344	176.58	294.3	2.112	0.75
21	600	21.352	0.43	284.49	284.49	1.96	0.5
22	600	33.912	0.245	127.53	362.97	1.67	0.46
23	600	51.119	0.287	196.2	323.73	1.71	0.51

24	600	78.5	0.344	186.39	255.06	1.79	0.59
25	600	121.204	0.382	147.15	206.01	1.75	0.7

Analysis Of Variance (ANOVA):

Analysis of Variance (ANOVA) is a powerful analyzing tool to identify which are the most significant factors and it's (%) percentage contribution among all control factors for each of machining response. It calculates variations about mean ANOVA results for the each response. Based on F-value (Significance factor value) important parameters can be identified. Table 4 and Table 5 are ANOVA Table obtained by Minitab 16 software. ANOVA Table contain Degree of freedom (DF), Sum of Squares (SS), Mean squares (MS), Significant Factor ratio (F-Ratio), Probability (P) and calculated percentage contribution.

Table 5 Result of ANOVA for Cutting Force

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution (%)
A	4	187.17	187.17	46.792	24.92	0.000	69.24
B	4	30.82	30.82	7.705	4.10	0.025	11.40
C	4	29.78	29.78	7.446	3.96	0.028	11.02
Residual Error	12	22.54	22.54	1.878			8.34
Total	24	270.31					

Table 6 Result of ANOVA for Feed force

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percent Contribution (%)
A	4	81.222	81.222	20.3056	31.55	0.000	74.85
B	4	10.289	10.289	2.5723	4.00	0.028	9.48
C	4	9.278	9.278	2.3194	3.60	0.038	8.55
Residual Error	12	7.723	7.723	0.6436			7.12
Total	24	108.512					

Table 7 Result of ANOVA for Surface Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percent Contribution (%)
A	4	97.504	97.504	24.3759	122.18	0.000	85.91
B	4	3.408	3.408	0.8530	4.27	0.022	3.00
C	4	10.186	10.186	2.5465	12.76	0.000	8.98
Residual Error	12	2.394	2.394	0.1995			2.11
Total	24	113.492					

Table 8 Result of ANOVA for Power Consumption

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percent Contribution (%)
A	4	27.520	27.520	6.8799	23.69	0.000	42.01
B	4	29.978	29.978	7.4945	25.80	0.000	45.76
C	4	4.523	4.523	1.1307	3.89	0.030	6.91
Residual Error	12	3.485	3.485	0.2904			5.32
Total	24	65.506					

IV. RESULTS AND DISCUSSION

A. Effect on Cutting Force

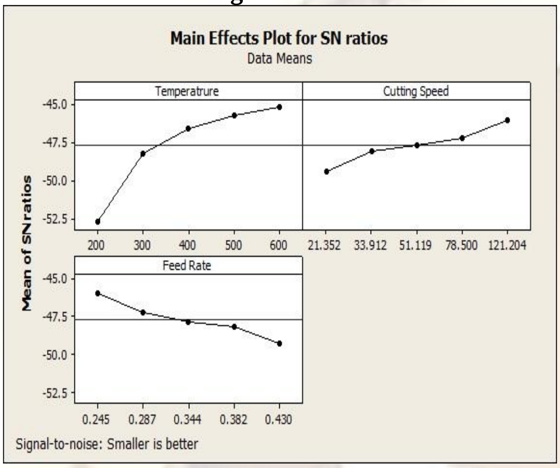

Fig. 2 Main effect plot for SN Ratios of Cutting force

- Figure 2 shows the main effect plot of Cutting force at different parameters like Temperature, Cutting speed and Feed rate in Hot machining of En 36 Steel.
- From the figure 2, it can be seen that minimum Cutting force obtained is at Temperature 600 °C, Cutting speed 121.204 m/min and Feed rate 0.245 mm/rev.

B. Effect on Feed force

- Figure 3 shows the main effect plot of Feed force at different parameters like Temperature, Cutting speed and Feed rate in Hot machining of En 36 Steel.
- From the figure 3, it can be seen that minimum Feed force obtained is at Temperature 600 °C, Cutting speed 121.204 m/min and Feed rate 0.430 mm/rev.

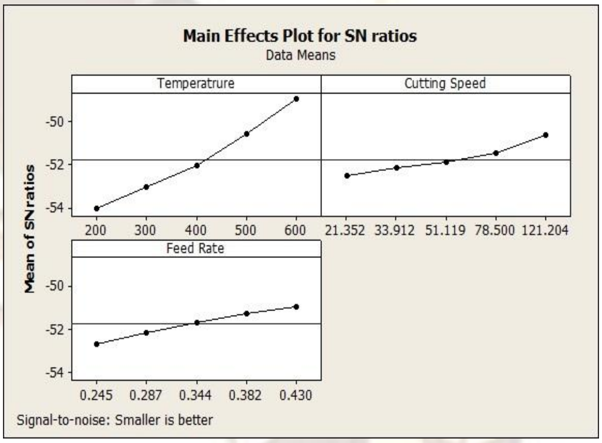

Fig. 3 Main effect plot for SN Ratios of Feed force

C. Effect on Surface Roughness

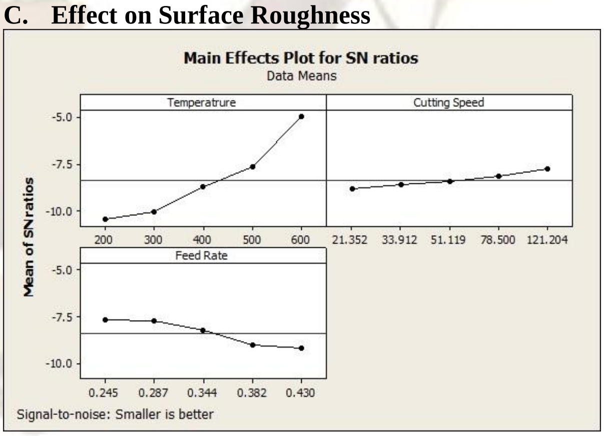

Fig. 4 Main effect plot for SN Ratios of Surface Roughness

- Figure 4 shows the main effect plot of Surface Roughness at different parameters like Temperature, Cutting speed and Feed rate in Hot machining of En 36 Steel.
- From the figure 4, it can be seen that minimum Cutting force obtained is at Temperature 600 °C, Cutting speed 121.204 m/min and Feed rate 0.245 mm/rev.

D. Effect on Power Consumption

- Figure 5 shows the main effect plot of Power Consumption at different parameters like Temperature, Cutting speed and Feed rate in Hot machining of En 36 Steel.

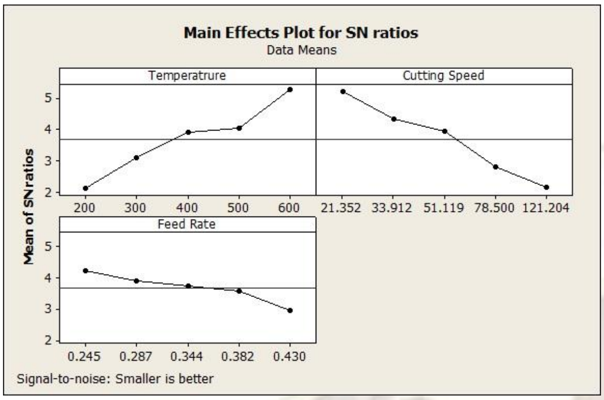

Fig. 5 Main effect plot for SN Ratios of Power Consumption

- From the figure 5, it can be seen that minimum Power Consumption obtained is at Temperature 600 °C, Cutting speed 21.352 m/min and Feed rate 0.245 mm/rev.

V. CONCLUSIONS

- Process parameters do not have same effect for every response. Significant parameters and its percentage contribution changes as per the behaviour of the parameter with objective response.
- Cutting force and Feed force are decreases with the increase in Temperature, Cutting speed and Feed rate. Temperature is the most significant control factor on Cutting force and Feed force. Hot machining is beneficial in terms of low Cutting force and Feed force.
- Surface Roughness decreases with increase in Temperature, with increases in Cutting speed and with decreases in Feed rate. Temperature is the most significant control factor on Surface Roughness. Hot machining gives good surface finish at high temperature, high cutting speed and low feed rate.
- Power consumption decreases with increases in Temperature and increases with increase in Cutting speed and Feed rate.
- In low cutting speeds, the discontinuous form chips produced in machining may be changed to continuous form.
- During Hot machining the change of the workpiece surface colour was also observed at Temperature 600c

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