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THOMSON REUTERS
[ICAME-2018]
ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

EXPERIMENTAL INVESTIGATION OF HEAT ASSISTED MACHINING OF EN8 STEEL USING CARBIDE TIPPED TOOL

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ABSTRACT
From the past few decades, ever-increasing the productivity and quality of the machined parts are the major challenges of metal cutting industry during turning process. These processes includes modelling of input-output parameter, in-process parameters relationship and determination of optimal cutting conditions are considered being vital. The experimental layout, Taguchi's L16 Orthogonal array was designed based on cutting parameters and their levels. Experiments were carried out to establish the influence of surface temperature, spindle speed, feed rate and depth of cut on cutting forces, surface roughness and MRR in hot-turning of EN8-Steel. Experiments were conducted on both hot turning and conventional turning to determine the relative advantage offered by hot turning. For hot turning, an LPG turning set-up was designed and attached to lathe machine. EN8 Steel specimen heated with LPG Gas flame was machined on a lathe under different cutting surface temperatures of 100˚C, 200˚C, 300˚C, and 400˚C.
Analysis of variance (ANOVA) was performed to recognize the result of the cutting parameters on the response variables. Analysis found that varying parameters are affected in different ways for different responses. In ANOVA analysis, main effect plots were used to obtain optimum cutting parameters. Finally the cutting parameters such as surface temperature, speed, feed and depth of cut in hot turning cutting of EN8 Steel are optimized. The relative advantages offered by hot turning over the conventional in terms of cutting force, surface roughness and MRR are calibrated. It was found from the experimental results that hot turning was effective in bringing down the cutting forces, surface roughness and increases MRR.

Keywords: *Hot machining, Cutting forces, Surface roughness, MRR, Regression analysis*.

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 [1].Non-conventional machining techniques such as abrasive jet machining, electro chemical machining and electrical discharge machining processes remove a very small amount of material per pass, which is very expensive and time consuming as well.

Therefore, there is a definite need to enhance the machinability for these materials. Hot machining is one of the most promising processes being developed to machine such materials. In hot machining either the whole or part of the material to be machined is heated before machining [2]. Whichever is the case, heating makes high-hardness materials soft, resulting in improvement in machinability, such as lower power and less heat generation in cutting [3]. Due to these advantages of hot machining, extremely hard and brittle materials like ceramics can also be machined using this technique. Different heating methods were used by different researchers [4, 5, 6, 7].

The amount of heat generated varies with the type of material being machined and machining parameters especially cutting speed, which had the most influence on the temperature [8]. Many of the economic and technical problems of machining are caused directly or indirectly by this heating action. Excessive temperatures directly influence the temperatures of importance to tool wear on the tool face and tool flank and inducing thermal damage to the machined surface [9].

Fig 1: Preheating Setup

All these difficulties lead to high tool wear, low material removal rate (MRR) and poor surface finish [10]. In actual practice, there are many factors which affect these performance measures, i.e. tool variables (tool material, nose radius, rake angle, cutting edge geometry, tool vibration, tool overhang, tool point angle, etc.), workpiece variables (material, hardness, other mechanical properties, etc.) and cutting conditions (cutting speed, feed, depth of cut and cutting fluids). Many papers has been published in experimental based to study the effect of cutting parameters on surface roughness [11, 12], tool wear [13], machinability [14], cutting forces [15], power consumption [16], material removal rate [17].

It was shown that the cutting mechanism of the ceramics changes from brittle fracture type to plastic deformation type in case of hot machining [18].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 [1].

Tigham first innovated the process of hot machining in 1989, since then it has created much interest among various investigators. Pal and Basu[19] 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[20] presented the experimental investigation of the factors that affect the tool wear in the hot machining of alloy steel. 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

In this experiment LPG heating setup was used to heat the workpiece. The flame was generated through torch and nozzle. The torch movement can either be automated or manually moved, here we used manual movement. The gas pressure was adjusted by a pressure regulator and it is varied with respect to requirement throughout the experiment. LPG heating is an obvious choice for hot machining since it requires low cost equipment, although the gross heat available and the energy transfer density will be low. Metallurgical damage to the workpiece will be low. However, the heating is not confined to a smaller region [21].

Fig 2: Flame torch

The turning test on the workpiece were conducted on TurnMaster 350 which have maximum spindle speed of 1800rpmand maximum power of 16kW .A hole was drilled on the face of the workpiece to allow it to be supported by tailstock. Prior to actual machining, the rust layer were removed by a new cutting insert in order to effect the experimental results.

Work piece is preheated for machining up to required temperature, heating continues in machining also. In order to maintain required steady temperature this heating is required throughout the machining. Machining time is taken into consideration to calculate MRR, and other parameters are also evaluated.

Workpiece and tool materials:

An EN-8 Steel rod of 46 mm diameter was used for experimentation. EN8 is also known as 080M40/AISI 1040. It posses good tensile strength.Suitable for shafts, stressed pins, studs, keys, etc.The chemical compositions of EN 8 Steel is given in Table.

Table 1: Composition of EN8 Steel

Elements	Carbon (C)	Silicon (Si)	Manganese (Mn)	Sulphur (S)	Phosphorus (P)
Percentage (%)	0.42	0.22	0.78	0.05	0.035

A tungsten carbide insert specified as TNMG 160408 EN-TM CTC1135 was supplied by CERATIZIT for the machining is used as the cutting tool.The chemical composition of cutting tool is Cobalt(Co) 9.5%, Composite Carbide 6.5%, WC is the rest. It is CVD coated with 1400Hv hardness.

The ranges of four input parameters were decided on the basis of machine capability, past experience, literature review and preliminary experiments. The selected ranges of parameters are:

- Temperature: 100˚C, 200˚C, 300˚C, 400˚C
- Spindle speed: 180rpm, 280rpm, 450rpm and 710 rpm
- Feed: 0.5mm/rev, 0.625mm/rev, 0.75mm/rev and 0.875 mm/revolution
- Depth of cut: 0.4mm and 0.6 mm

Measurements:

Measurement of Cutting Forces:

Cutting forces were measured in tuning operation with the help of Dynamometer which is connected tool post of the TurnMaster 350. The forces produced were displayed in Kgf units.

Measurement of Surface Temperature:

The surface temperature of the machined samples were measured by the use of infrared thermometer (make: HTC MTX-2) having temperature range of -300C to 5500C and with optical resolution of 10:1.

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Fig 3:Talysurf [Surface Measuring Device]

Measurement of power consumption:
Power consumption is measured with the aid of Watt Meter which can measure up to 5000W.

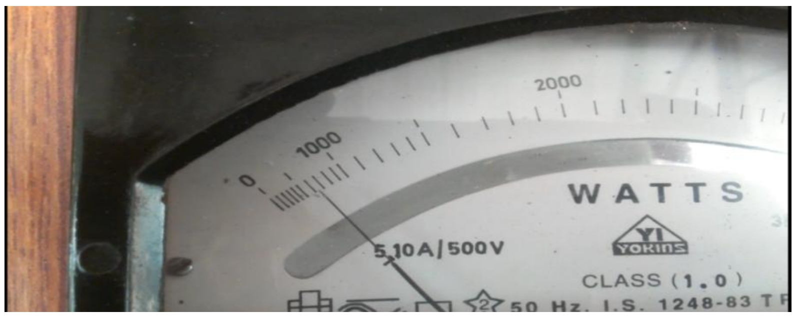

Fig 4:Watt meter

Measurement of MRR:
Material Removal Rate is known as the material removed per minute .i.e.

$$MRR=\frac{Wb-Wa}{T}$$

Whereas, MRR=material removal rate, Wb= weight of material before machining, Wa weight of the machining after machining, T=time taken for machining

III. DESIGN OF EXPERIMENT BASED ON TAGUCHI METHOD

The aim of the experiments was to analyze the effect of cutting parameters on cutting forces, surface roughness and MRR of EN8 steel. The experiments were planned using Taguchi's orthogonal array in the design of experiments which help in reducing the number of experiments. In this investigation carried out by varying four control factors Temperature, Cutting Speed, Feed rate and Depth of cut on Hot machining. For experimental work of Hot turning 46 mm diameters EN 8 Steel bar used. In Taguchi method L16 Orthogonal array provides a set of well-balanced experiments.

IV. RESULTS AND ANALYSIS

Table 2: Experimental Results

S.No	Temperature [˚C]	Speed [rpm]	Feed Rate [mm/ rev]	DOC [mm]	Cutting forces [Kgf]	Surface Roughness [µm]	Power Consumption [W]	MRR [gm/min]
1	100	180	0.5	0.4	25	0.667	550	1.6735
2	100	280	0.625	0.4	27	0.487	580	4.083

3	100	450	0.75	0.6	32	0.326	700	9.7946
4	100	710	0.875	0.6	37	0.45	730	12.2857
5	200	180	0.625	0.6	27	0.573	600	3.4372
6	200	280	0.5	0.6	25	0.48	660	3.5415
7	200	450	0.875	0.4	30	0.57	710	8.6304
8	200	710	0.75	0.4	26	0.482	760	7.7482
9	300	180	0.75	0.4	24	0.587	620	2.6921
10	300	280	0.875	0.4	28	0.447	680	5.3856
11	300	450	0.5	0.6	24	0.636	710	7.1579
12	300	710	0.625	0.6	25	0.886	750	15.5203
13	400	710	0.5	0.4	18	0.287	760	7.3979
14	400	450	0.625	0.4	20	0.322	680	3.5616
15	400	280	0.75	06	21	0.387	650	4.4211
16	400	180	0.875	06	26	0.416	610	4.5259

Table 1: Experimental Results for Conventional Turning

S.No	**Speed [rpm]**	**Feed Rate [mm/rev]**	**DOC [mm]**	**Cutting forces [Kgf]**	**Surface Roughness [µm]**	**MRR [gm/min]**
1	180	0.5	0.4	33	0.8671	0.861
2	280	0.625	0.4	36	0.8333	2.485
3	450	0.75	0.6	41	0.8073	4.665
4	710	0.875	0.6	44	0.7813	6.704
5	180	0.625	0.6	39	0.7449	2.302
6	280	0.5	0.6	36	0.6890	2.425
7	450	0.875	0.4	38	0.6630	4.981
8	710	0.75	0.4	34	0.6266	5.666
9	180	0.75	0.4	36	0.5980	1.431
10	280	0.875	0.4	38	0.5811	3.023
11	450	0.5	0.6	37	0.5200	5.120
12	710	0.625	0.6	39	0.5018	7.304
13	710	0.5	0.4	28	0.3731	4.522
14	450	0.625	0.4	34	0.4186	3.799
15	280	0.75	06	41	0.5031	2.408
16	180	0.875	06	44	0.5408	3.147

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. This analysis was carried out for significance level of α=0.05 i.e. for a confidence level of 95%. The sources with a P-value less than 0.05 are considered to have a statistically significant contribution to the performance measures. The last column of the tables shows the percent contribution of significant source of the total variation and indicating the degree of influence on the result.

Table 3: Analysis of Variance for Cutting Forces

Source	DOF	SS	MS	F-Value	P-Value	% Contribution
Temperature	3	155.187	51.729	91.96	0.000	51.31
Speed	3	5.687	1.8958	3.37	0.112	1.88
Feed	3	116.187	38.7292	68.85	0.000	38.42
DOF	1	22.563	22.563	40.11	0.001	7.46
Residual Error	5	2.813	0.5625			0.93
Total	15	302.438				100
S=0.75		R-Sq= 99.07%		R-Sq(Adj)= 97.21%	R-Sq(Pred)= 90.48%	

Table 4: Analysis of Variance for Surface Roughness

Source	DOF	SS	MS	F-Value	P-Value	% Contribution
Temperature	3	0.176675	0.058892	1321.55	0.000	89.09
Speed	3	0.019779	0.006593	147.95	0.000	9.97
Feed	3	0.000898	0.000299	6.71	0.033	0.45
DOF	1	0.000743	0.000743	16.66	0.100	0.37
Residual Error	5	0.000223	0.000045			0.112
Total	15	0.198317				100
S=0.0066755		R-Sq= 99.89%		R-Sq(Adj)= 99.66%	R-Sq(Pred)= 98.85%	

Table 6: Analysis of Variance for Material Removal Rate:

Source	DOF	SS	MS	F-Value	P-Value	% Contribution
Temperature	3	8.684	2.8946	4.46	0.070	5.53
Speed	3	116.496	38.8321	59.89	0.000	7.25
Feed	3	19.073	6.3577	9.81	0.016	12.16
DOF	1	9.394	9.394	14.49	0.013	5.99
Residual Error	5	3.242	0.6484			2.07
Total	15	156.889				100
S=0.802344		R-Sq= 97.98%		R-Sq(Adj)= 93.80%	R-Sq(Pred)= 78.85%	

Table3 shows the results of ANOVA for Cutting Forces. It is observed from the ANOVA table, temperature (51.31%) is the most significant cutting parameter followed by Feed Rate(38.42%) and Depth of Cut(7.46%) . However, spindle speed has least effect (1.88%) in controlling the Cutting Forces which is not statistically significant. From the analysis of the Table4 shows that P-value oftemperature(0.000), spindle speed (0.000) and feed

(0.033) which are less than 0.05. It means that temperature, cutting speed and feed influence significantly on workpiece surface temperature, T. The temperature, spindle speed and feed have a contribution for the workpiece surface temperature are 89.09%, 9.97% and 0.45% respectively. The next contribution comes from DOC(0.37%) which is not statistically significant. And same comes to Power Consumption(Table 5) in which temperature, speed and DOC are contributing where as feed is not statistically significant and in MRR(Table 6) speed, feed and DOC are contributing and temperature is not statistically significant.

The error contribution is 0.93%, 0.112%, 1.83% and 2.07% for cutting forces, surface roughness, power consumption and MRR respectively. As the percent contribution due to error is very small it signifies that neither any important factor was omitted nor any high measurement error was involved (Ross, 1996).

Main effect plots:
The data was further analyzed to study the interact on amount cutting parameters [T, V, D, F] and the main effect plots on cutting forces, surface roughness, power consumption and MRR were analyzed with the help of software package MINITAB17 and shown in Figures 5, 6, 7, and 8 respectively. The plots show the variation of individual response with the four parameters; temperature, cutting speed, depth of cut and feed separately. In the plots, the x-axis indicates the value of each process parameters at three level and y-axis the response value. The main effect plots are used to determine the optimal design conditions to obtain the low tool wear and low surface temperature.

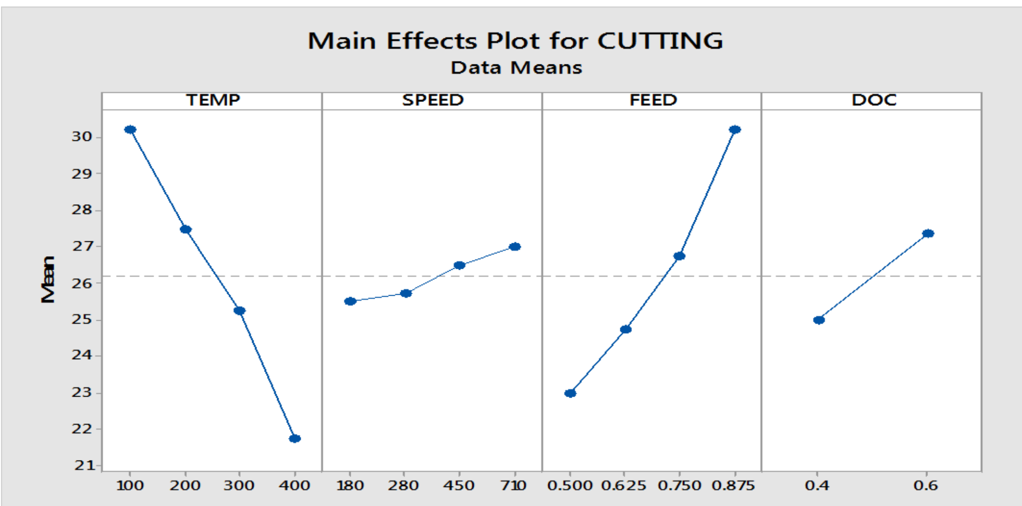

Fig 5: Main effect plots for cutting forces

Figure 5 shows the main effect plot for cutting forces. The results show that with the increase in cutting speed, feed and depth of cut there is a continuous increase in cutting forces. On the other hand, as the temperature increases the cutting forces decreases. However, with the increase in depth of cut there is an increase in tool wear up to 0.75 mm. Based on analysis usingFigure 5 low value of cutting forces was obtained at cutting speed of 180rpm , DOC of 0.4 mm and feed of 0.5 mm/rev.

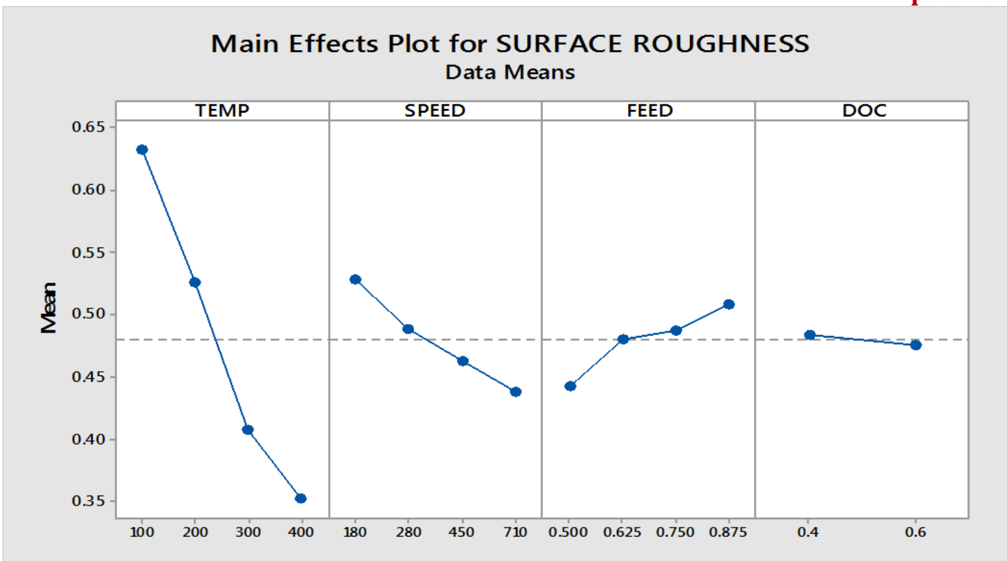

Fig 6: Main effect plot for Surface roughness

For comparison, the main effects plot for surface roughness Figure 6 shows that same levels of cutting parameters [T:400˚C, V: 710 rpm, D: 0.6 mm and F: 0.875 mm/rev] produce lower workpiece surface roughness. Thus, the lower surface roughness produces smooth surfaces on the machined surface.

Based on analysis using Figure 7 low value of tool wear was obtained at temperature of 100˚C, cutting speed of 180rpm, DOC of 0.4 mm and feed of 0.625mm/rev.

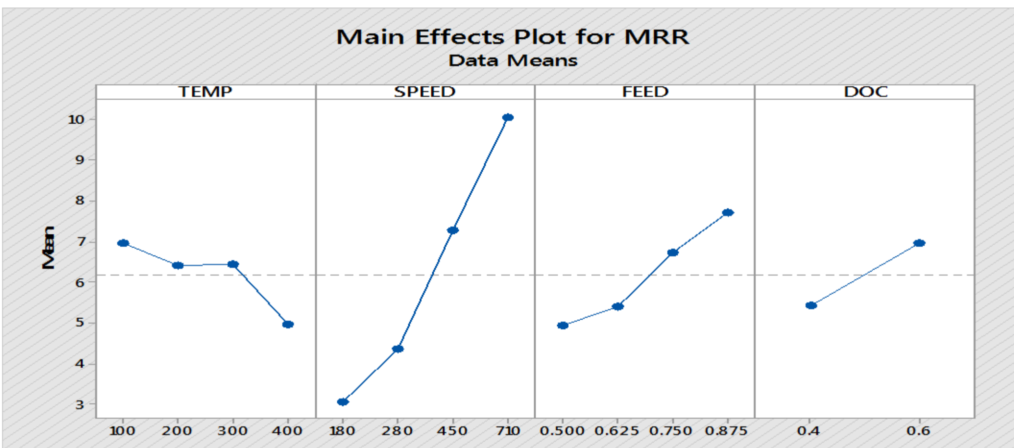

Fig 8: Main effect plot for MRR

The main effects plot for MRR Figure 8 shows that same levels of cutting parameters (T:100˚C, V: 710 rpm, D: 0.6 mm and F: 0.875 mm/rev) produce highest MRR.

Comparisons of Hot-turning with conventional turning

Variation of Cutting forces with Cutting parameters

The relative advantage offered by hot machining over the conventional cutting in terms of cutting force can be seen from the Figures 6.4–6.6. It is clear from the curves that, the cutting force required in hot machining is less than that

ISSN 2348 – 8034
Impact Factor- 5.070

of conventional cutting which is explained by the fact that the shear strength of the work material decreases and the machinability improves due to heating. From the Figure 6.5 it is evident that, the effect of heating is more predominant at low values of feed. This is because of the insufficient transfer of heat to the cutting zone during hot machining performed at high feed, due to which an adequate reduction in shearing stress of the workpiece was not reached.

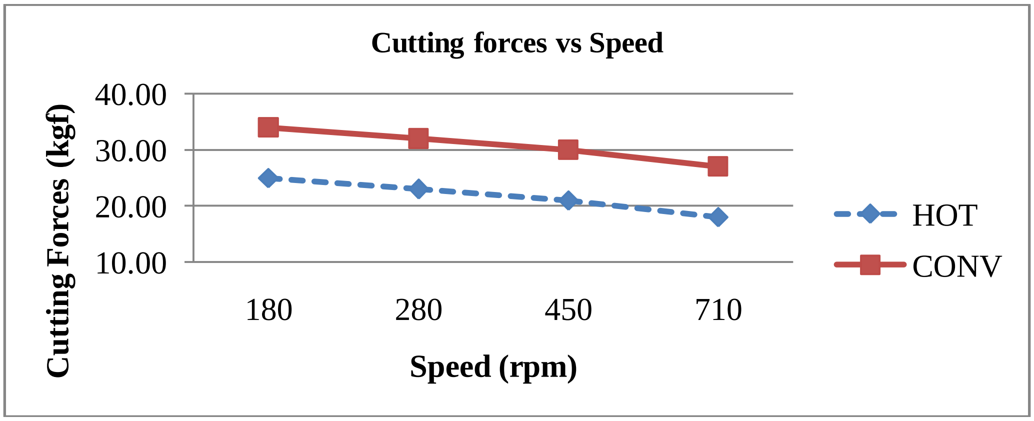

Fig.6. 1: Cutting forces vs. Speed

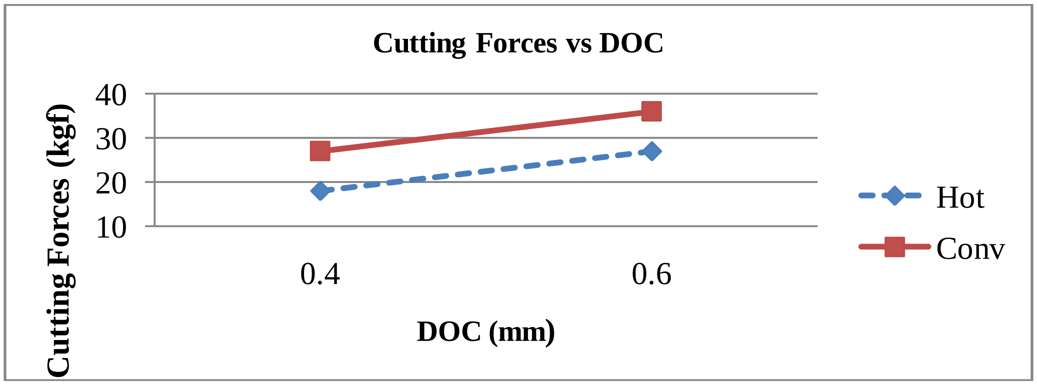

Fig.6. 2: Cutting Forces vs. DOC

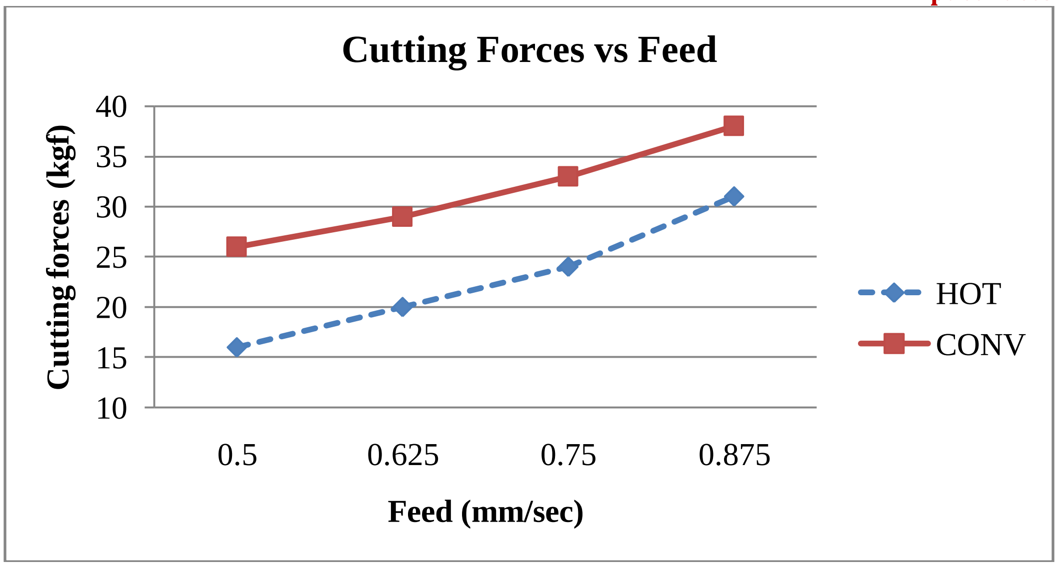

Fig.6. 3: Cutting Forces vs. Feed

Variation of Surface Roughness with Cutting parameters

The effect of hot machining in improving surface finish is depicted in Figures 6.7–6.9. This Phenomenon can be explained by the following three mechanisms (Uehara et al., 1983;
Lal and Choudhury, 2005).

- Decreasing of chatter vibrations with the decrease in cutting force.
- Changing of the mechanism of chip formation from discontinuous type to continuous type.
- The absence of built-up edge formation.

Figure 6.9 shows that the depth of cut has negligible effect on surface roughness. It is shown in ANOVA table for surface roughness that Depth of cut has negligible very least contribution and it is statistically insignificant because the P-Value is greater than 0.05 i.e. 0.100. (Lal and *Choudhury, 2005)* in both normal and hot machining.

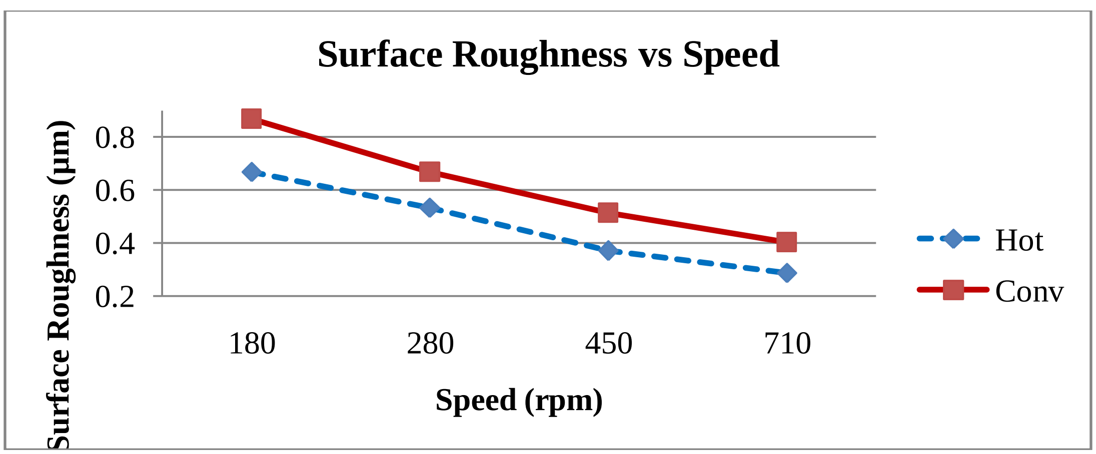

Fig6.4: Surface Roughness vs. Speed

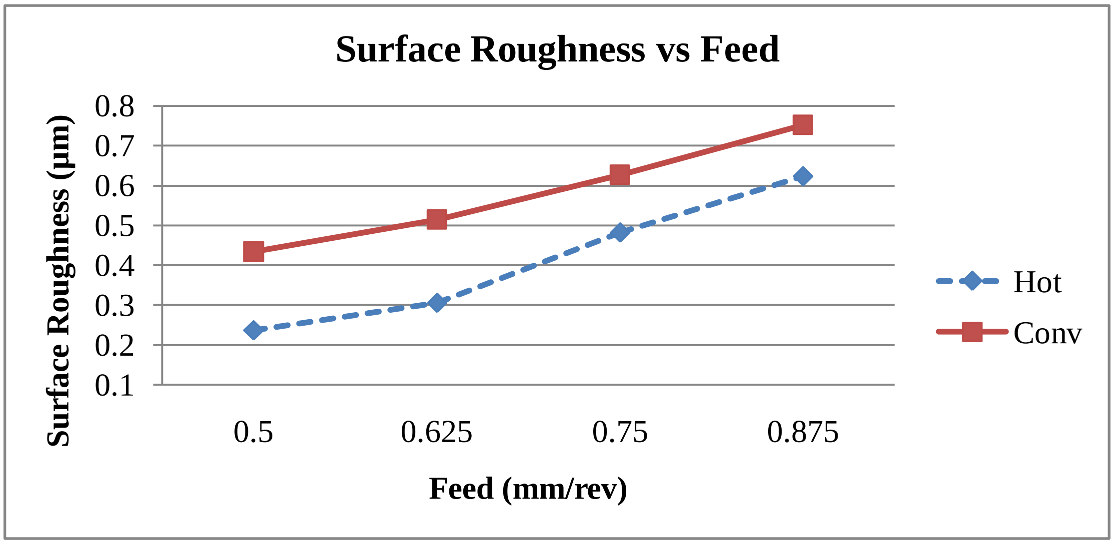

Fig6.5: Roughness vs. Feed

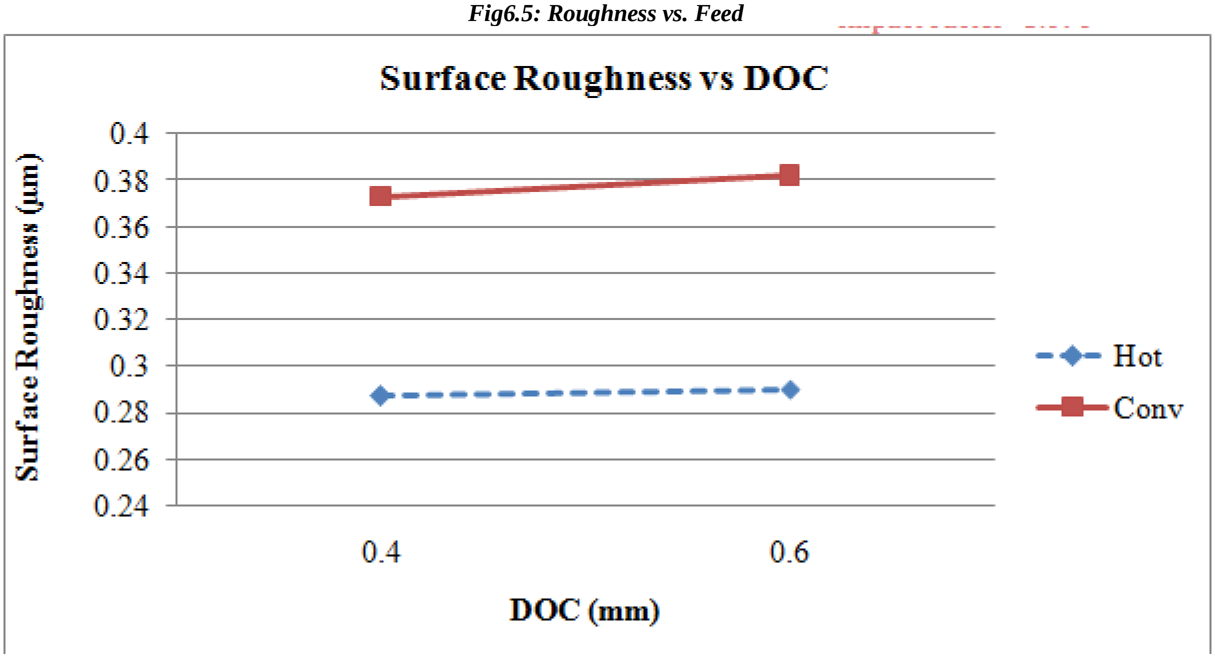

Fig.6. 6: Surface Roughness vs. DOC

Variation of MRR with Cutting parameters

- MRR is higher in Hot Turning when compared to conventional machining for individual responses like cutting speed, feed anddepth of cut.
- The difference increases with speed, feed and constant for DOC.

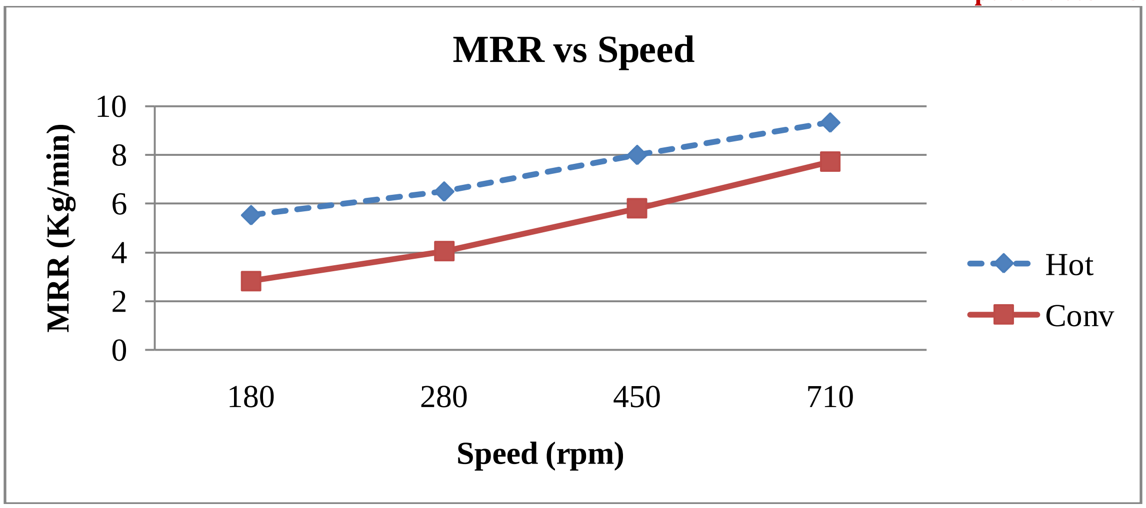

Fig.6. 7: MRR vs. Speed

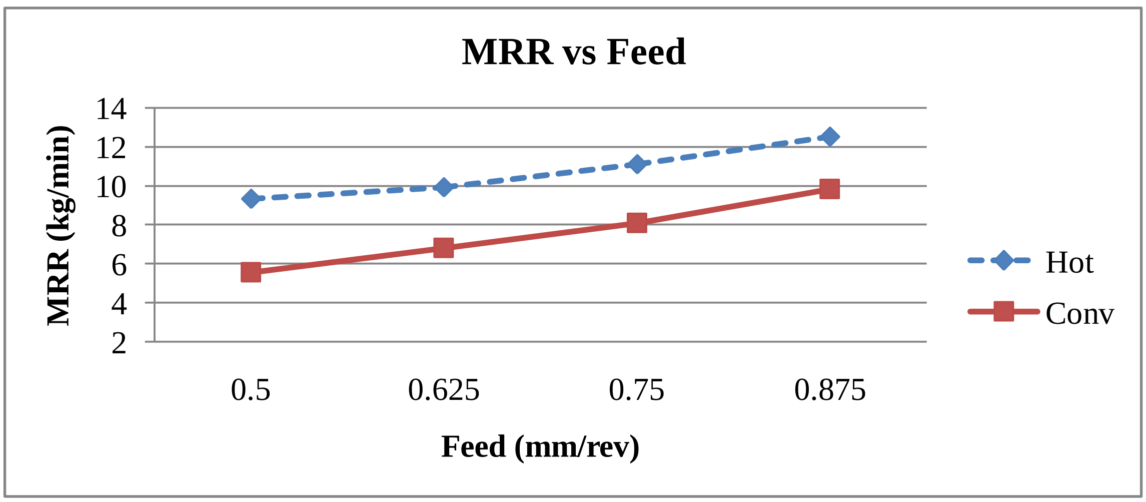

Fig.6. 8: MRR vs. Feed

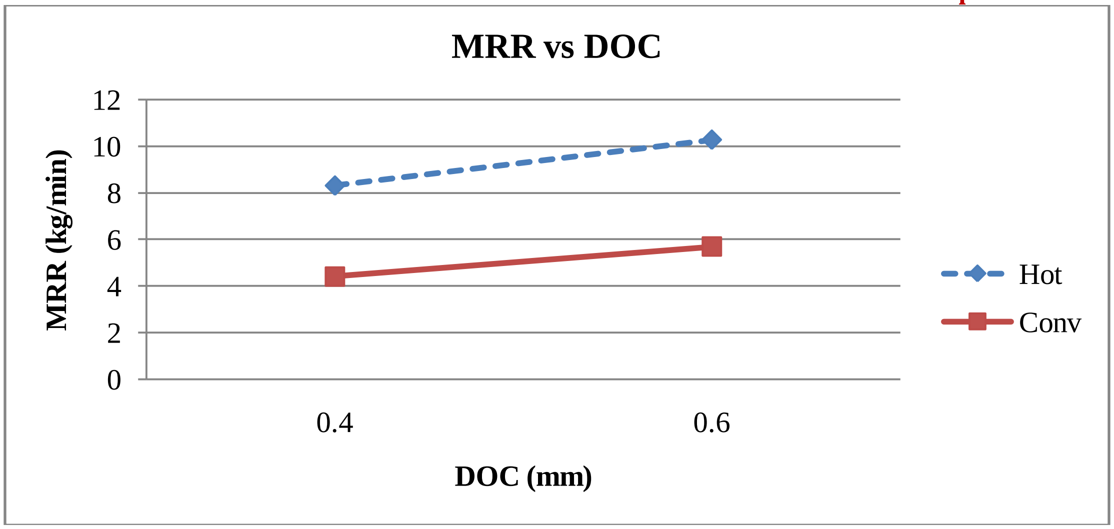

Fig.6.9: MRR vs. DOC

V. CONCLUSIONS

From the research of present work, the following conclusions are drawn.

- Temperature(51.31%), feed(38.42%) and depth of cut(7.46%) are mostly influencing the Cutting Forces. Likewise, Speed and feed are influencing MRR, temperature and speeds are influencing the Surface Roughness.
- 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**.**
- Surface finish was improved remarkably in hot machining. About 23.08% reduction in surface roughness was observed in hot machining compared to conventional cutting.
- The percentage gain factor, indicating the percentage reduction in Cutting Forces with hot machining over conventional machining was observed to be 30.622%.
- About 28.721% is Increased in MRR was observed in hot machining compared to conventional cutting.
- Hot machining affected the mechanics of chip formation. Continuous chips were observed during hot machining of EN-8 steel.
- Effect of hot machining was observed to be predominant at lower values of speed and feed due to the efficient transfer of heat to the cutting zone.
- Decrease of chatter vibrations with the decrease in cutting force in HOT-TURNING.

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