Scientific Journal Impact Factor (SJIF): 1.711

e-ISSN: 2349-9745
p-ISSN: 2393-8161

International Journal of Modern Trends in Engineering and Research
www.ijmter.com

MODELLING OF CUTTING TEMPERATURE USING RSM DURING MACHINING OF SOME ALLOYS

Seema S. Billur[1], Ravi Yerigeri[2], Vaijanath V. Yerigeri[3]
[1]Mechanical Department, M.B.E.Society's College of Engineering, Ambajogai
[2]Mechanical Department, TERNA College of Engineering, Nerul, Mumbai
[3]Instrumentation Department, M.B.E.Society's College of Engineering, Ambajogai

Abstract— In modern industry, trend towards using dry and high speed machining has caused much greater heat dissipation in the chip formation zone and for this reason thermal phenomena play a key role in tool life and machinability of the materials. For the improvement of cutting performance, the knowledge of temperature at the tool-work interface with good accuracy is essential. In the present work, the most simplest and economical technique i.e. tool-work thermocouple set-up is developed for the measurement of the cutting temperature in machining. The performance of the setup is evaluated for the materials like EN-8, Al-380, SS-316 and SAE-8620. Machining tests are carried out for these materials for various cutting parameters using carbide tool. Response surface model has been developed for cutting temperature for these materials. Further, the influence of cutting parameters and the thermo-physical properties of work piece materials on response parameters has been studied.

Keywords- tool-work thermocouple; cutting temperature; carbide tool; Response surface methodology; thermo-physical properties.

I. INTRODUCTION

Machining operations consumes a large amount of money annually worldwide. Over US $100 billion is spent annually worldwide on finishing processes such as turning, milling, boring and other cutting operations. It is also known that the machining industry converts about 10% of all the metal produced into scrap (wastage). It is investigated that up to 20% savings should be possible by using the correct choice of tooling and machining conditions. Typical problems that can be associated with machining operations range from the high cost of consumable tooling and setup time for high volume production to components often requiring several machining operations thereby making it difficult to effectively control the machine shop and consequently an increase in work-in-process. These, in addition to the large amount of scrap produced, tend to form the basis for continued research and development activities in this area of manufacturing technology.

The machining system consist of cutting tool, work piece and machine tool with the cutting tool playing a major role as the cutting speed employed depend to a greater extent on the cutting tool materials. Machinists are continually exploring a cutting tool, machine tool–work piece combination which will allow rapid metal removal rate for roughing cuts with large depth of cuts at very fast speeds and will also produce required surface finishes and dimensional accuracy associated with finishing passes. To achieve this, efforts have been made in developing cutting tool materials that can survive aggressive conditions at the cutting edges. Machinability is the term used to describe how easily a material can be cut to the desired shape with respect to the tooling and machining processes involved. In a machining operation tool life achieved, metal removal rate, component forces and power consumption, surface finish generated and surface integrity of the machined component as well as the shape of the chips can all be used to measure machinability. The machinability is affected by the properties of the material being machined, properties and geometry of the cutting tool, cutting conditions employed and other miscellaneous factors such as rigidity of the machine tool, cutting environment, etc. Machining productivity can be significantly improved by employing the right combination of cutting tools, cutting conditions and machine tool that will promote high speed machining without compromising the integrity and tolerance of the machined components.

Turning process is a widely used operation in the engineering industry. Mostly the cutting parameters are selected based on the experience or by use of handbook. However, this does not guarantee that the selected parameters can give expected results. Selection of wrong or non proper parameters leads to the wastage of raw material, man power, electricity, cutting fluid, cutting tools, etc. Hence, there is an increase in manufacturing cost of the product.

In the present work it is an attempt to study the machinability into turning mild steel, aluminium alloys, low alloy steel and stainless steel and the effect of the input parameters and the thermo-physical properties of the materials on the response parameters (cutting tool temperature of the materials).

Sullivan (2001), Showed different methods used for the measurement of temperature of a single cutting tool. Use of the tool-chip interface as a thermocouple was one of the first methods of estimating interfacial temperatures in machining process.

Abhang, Hameedullah (2010) Measured the tool-chip interface temperature experimentally during turning of EN-31 steel alloy with tungsten carbide inserts using a tool work thermocouple technique. First and second order mathematical models were developed in terms of machining parameters by using the response surface methodology on the basis of the experimental results. Results were that, tool-work thermocouple technique is the best method for measuring the average chip-tool interface temperature during metal cutting. The benefits of using the tool-work thermocouple are its ease of implementation and its low cost as compared to other thermocouples. The proposed model could be utilized to predict the corresponding cutting temperatures of EN-31 steel at different parameters in turning. This could also be used for metal cutting process optimization, increasing productivity and reducing manufacturing costs. The cutting speed was main influencing factor on chip-tool interface temperature as compared to others. It had been shown that increasing cutting speed, feed rate and depth of cut lead to an increase in cutting temperature. However, increasing the tool nose radius decreases the cutting temperature. A good combination among the cutting speed, feed rate, depth of cut and tool nose radius can generate minimum cutting temperature during steel turning. Response surface methodology coupled with factorial design of experiments actually save a lot of time and cost of experiments.

II. EXPERIMENTATION

The turning trials were carried out on CNC lathe machine. Cutting speed, feed and depth of cut are the three adjustable factors in turning operation.

Figure 1. CNC Machine Tool

In the present work, four different workpiece materials each of 300mm length are considered ie., Mild Steel (EN-8) of 78mm diameter, Aluminium alloy (AL-380) of 50mm diameter, Stainless Steel (SS-316) of 75mm diameter, and Low Alloy Steel (SAE-8620) of 77mm diameter.

Table 1. Chemical composition of Mild Steel (EN-8)

% C	% Mn	% Si
0.435	0.69	0.20

Table 2. Chemical composition of Aluminium Alloy (Al-380)

% Al	% Cu	% Fe	% Mg	% Mn	% Ni	% Other	% Si	% Sn	% Zn
79.6 - 89.5	3.0 - 4.0	<= 2.0	<= 0.10	<= 0.50	<= 0.50	<= 0.50	7.50 - 9.50	<= 0.35	<= 3.0

Table 3. Chemical composition of Low Alloy Steel (SAE-8620)

% C	% Cr	% Fe	% Mn	% Mo	% Ni	% P	% Si	% S
0.18- 0.23	0.40- 0.60	96.89-98.02	0.70-0.90	0.15-0.25	0.40-0.70	<= 0.035	0.15 - 0.35	<= 0.040

Table 4. Chemical composition of Stainless Steel (SS-316)

% C	% Cr	% Fe	% Mn	% Mo	% Ni	% P	% Si	% S
<= 0.080	16 -18	61.8 -72.0	<= 2.00	2.00 -3.00	<= 10.0 - 14.0	<= 0.0450	<= 1.00	<= 0.0300

Figure 2. Work pieces used for machining

A Sandvik make PVD (TiAlN) coated carbide inserts having eight cutting edges designated with the grade as CNMG-120408 MS PR1310 (0.8mm corner radius) was used for 18 trials under dry environment. For every experimental run a new cutting edge was used.

Figure 3. Insert schematic (Sandvik Coromant Handbook, 2011)

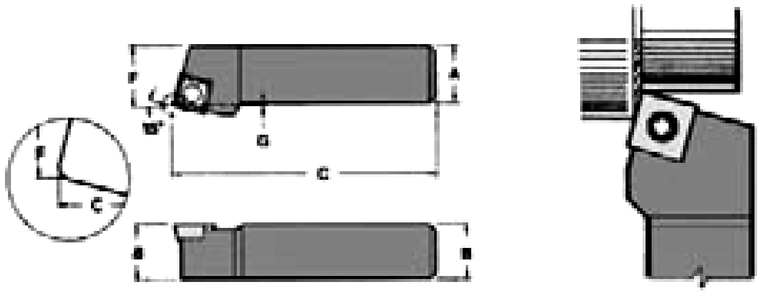

Figure 4. Tool holder schematic (Sandvik Coromant Handbook, 2011)

3.1. Tool-work Thermocouple Setup

Tool and work-piece junction at the time of machining is taken as hot junction while the carbon brush touching the work-piece is cold junction. Work-piece is mounted on a three jaw chuck and insulation is provided in between work-piece and jaw. One end of connecting copper wire is attached to the carbon brush and the other end to the millivolt-meter. Insulation is provided between tool holder and insert. One end of connecting copper wire is placed between insert and tool holder and the other end to the millivolt-meter. Insulation is provided to avoid generation of parasitic e.m.f. which is generated due to more than two metal contacts. Copper wire of 1 mm diameter is used for the connection purpose. The experiemental setup for measuring the temperature of the cutting tool is shown in the Figure 3.5.

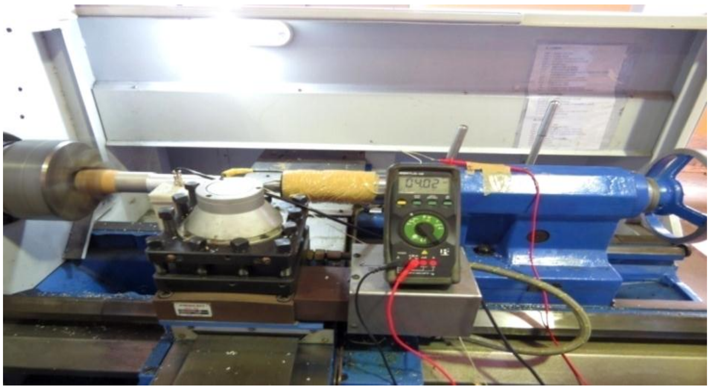

Figure 5. Experiemental setup

3.2. Calibration setup

Tool and work Calibration set-up is developed in order to establish the relationship between the e.m.f. produced and cutting temperature during machining. In calibration set-up, tool-work thermocouple junction is constructed using a long continuous chip of different workmaterial and fresh tungsten carbide inserts used in actual machining operation. Electric air heater is used to as a heating element for the work-tool junction and it simulates the thermal performance phenomena in machining and raised the temperature at the chip-tool interface. Work-tool material and the thermocouple wire are heated directly as they are in contact with the electric heater. A standard alumel- chromel thermocouple wire is mounted at the junction of chip and insert. It has high temperature range of -200 °C to 1350°C. It has better oxidation resistance. Type-K sensors are recommended for use in oxidizing or completely inert environments.

Figure 6. Calibration setup

3.3. Calibration experimental procedure

First, work-piece chip and tool material to be calibrated are clamped with the help of clamping assembly in the set- up. While clamping, care is taken to ensure the perfect contact between the work-tool materials because improper contact can result in the erratic readings. After maintaining the proper contact, one end of the copper wire is connected to the tool and chip material and other end is connected to the milli-voltmeter terminals. Then electric air heater is brought in contact with the junction point for heating the junction point. A standard alumel-chromel thermocouple wire is mounted at the junction of chip and insert. It is connected to the temperature indicator calibrated for the Type-K thermocouple wire. After this, whole assembly is kept in the container insulated with glass wool in order to reduce heat losses and electric heater is turned on and junction point is heated gradually up to 750 °c and corresponding e.m.f. is recorded. Graph of temperature v/s generated e.m.f. is plotted and calibration constant is found out by using regression analysis.

In order to establish an adequate functional relationship between the responses (such as tool temperature, surface roughness) and the cutting parameters (cutting speed, feed, doc), a large number of tests are needed, requiring a separate set of tests for each and every combination of cutting tool and work piece material. This increases the total number of tests and as a result the experimentation cost also increases. As a group of mathematical and statistical techniques, response surface methodology (RSM) is used for modeling the relationship between the input parameters (cutting conditions) and the output variables.

Table 5. Parameters and their levels

Parameters/Levels	-2	-1	0	+1	+2
Cutting speed, C_s (m/min) (X1)	140	190	240	290	340
Feed, f (mm/rev) (X2)	0.08	0.12	0.16	0.20	0.24
Depth of cut, d ((mm) (X3)	0.6	0.7	0.8	0.9	1.0

Table 6. Experimental Data of Temperature for four different materials

Run No.	Speed, C_s (m/min) X1	Feed, f (mm/rev) X2	DoC, d, (mm) X3	SS- 316 T1	EN-8 T2	SAE-8620 T3	AL- 380 T4
1	190	0.12	0.7	635	636	629	243
2	290	0.12	0.7	812	657	733	264
3	190	0.2	0.7	643	654	648	247
4	290	0.2	0.7	997	672	741	318
5	190	0.12	0.9	782	647	675	236
6	290	0.12	0.9	1082	665	782	271
7	190	0.2	0.9	815	664	735	274
8	290	0.2	0.9	1157	679	818	334
9	140	0.16	0.8	732	644	595	229
10	340	0.16	0.8	1243	689	837	323
11	240	0.08	0.8	619	629	625	216
12	240	0.24	0.8	883	666	718	306
13	240	0.16	0.6	646	644	693	289
14	240	0.16	1	1082	653	791	310
15	240	0.16	0.8	805	649	704	283
16	240	0.16	0.8	766	642	694	291
17	240	0.16	0.8	775	644	699	293
18	240	0.16	0.8	764	645	701	296

III. RESULTS AND DISCUSSION

In this section, the results based on the proposed model are presented, and compared against the experimental data.

Using the Response Surface Methodology, the obtained regression equations of temperature for all the four materials after analysis from experimental data :

$T1 = 2452.65 - 12.00 \times C_s + 1188.65 \times f - 2905.21 \times d + 13.68 \times C_s \times f + 2.77 \times C_s \times d - 2656.25 \times f \times d + 0.02 \times C_s^2 - 3291.67 \times f^2 + 2298.33 \times d^2$ ………………………… (4.1)

$T2 = 726.16 - 0.74 \times C_s + 132.29 \times f - 138.91 \times d - 0.37 \times C_s \times f - 0.15 \times C_s \times d - 62.50 \times f \times d + 0.002 \times C_s^2 + 697.91 \times f^2 + 136.66 \times d^2$ ……………………………… (4.2)

$T3 = 1046.77 + 0.62 \times C_s + 511.14 \times f - 1855.96 \times d - 2.18 \times C_s \times f - 0.175 \times C_s \times d + 2156.25 \times f \times d + 0.001 \times C_s^2 - 3838.54 \times f^2 + 1148.33 \times d^2$ ………………………….. (4.3)

$T4 = 293.23 + 0.47 \times C_s - 70.31 \times f - 439.87 \times d + 4.68 \times C_s \times f + 0.075 \times C_s \times d + 1343.75 \times f \times d - 0.001 \times C_s^2 - 5000.00 \times f^2 + 162.50 \times d^2$ ……………………………… (4.4)

The normal probability plot, residual versus fits, histogram, and residual versus order has been plotted during analysis. Contour plots has been generated using Minitab version 16 software, the shape of surface is characterized and located the optimum with reasonable precision.

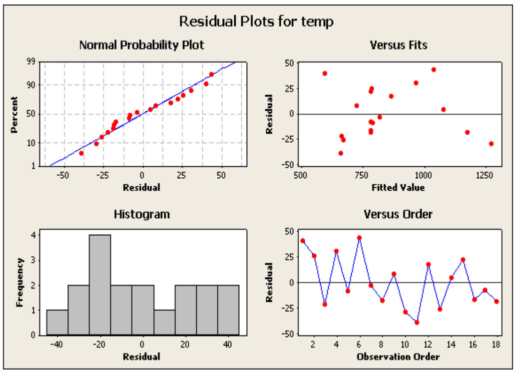

Figure 7. Residual plot for Temperature of SS-316

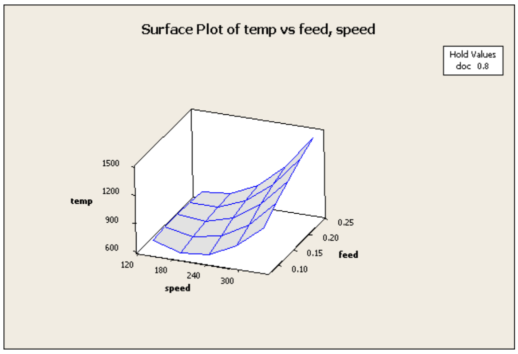

Figure 8(a). Surface Plot of Temp Vs Feed, Speed for SS-316

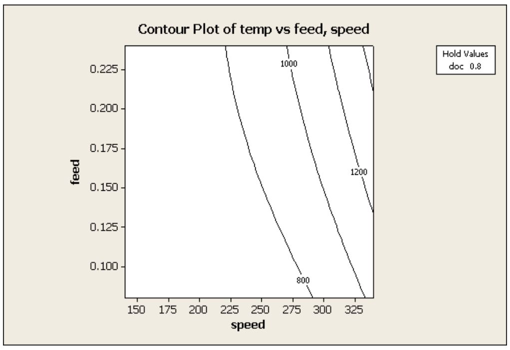

Figure 8(b). Contour Plot of Temp Vs Feed, Speed

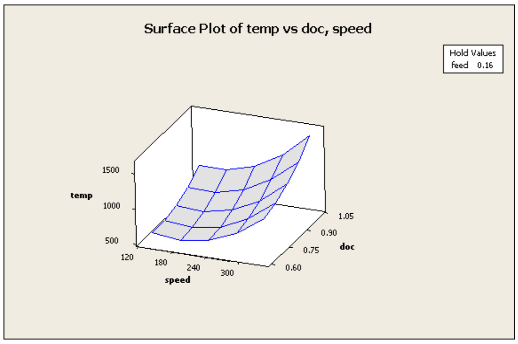

Figure 9(a). Surface Plot of Temp Vs doc, Speed for SS-316

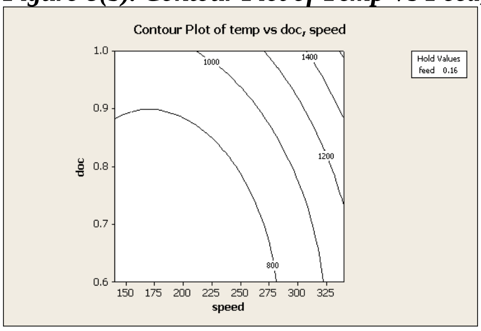

Fig. 9(b). Contour Plot of Temp Vs doc, Speed for SS-316

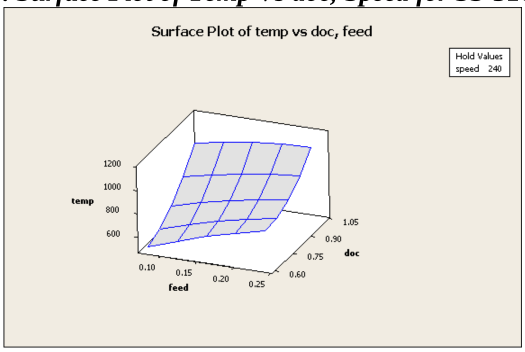

Fig.10(a). Surface Plot of Temp Vs doc, Feed for SS-316

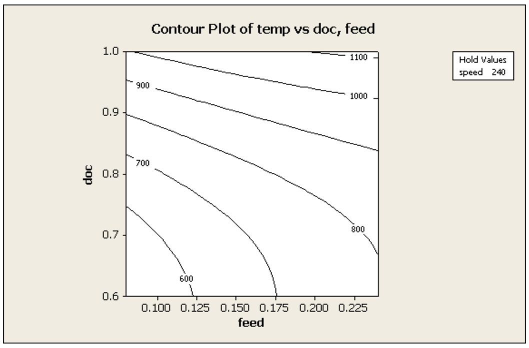

Figure 10(b). Contour Plot of Temp Vs doc, Feed for SS-316

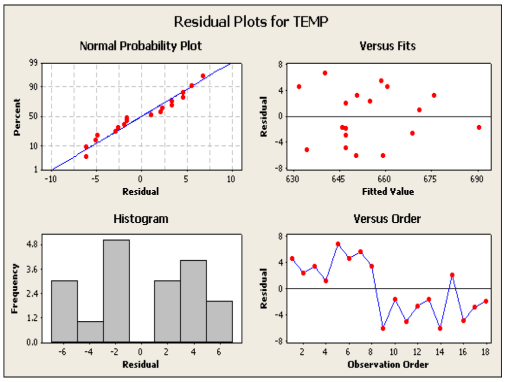

Figure 11. Residual plot for Temperature of EN-8

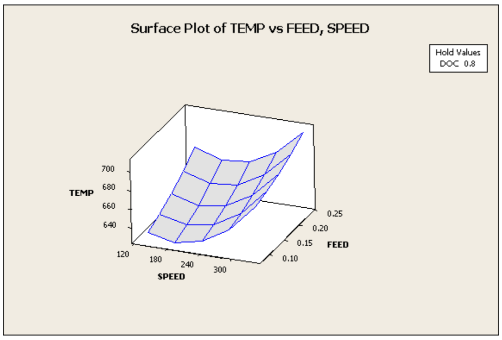

Figure 12(a) Surface Plot of Temp Vs Feed, Speed for EN-8

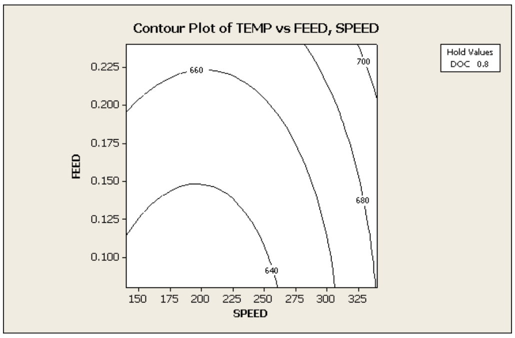

Figure 12(b). Contour Plot of Temp Vs Feed, Speed for EN-8

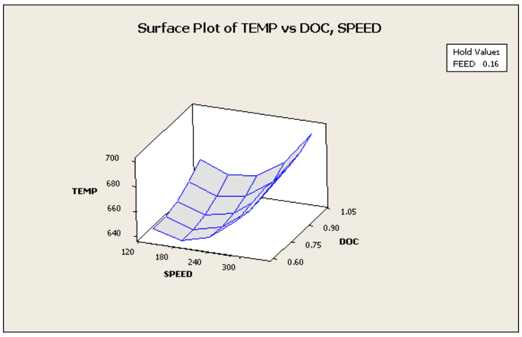

Figure 13(a). Surface Plot of Temp Vs doc, Speed for EN-8

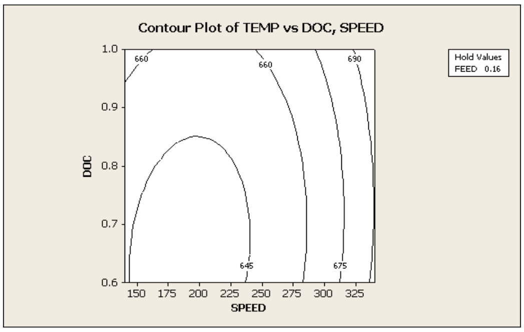

Figure 13(b). Contour Plot of Temp Vs doc, Speed for EN-8

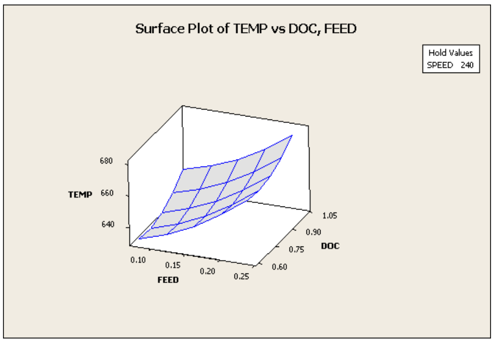

Figure 14(a). Surface Plot of Temp Vs doc, Feed for EN-8

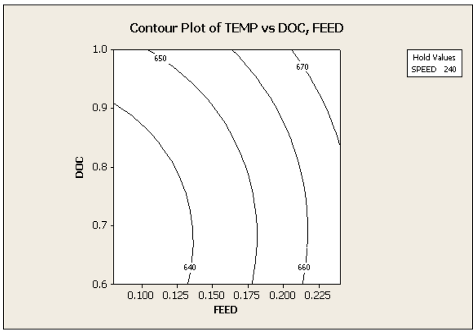

Figure 14(b). Contour Plot of Temp Vs doc, Feed for EN-8

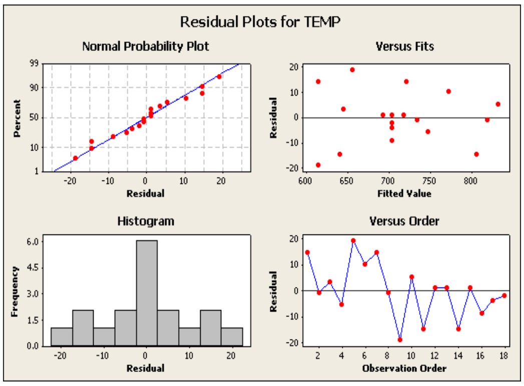

Figure 15. Residual plot for Temperature of SAE-8620

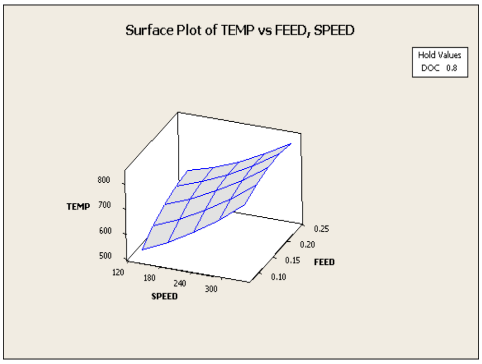

Figure 16(a). Surface Plot of Temp Vs Feed, Speed for SAE-8620

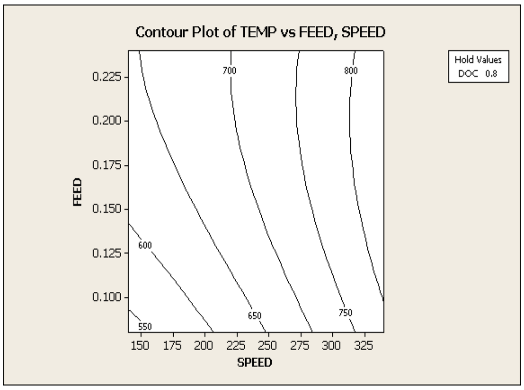

Figure 16(b). Contour Plot of Temp Vs Feed, Speed for SAE-8620

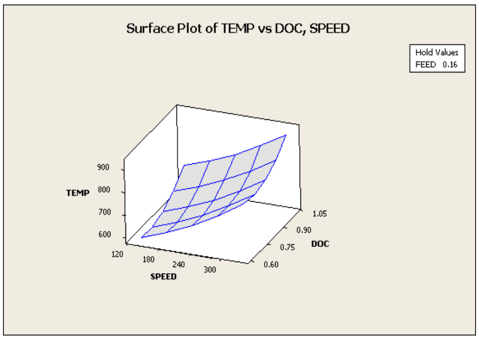

Figure 17(a). Surface Plot of Temp Vs doc, Speed for SAE-8620

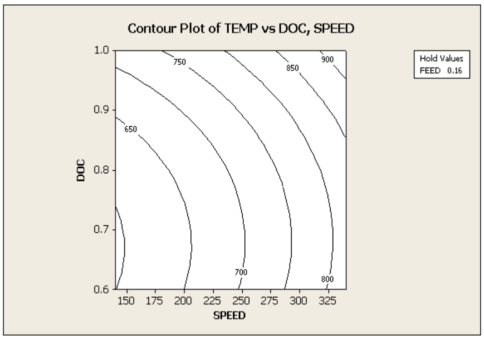

Figure 17(b). Contour Plot of Temp Vs doc, Speed for SAE-8620

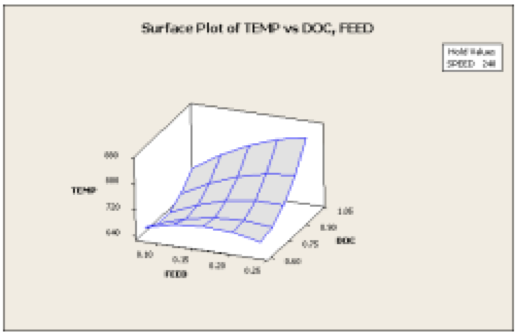

Figure 18(a). Surface Plot of Temp Vs doc, Feed for SAE-8620

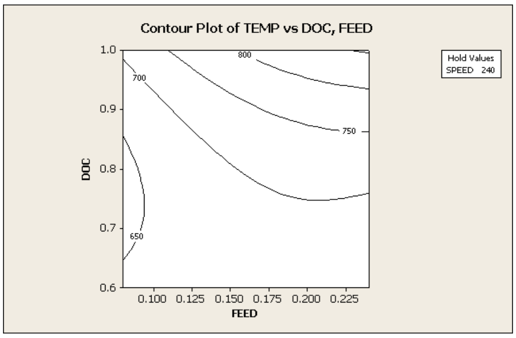

Figure 18(b). Contour Plot of Temp Vs doc, Feed for SAE-8620

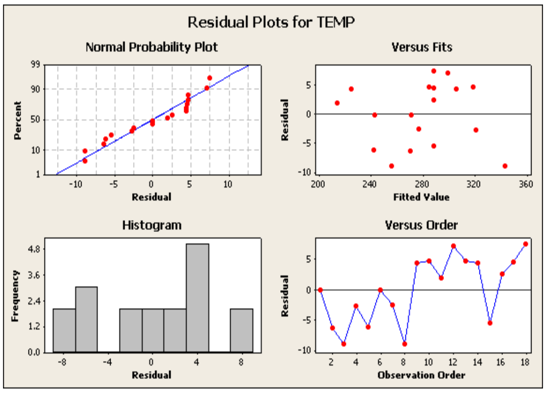

Figure 19. Residual plot for Temperature of AL-380

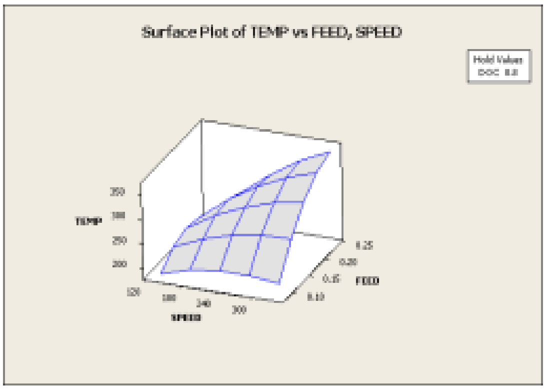

Figure 20(a). Surface Plot of Temp Vs Feed, Speed for Al-380

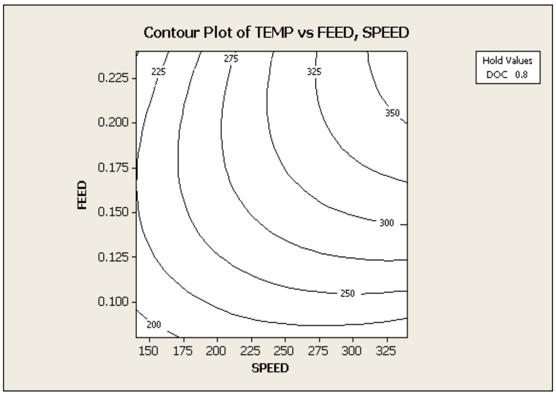

Figure 20(b). Contour Plot of Temp Vs Feed, Speed for Al-380

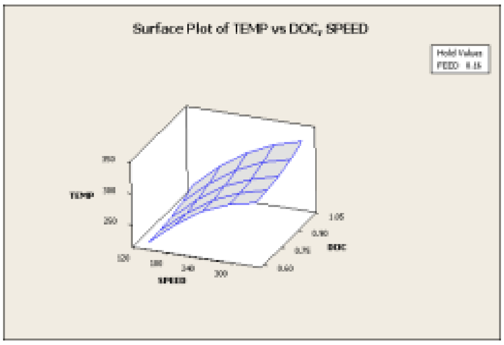

Figure 21(a). Surface Plot of Temp Vs doc, Speed for Al-380

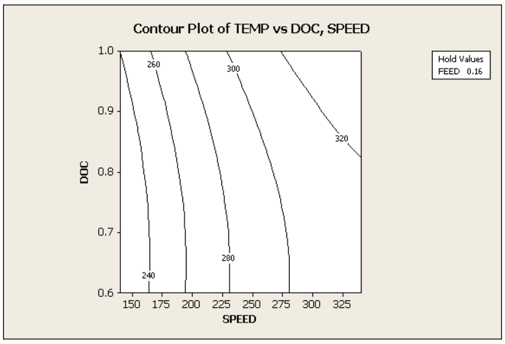

Figure 21(b). Contour Plot of Temp Vs doc, Speed for Al-380

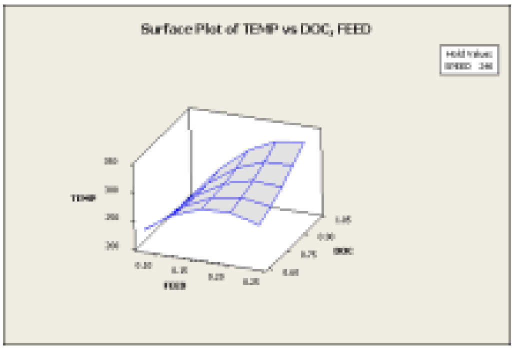

Figure 22(a). Surface Plot of Temp Vs doc, Feed Al-380

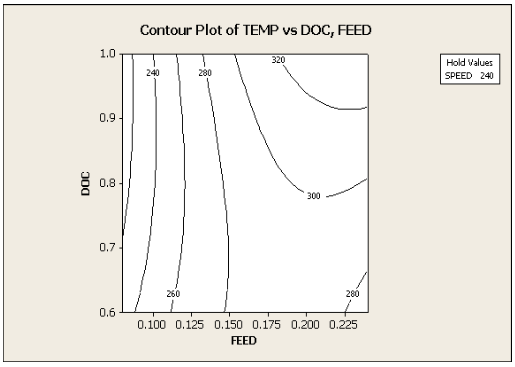

Figure 22(b). Contour Plot of Temp Vs doc, Feed Al-380

4.1. COMPARISON OF TEMPERATURE Vs CUTTING PARAMETERS

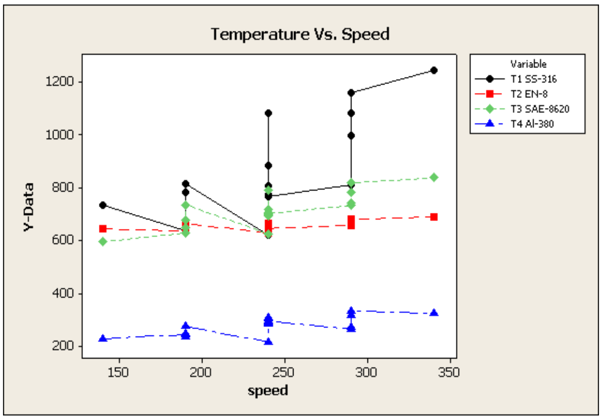

Figure 23. Temperature Vs Speed of materials according to their thermal conductivity

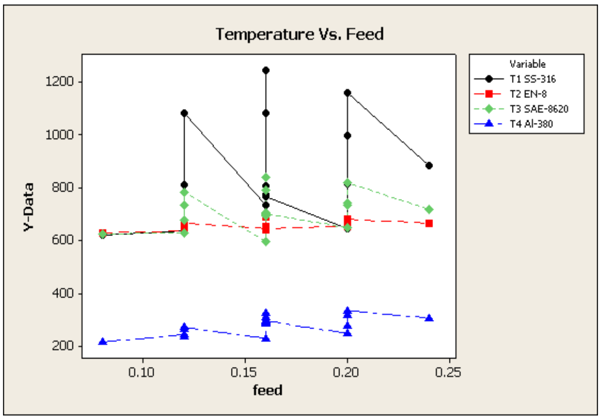

Figure 24. Temperature Vs Feed of materials according to their thermal conductivity

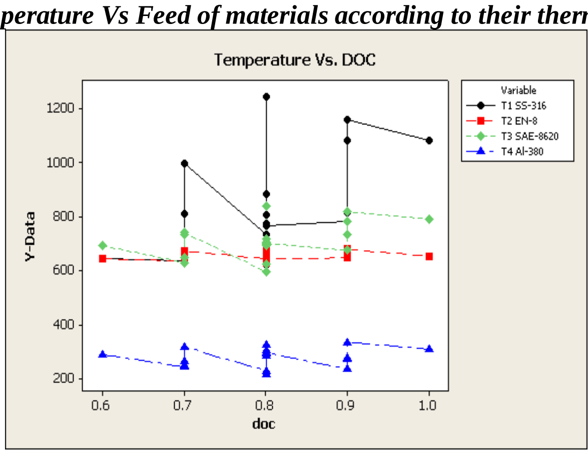

Figure 25. Temperature Vs Depth of cut of materials according to their thermal conductivity

IV. CONCLUSION

The cutting temperature was found to be maximum while machining of SS-316 (having thermal conductivity-16.3W/m-K) and minimum in case of Al-380 (having thermal conductivity-109W/m-K). This is attributed to a significant difference of thermal conductivity of these materials.

While machining EN-8 (having thermal conductivity-24.7W/m-K) and SAE-8620 (having thermal conductivity-46.6W/m-K), the range of cutting temperature was found to be in between the temperature ranges of SS-316 and Al-380 materials.

In addition, response surface models of cutting temperature has been developed for all these above materials. These models have been found to be in good agreement with the experimental results. The correlation coefficients have found to be above 90% in all cases. Hence, these models can be used in the given range of parameters.

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