Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 19 Issue 1 Version 1.0 Year 2019
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN:2249-4596 Print ISSN:0975-5861

Machinability of Nickel Chromium Case Hardened Steel (EN36C)

By Vishal Mishra & Dr. Kalyan Chakraborty
National Institute of Technology

Abstract- Nickel Chromium Case Hardened Steel (EN36C) is surface hardened low carbon steel provided with a strong core prepared by the thermo-mechanical process. Owing to high strength, corrosion resistance, shock resistance, and good fracture toughness properties this kind of steel is used. Heavy duty crane shafts, airplane gears, cam, rollers, truck construction, some structural members and other more are the applications of this steel. It is compatible with dynamic conditions where the load is fluctuating with time, but the rigorous amount of temperature develops due to friction. The paper presents the experimental study on machinability of the EN36C steel. Experimentation was carried out by Chemical vapor deposition (CVD) coated carbide tool. Speed, feed and depth of cuts are the input parameters and chip reduction coefficient, material removal rate (MRR) and Von Mises stress are the output responses. The input parameters were assigned with code and arranged in 3^3 factorial design forms according to the Design of Experiment (DOE).

Keywords: machinability; chip thickness; strain hardening; von mises stress.

GJRE-A Classification: FOR Code: 091399p

MACHINABILITYOFNICKELCHROMIUMCASEHARDENEDSTEELEN36C

Strictly as per the compliance and regulations of:

Machinability of Nickel Chromium Case Hardened Steel (EN36C)

Vishal Mishra [α] & Dr. Kalyan Chakraborty [σ]

Abstract- Nickel Chromium Case Hardened Steel (EN36C) is surface hardened low carbon steel provided with a strong core prepared by the thermo-mechanical process. Owing to high strength, corrosion resistance, shock resistance, and good fracture toughness properties this kind of steel is used. Heavy duty crane shafts, airplane gears, cam, rollers, truck construction, some structural members and other more are the applications of this steel. It is compatible with dynamic conditions where the load is fluctuating with time, but the rigorous amount of temperature develops due to friction. The paper presents the experimental study on machinability of the EN36C steel. Experimentation was carried out by Chemical vapor deposition (CVD) coated carbide tool. Speed, feed and depth of cuts are the input parameters and chip reduction coefficient, material removal rate (MRR) and Von Mises stress are the output responses. The input parameters were assigned with code and arranged in 3^3 factorial design forms according to the Design of Experiment (DOE). The true stress-true strain curve helped to evaluate the material properties such as strain hardening exponent and strength coefficient. Von Mises stress evaluated owns the function of strain hardening exponent and strength of coefficient of the material. The study showed that low and moderate cutting speeds are the favorable conditions for machining on EN36C steel.

Keywords: machinability; chip thickness; strain hardening; von mises stress.

I. Introduction

Steel has a vital role in the manufacturing industries. As per manufacturing is concerned, the material should be deformable but so far as functioning is related material must not deform during its application. For designing any mechanical component made out of steel, it is necessary to know about the working environment of the component. For maintaining the required conditions, the steel needs to be alloying, and heat treated followed by some other processes.

Case hardening of steel is used to improve the mechanical property of steel such as wear resistance without affecting the inner core. The alloying elements take care the strength of the inner core and the thermo-mechanical processes hardens the outer surface. There are many methods by which case hardening can be achieved; some among them are surface coatings, diffusion methods, carburising methods, applied energy methods, etc. Energy applied method which includes flame hardening, induction heating, laser surface heat treatment, and laser transformation hardening is the case hardening process used for EN36C steel.

The work presented aimed at experimental investigation of the Von Mises stresses generated during dry turning of EN36C steel. The work focuses on the chip formation process which was the result of the input process parameters applied during machining. Chip formation and its thickness showed the extent of the rigorous plastic deformation of the material. The plastic deformation of material causes the generation of the Von Mises stress during machining. The generated Von Mises stress lies in the flow zone during the process of chip formation. There are many experimental ways to determine the stresses generated in the material during machining which requires some extra setup such as dynamometer installation, the force measuring sensors and many more which makes the whole machining process complex. Considering the material properties such as Strength coefficient 'K' and strain hardening exponent 'n' and the chip reduction coefficient 'ξ' evaluation of Von Mises stress has been carried. The chips formed during machining of EN36C steel are sometimes twisted and curl with an irregular surface which creates a problem of direct measurement of its length and width. Therefore we considered the length and weight of a chip to evaluate the cut chip thickness. The weight of the chip takes care of the inaccuracies occurred for the determination of the cut chip thickness. Chips are further subjected to SEM examination and analysis continues.

II. Literature Review

Kaushal Pratap Singh et al. [1] used Taguchi optimization technique to optimize input process parameters so to improve surface finish and material removal rate (MRR) during turning operation of EN36 steel. In the experiment, researchers adopted three levels (wet, dry, neutral) of the cutting environment with different spindle speed, feed, depth of cut, and nose radius. After performing the experiment and analysis, researchers concluded that cutting parameters effects MRR by 0.33%, 0.276%, 0.222%, 0.503% and 0.840% respectively and surface roughness by 0.105%, 0.412%, 0.261%, 0.703% and 0.447% respectively.

Author α: M.Tech (Mechanical) Student, Department of Mechanical Engineering, National Institute of Technology, Silchar, Assam.
e-mail: vishalmishra2812.me@gmail.com
Author σ: Associate Professor, Department of Mechanical Engineering, National Institute of Technology, Silchar, Assam.
e-mail: kalyan.ch2013@gmail.com

Manan Kulshreshtha [2] studied the effect of machining parameters over the surface roughness of EN36 steel shafts by the use of carbide and cobalt-based tool insert using CNC lathe. Types of tool insert used, spindle speed, feed rate and depth of cut are the input process parameters used. The sequence of the input parameters was generated and considered according to Central Composite Design (CCD). As a result of the experiment, feed rate contributes most and cutting speed contributes least as an input factor affecting the surface roughness. By the use of Tungsten carbide tool, 2.1 micron was the optimum surface roughness value recorded at 0.2mm DOC, 10mm/min feed rate and 1200 rpm cutting speed.

However, by machining with cobalt insert, it was observed that 2.3 micron was the optimum surface roughness value recorded at 0.2mm DOC, 15mm/min feed rate and 1200rpm cutting speed.

A.Venkata Vishnu et al. [3] used Taguchi approach to optimize the turning process parameters of EN36 alloy. By using a Taguchi robust design approach, the optimum value of the selected control parameters was found to improve the material removal rate. EN36 steel in annealed condition was the work material, CNC machine with three types of tool inserts (Uncoated, PVD coated (TiAlN), CVD coated (CVD Al_2O_3 film MT-TiCN + TiC + Al_2O_3) was used for turning the work material. Researchers removed a ring-shaped layer of material, measured difference in the initial and final weight of the workpiece to calculate the MRR Number of the experiments conducted are nine. The work shows the Taguchi method application.

The result obtained that MRR increases with increase in cutting speed and feed rate respectively and also MRR increases till the moderate depth of cut and then decreases on increasing the depth of cut and at last MRR was maximum for the Uncoated tooltip, moderate for CVD tool and minimum for PVD coated tool.

They concluded that 100m/min cutting speed, 0.4mm/rev feed, 1 mm depth of cut were the optimum values and the uncoated tool was good for MRR.

III. Experimental Analysis

For the assessment on machinability of EN36C steel, Von Mises stress and the chip formation mechanism are two primary factors considered. The work material is of 110 mm diameter and 400 mm length dimension. The work material is Nickel Chromium case hardened steel prepared by the thermo-mechanical process. For turning of the work material, the present work employed Tungaloy made CVD (Chemical Vapour Deposition) coated (3 to 16 μm thick) carbide grades consisting of cemented carbide substrate TiCN tool insert. The coating over the tool insert improves the hot hardness and oxidation resistance property of the tool, thus making the tool chemically stable which increases the tool life and efficiency of machining.

Table 1: Chemical composition of EN36C steel

%Fe	%C	%Mn	%Si	%P	%Cr	%Mo	%Ni	%Al	%S
Balanced	0.159	0.386	0.182	0.0164	0.820	0.131	3.10	0.0182	0.0199

The present work employed gear driven central lathe for turning the workpiece. Spindle speed range of 45 rpm to 1000 rpm, and feed a range of 0.06mm/rev to 1.72 mm/rev are values available in the central lathe.

a) Tool Used

Holder specification: ASBNR 25*25 M12-A

Carbide inserts Specification: SNMG 120404 TM T9125

b) Selection of process parameters

The input process parameters were selected based on the values available on the lathe.

Table 2: Input Process Parameters used for machining

Factors	Level 1	Level 2	Level 3
Coding	-1	0	1
Speed (m/min)	36	60	100
Feed (mm/rev)	0.49	0.63	0.86
DOC (mm)	0.67	1	1.5

Table 2 describes the codes for each input process parameters. As per 3^3 factorial design, 27 experiments are available in the present work.

Table 3: 3^3 factorial design showing the input for machining

S. No.	Velocity Code	Feed Code	DOC Code	V (m/min.)	f (mm/rev)	d (mm)
1	-1	-1	-1	36	0.49	0.67
2	-1	-1	0	36	0.49	1
3	-1	-1	1	36	0.49	1.5
4	-1	0	-1	36	0.63	0.67
5	-1	0	0	36	0.63	1
6	-1	0	1	36	0.63	1.5
7	-1	1	-1	36	0.86	0.67
8	-1	1	0	36	0.86	1
9	-1	1	1	36	0.86	1.5
10	0	-1	-1	60	0.49	0.67
11	0	-1	0	60	0.49	1
12	0	-1	1	60	0.49	1.5
13	0	0	-1	60	0.63	0.67
14	0	0	0	60	0.63	1
15	0	0	1	60	0.63	1.5
16	0	1	-1	60	0.86	0.67
17	0	1	0	60	0.86	1
18	0	1	1	60	0.86	1.5
19	1	-1	-1	100	0.49	0.67
20	1	-1	0	100	0.49	1
21	1	-1	1	100	0.49	1.5
22	1	0	-1	100	0.63	0.67
23	1	0	0	100	0.63	1
24	1	0	1	100	0.63	1.5
25	1	1	-1	100	0.86	0.67
26	1	1	0	100	0.86	1
27	1	1	1	100	0.86	1.5

After mounting the work material on the lathe, turning operation was carried out for 30 seconds for each experiment. The experiment performed results in the formation of 27 different types of chips.

Fig. 1: (a). EN36C Steel mounted on the lathe. (b). EN36C Steel after machining.

Global Journal of Researches in Engineering (A) Volume XIX Issue I Version I Year 2019

IV. Theory and Result

After the machining operation from 27 different experiments, the weight and the length of 27 experimental chips are available in the present study. Chip thickness and Von Mises stress values are available as subsequent machining response from the present work material. The below given formaulations are considered for the calculations:

Uncut Chip Thickness $t_1 = f * \sin \boldsymbol{\phi}$

Where,
f = Feed (mm/rev)
$\boldsymbol{\phi}$ = Principle Cutting edge angle (in degree)

$$Cut\ chip\ thickness\ t_2 = \frac{W}{\rho w l}$$

Where,
W = Weight of a chip (gm)
$\boldsymbol{\rho}$ = Density of the steel (0.008 gm/mm^3)
l = Length of a chip (mm)
w = width of a chip (mm)

$$width\ of\ a\ chip\ w = \frac{d}{\cos(90-\theta)}$$

Where,
d = Depth of cut (mm)
θ = Principle approach angle (in degree)

Chip reduction coefficient $\xi = \frac{t_2}{t_1}$

$$Shear\ angle\ \hat{Y} = \frac{\cos\alpha}{\xi - \sin\alpha}$$

Where, α = Rake Angle (in degree)

Von Mises stress $\sigma_v = 1.74*K*(\ln\xi)^n$ (MPa)

Where,
K = Strength coefficient (MPa)
n = strain hardening exponent

The above mentioned 'K' and 'n' values were calculated by selecting the points from true stress-true strain curve and plotting them on log-log graph paper. INSTRON 1195 UTM machine shows tensile test data of ASTM-E8 specimen prepared from the work material.

Fig. 2(a): ASTM-E8 EN36C steel Specimen before the tensile test.

Fig. 2(b): ASTM-E8 EN36C steel Specimen (Broken) after the tensile test.

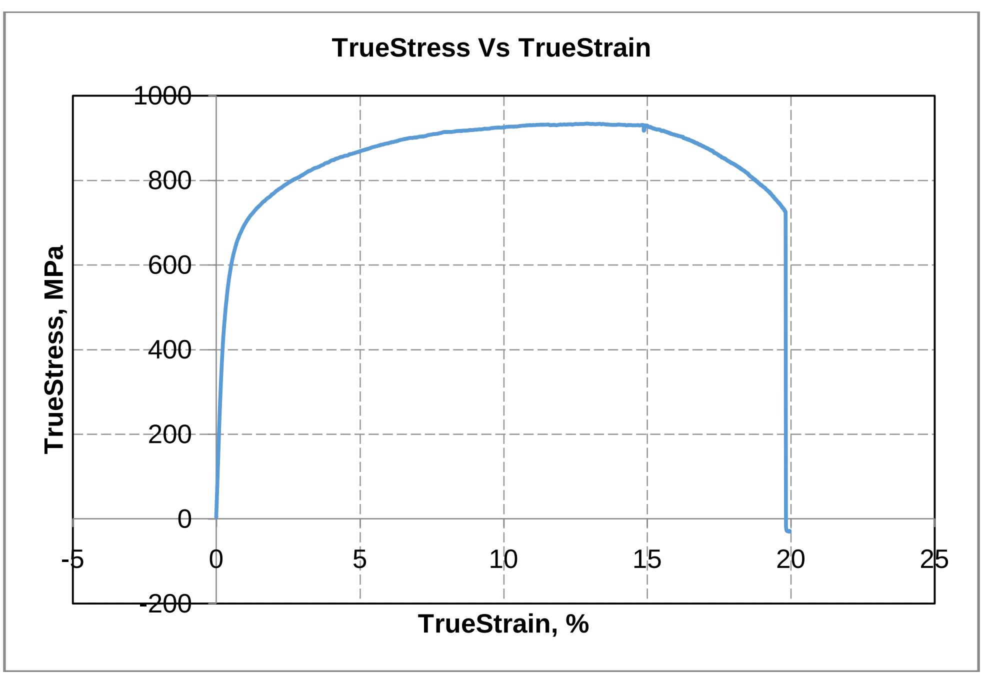

Fig. 3: True stress - True strain curve.

From the true stress-true strain curve points were selected which lies between the yield stress point and the ultimate stress point. Strain hardening exponent 'n' and strength coefficient 'k' values are available in the present work obtained from plotting the points of true stress-true strain curve on log-log graph paper and extrapolating the line to strain value 1. Value of 'K' is the value of true stress at true strain equals to 1 on the log-log graph (Fig. 4).

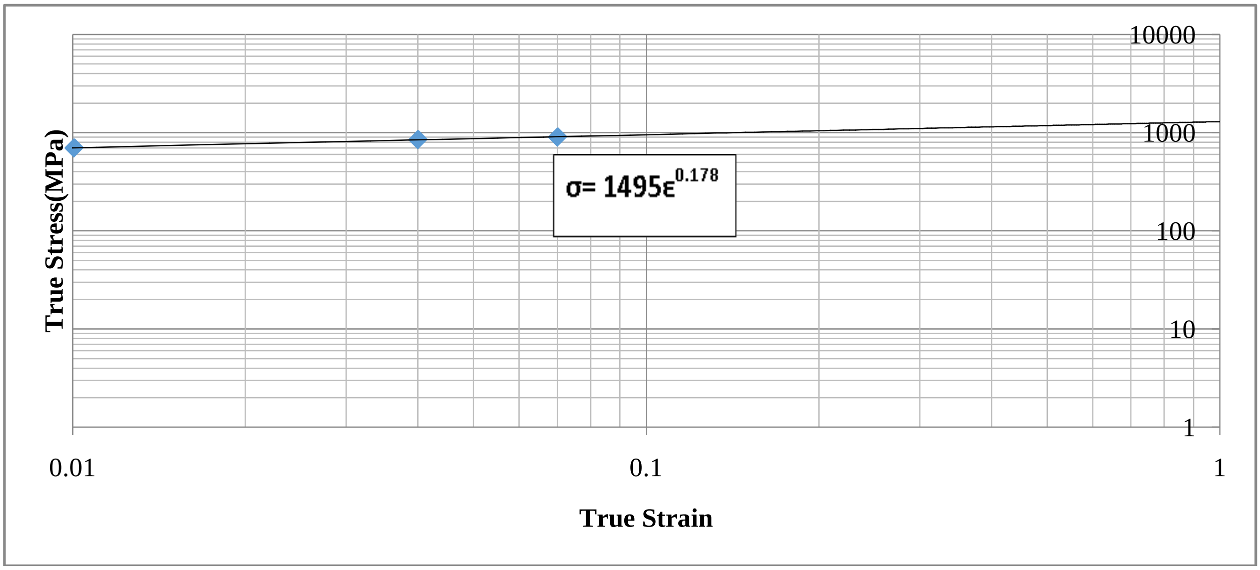

Fig. 4: True stress v/s True strain log-log graph.

So by getting the value of 'K' and 'n' power equation $\sigma = K\varepsilon^n$ was obtained as:

$$\sigma = 1495\varepsilon^{0.178}$$

Where,
σ = True Stress (MPa)
ε = True Strain

For total work done, elemental work done was to be evaluated first as shown below:
Elemental work done W_e,

$$W_e = \frac{K(1.15 ln\xi)^{n+1}}{n+1}$$

Total Work done T_W,

$$T_w = W_e * V * f * d * t \text{ (Nm)}$$

Where,
V = Cutting speed (m/min)
f = feed (mm/rev)
d = depth of cut (mm)
t = time (minutes)

The regression coefficients were obtained through Minitab software. The second order equations for the chip reduction coefficient (b_{CRC}) and Von Mises Stress (b_{VMS}) are obtained as:

$$b_{CRC} = 1.3334 - 0.0561x_1 - 0.0322x_2 - 0.0163x_3 - 0.2708x_1^2 + 0.1474x_2^2 + 0.0563x_3^2 + 0.0366x_1x_2 + 0.0183x_1x_3 - 0.0093x_2x_3 \quad \text{(eq. i)}$$

$$b_{VMS} = 1810.7 - 76.2x_1 - 25.1x_2 - 7x_3 - 324x_1^2 + 265.7x_2^2 + 157.9x_3^2 + 101.5x_1x_2 + 129.5x_1x_3 - 374x_2x_3 \quad \text{(eq. ii)}$$

Where,
x_1 = Speed.
x_2 = Feed.
x_3 = Depth of cut.

Design of experiment equations helped us to obtain 3D graphs for chip reduction coefficient 'CRC', and Von Mises stress for various cutting parameters.

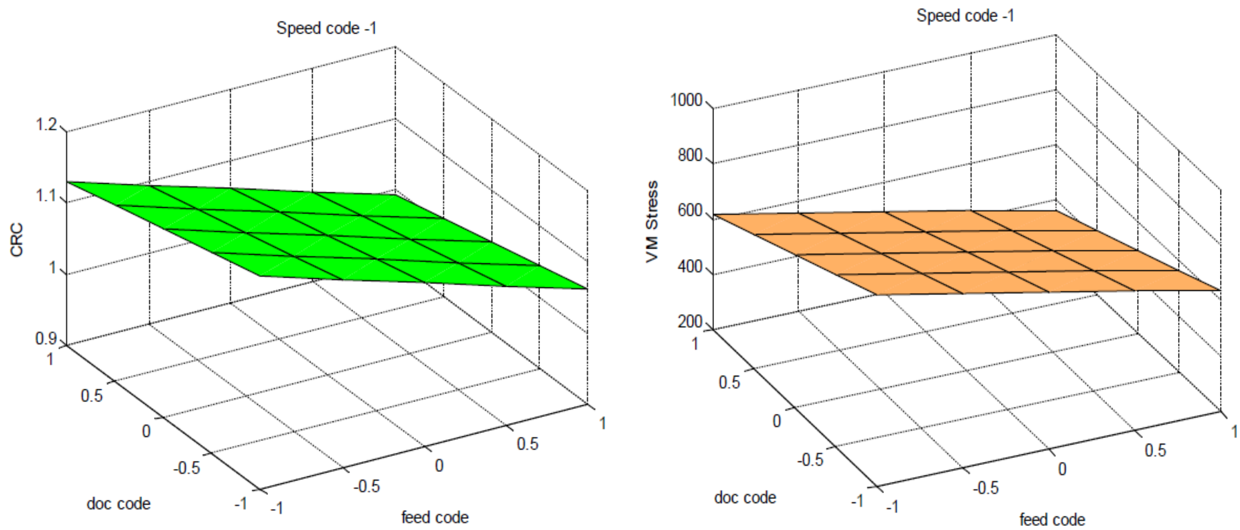

Fig. 5: (a). Variation of CRC concerning to the feed and depth of cut code for the speed code -1.
(b). Variation of Von Mises Stress concerning the feed and depth of cut code for the speed code -1.

The fig. 5 (a) and 5 (b) shows that at the lowest speed (speed code -1), both CRC and Von Mises stress decrease with an increase in the feed. Strain hardening of the work material and brittleness transition becomes effective with increased feed to reduce the value of CRC and Von Mises stress.

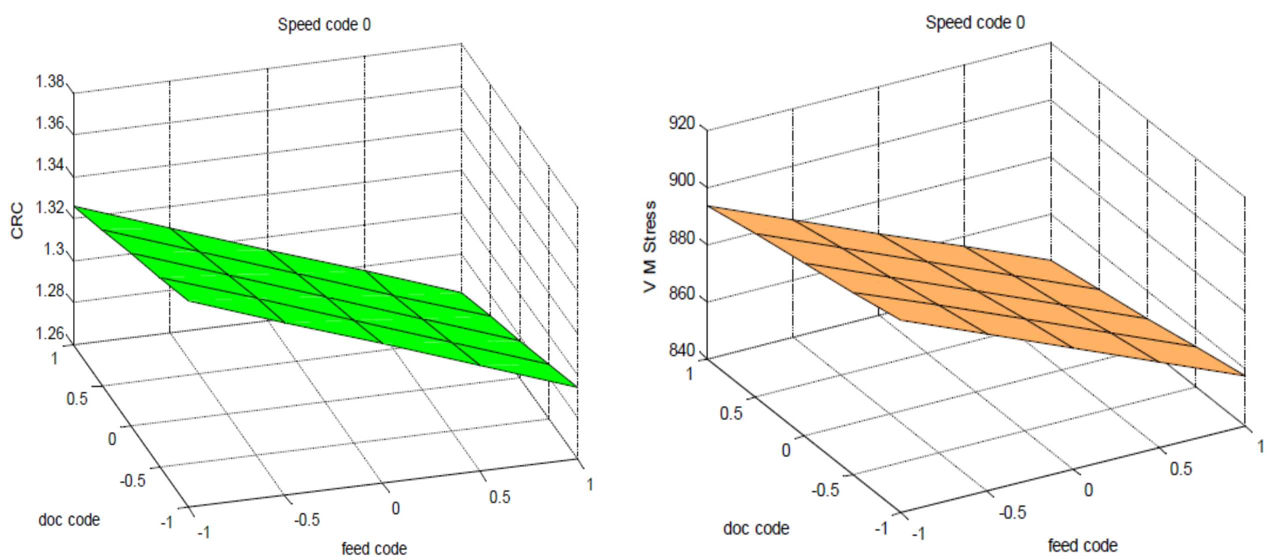

Fig. 6: (a). Variation of CRC concerning to the feed and depth of cut code for the speed code 0.
(b). Variation of Von Mises Stress concerning to the feed and depth of cut code for the speed code 0.

From fig. 6 (a) and 6 (b) shows that both CRC and Von Mises stress decreases with an increase in feed. At increased feed, material hardening and brittleness transition become more effective to reduce the value of CRC and Von Mises stress during the process of chip formation. Variation of the depth of cut at this cutting condition is found to be less effective to vary both CRC and Von Mises stress.

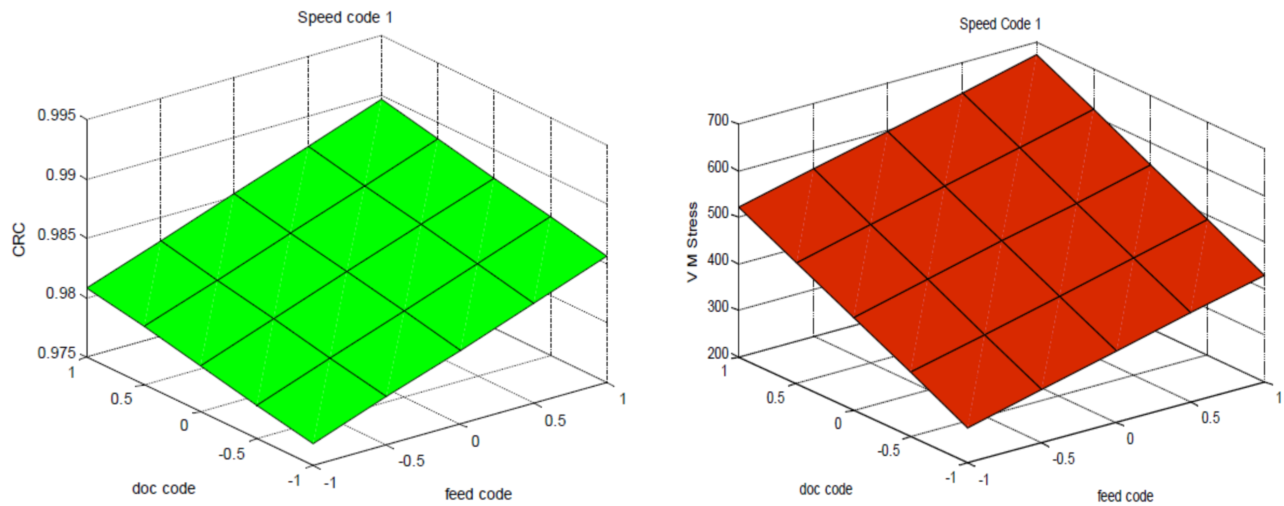

Fig. 7: (a). Variation of CRC concerning to the feed and depth of cut code for the speed code 1.
(b). Variation of Von Mises Stress concerning the feed and depth of cut code for the speed code 1.

From fig. 7 (a) and 7 (b) shows that both CRC and Von Mises stress are increasing with the feed and depth of cut. In the present work, code 1 is the highest code value for each input parameters. At maximum speed, feed and depth of cut condition, the thermal effect becomes pronounced causing the thermal softening to raise the CRC value for the produced chip at this specific cutting condition. A ductile transition of the work material occurs at the cutting zone during the process of chip formation causing pronounced cohesive energy in the flow zone due to thermal effect and Von Mises stress increases enormously owing to the ductile separation of the chip material during the process of chip formation.

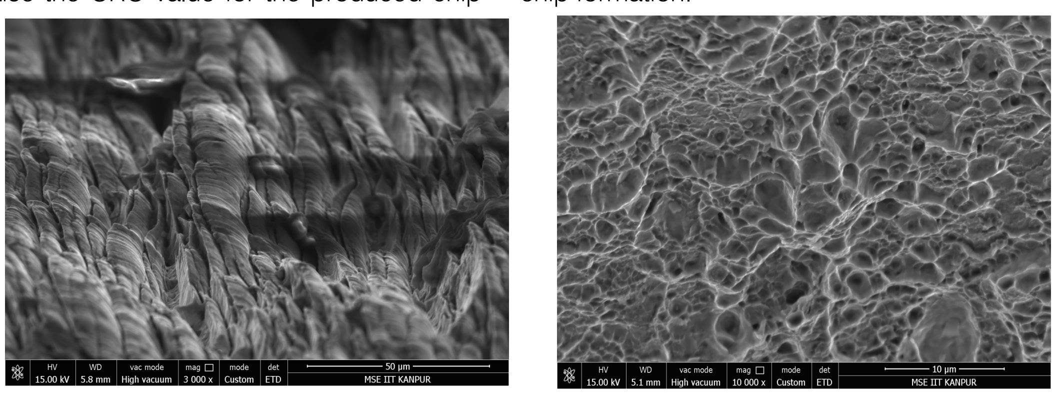

Fig. 8: (a). SEM image of the side edge of a chip at 3000X magnification.
(b). SEM image of the fractured tip surface of a chip at 10000X magnification.

Chip specimen obtained at maximum speed, feed and depth of cut (v = 100 m/min, f = 0.86 mm/rev and d = 1.5 mm) condition was examined under the Scanning Electron Microscope (SEM). Chip image for the chip side edge along with chip top surface was viewed under the Scanning Electron Microscope (Fig. 8 (a)). Enormous ductile separation of the material occurs during the process of chip formation. SEM examination of chip fractures surface shows ductile fracturing (fig. 8 (b)). Numerous dimples are available at the fractured surface. The fig. 8 (b) showed that ductile tearing mode took place during the process of chip formation. This finding clearly illustrates the dominating effect of temperature causing ductile transition at the flow zone during the process of chip formation.

V. Conclusion

1. Property transition of the work material occurs at the cutting zone during the process of chip formation.
2. Machining of EN36C steel should be in respective to the lower speed and moderate speed at variable feed and depth of cut.
3. High-speed machining is not good for machining EN36C steel.

Acknowledgement

The authors sincerely and gratefully acknowledge the financial assistance provided by our institution NIT Silchar for accomplishing this work, and express deep gratitude towards the production engineering lab of NIT Silchar, SEM lab and material testing lab of IIT Kanpur to conduct different experiments related to this project and to all other people who helped in success of this work.

References Références Referencias

1. Kaushal Pratap Singh, Girish Dutt Gautam, Rupesh Yadav, Lalit Bisht, Gavendra Norkey. "Selection of Optimum Machining Parameters for EN36 Alloy Steel in CNC Turning Using Taguchi Method". International Journal of Scientific & Engineering Research, Volume 5, Issue 3, March-2014. https://www.ijser.org/researchpaper/selection-of-optimum-machining-parameters.pdf
2. Manan Kulshreshtha. "Analysis of the Effect of Machining Parameters on Surface Roughness of EN 36 Nickel Steel". International Journal of Advanced Information Science and Technology (IJAIST) Vol.16, No.16, August 2013 ISSN: 2319:2682 http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.679.8384&rep=rep1&type=pdf
3. A. Venkata Vishnu, G. Guruvaiah Naidu, K.B.G. Tilak, J. Ramakrishna. "Application of Taguchi Method in the Optimization of Turning Parameters for Material Removal Rate of En-36 Material". International Journal of Advance Engineering and Research Development. (Scientific Journal of Impact Factor (SJIF): 3.134). Volume 2, Issue 8, August-2015 e-ISSN (O): 2348-4470 p-ISSN (P): 2348-6406. https://www.researchgate.net/publication/320042160_Application_of_Taguchi_Method_in_the_Optimization_of_Turning_Parameters_for_Material_Removal_Rate_of_En-36_Material