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Research Article

HEAT TREATMENT OF TOOL STEEL D3 AND EFFECTS ON MECHANICAL PROPERTIES

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ABSTRACT

Investigation of my project is to evaluate the effects of heat treatment process on mechanical properties machinability of material. Material used for this project is Tool steel D3 and CBN insert tool is chosen for performing machining operations on CNC. Comparison of roughness has been done for before and after conventional heat treatment process. Similarly tool wear and chip morphology before and after conventional heat treatment process are also established in detail. Working conditions like cutting speed, depth of cut & feed rate are varied for different values. Mitutoyo surface roughness tester is used for before and after result comparisons. Optimisation is done using Response surface method technique. Resultant machining properties show improvement after heat treatment.

INTRODUCTION

Tool steels are the alloys which are used to manufacture the dies tools and mold, and cut other materials, including ferrous and nonferrous materials and plastics etc[1-3]. Properties of tool steel depend upon the composition of alloys therefore we can say that when we change the composition of tool steel then properties of tool steel will also change and therefore by changing the composition of tool steel we can obtain the desire properties[4-5]. Properties of tool steel also depend on the crystal structure of tool steel so we can also change the properties of tool steel by using the different type of heat treatment process because heat treatment process change the crystal structure of material such as crystal structure of steel in iron carbon diagram change from face center cubic (FCC) to body center cubic (BCC) during cooling of y-austenite ateutectoid point in iron carbon diagram [6].

Tool steel is also classified on the basic of American iron and steel institute (AISI) such as water hardening tool steel, hot work tool steel , tungsten high speed tool steel, chromium based tool steel etc. Tool Steel D3 is classified by AISI system which is chromium hot work tool steel, UNS (unified numbering system) number of tool steel D3 is T20813 which has 0.35%C, 5%Cr, 1%V, 1.5%Mo [7].

An overview of important heat treatment process Heat treatment process are used to improve the mechanical properties of material by changing the crystal structure (such as change the FCC to BCC etc.) or we can say that we can obtain desire properties of material by use of heat treatment process. Heat treatment process consist full annealing process, recrystallization annealing, stress relief annealing, spherodisation annealing, cooling process, surface hardening, case hardening, work hardening process, tempering, normalizing etc.[8-9], and heat treatment process can affect the entire work piece or only Surface or some region in material depends upon the heat treatment process and parameter used in heat treatment process. Different types of heat treatment process are almost same because all heat treatment process requires the heating and cooling process. But difference is distinguished by rate of heating and cooling. Heat treatment process is mainly three step process.

Stage 1 – heat the metal (sample) to the desire temperature and ensure the uniformtemperature
Stage 2 – hold the metal at high temperature for sufficient time period according torequirement
Stage 3 – cool the metal to room temperature

Types of Heat Treatment Process

Annealing- Annealing is used to relieve the internal stress of material and soften the material then make it more ductile and refine the structure of grains.

Normalizing: Normalizing is the heat treatment process for ferrous metals only. Normalizing less differs from annealing. In normalizing, we heat the metal to high temperature in furnace

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then remove from furnace and cool in air. The aim of normalizing is to relieve the internal stress of metal and increase the ductility of metal but annealing increase the more ductility of metal as compare to normalizing. Low carbon steel are not so good for this process.

Quenching or Hardening- In hardening, metals are heated to slightly above the critical temperature (from iron carbondiagram) and then cooled rapidly in water, oil, brine etc. hardening process increase the hardness, brittleness and strengthof metal but decrease the ductility of metal.

Tempering- Tempering is performed to decrease the hardness of metal and relieve the internal stress, tempering is used. In general tempering process, metal is heated to its lower critical temperature and then held at this elevated temperature for sufficient time period and then normally cool in air. The main aim of tempering occurs to increase the ductility ofmetal, to reduce the hardness and strength of metal and to obtain the desire physical properties.

Case Hardening- Case hardening also knows as surface hardening because case hardening is mainly used to increase the hardness of metal's surface and Case hardening also increase the wear resistance of metal's surface. Types of casehardening are flame hardening, cyaniding, carburizing, nit riding etc.

Literature Review

I read many literature papers to know some main factors which affect the machining process. Name of authors and used material and other used factors are discussed one by one for each literature papers which are read by me. There papers are given –

Ng and Aspin wall investigate that every tool steel is very hard and it exhibit high toughness, high hardness and good resistance against thermal softening. Doe to these mechanical properties, machining of hardened tool steel is very difficult and this researcher investigated at effect of hardness of work piece and cutting speed onmachinability for AISI D3 with use of PCBN insert tool. And similarly many researchers have been done machining process on hardened tool steel with several insert tool and with different working condition such as dry machining and wet machining.

Xiong et. - Investigated effect of cutting variable on tool wear and tool life mechanism with use of ceramic tool. The results showed by use of WC – 5TiC – 10Co cemented carbide tool which has higher hardness value exhibit the better performing results than results obtained by use of conventional insert with same cutting condition.

RESEARCH METHODOLOGY

Heat treatment is used to improving the mechanical properties and mach inability of work piece. Turning operation is used for machining of work piece on CNCla the machine with insert tool. Insert tool that is used during machining has the high strength and toughness that can withstand at high temperature and high cutting speed which is CBN insert tool. Roughness, chip morphology and tool wear are measured before and after the heat treatment process and then compared roughness with roughness tool wear with tool wear and chip morphology with chip morphology. Dry machining process is used means no cutting fluid is used. Two rod of Tool steel D3 is used asworkpiece which dimensions are – length 200mm, diameters 50mm. Scanning electron microscope is used for determining the chip morphology. 50x, 100x, 500x, 100xmagnification are used for determining chip morphology.

Composition of tool Steel D3

Elements	Percentage of weight
Carbon	2.1
Vanadium	0.9
Manganese	0.5
Silicon	0.6
Chromium	12
Properties of material	Values
Ultimate compression strength	2151 N/mm2
Density	7861 kg/m³
Poisson ratio	0.3
Modulus of rigidity	80*10³
Modulus of rigidity	211*10³ N/mm³

Insert tool Material

According to my studied research papers I found that hardness and strength of insert tool should be higher than hardness and strength of working material thus CBN insert tool is preferred by me for machining of tool steel D3 here. Dry cutting condition is used during my experiments process. Dry cutting condition means no cutting fluid is used and no specific environment is required (normal environment), therefore machining cost is low in dry machining as compared to wet machining. Also insert tools perform better result at higher cutting temperature which achieved at dry cutting. Here, depth of cut is kept constant while cutting speed and feed rate are varied, feed rate is varied from 0.3 to 0.6 mm and cutting speed is varies from 100 to 200 rpm.

Surface Roughness Measurement

Roughness tester is used for measuring the roughness of machined surface precisely. Roughness tester measures the roughness with help of portable type mitutoyo, profilometer.

Parameters for Machining

The table given blow shows different fixed cutting parameters which are used for this study.

Code	Parameters	Level 1	Level 2
1	Feed rate in mm/ rev	0.08	.16
2	Cutting speed in meter/ min	100	200
3	Depth of cut in mm.	0.3	0.3

RESULTS

Here are results which are obtained when machining whithout without the heat treatment of Tool Steel D3.

S.No	Speed (m/min)	RPM	Depth of cut	Feed rate(mm/rev)	Average surfaceroughness Ra (um)
1	100	637	0.3	0.16	1.7
2	100	637	0.3	0.08	0.9
3	150	955	0.3	0.0634	1.65
4	150	955	0.3	0.08	0.65
5	200	1274	0.3	0.16	0.6
6	200	1274	0.3	0.08	1.6
7	220	1401	0.3	0.12	1.53
8	80	509	0.3	0.12	1.43

All of these result values obtained during the experiment were used as input in design expert 2011 software which does the further analysis. And this design expert software contains the

ANOVA application which analyse the whole for producing the optimum results in different representation such as numerical representation, graphical representation etc.

Anova for Linear Model

Analysis of the variance were used for studying significance and the effect of cuttingparameter on response variable (Ra).

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1.33	2	0.6640	19.27	0.0045	significant
A-cutting speed	0.0366	1	0.0366	1.06	0.3497	
B-feed rate	1.29	1	1.29	37.47	0.0017	
Residual	0.1723	5	0.0345			
Cor Total	1.50	7				

The Model F-value of 19.27 implies the model is significant. There is only a 0.45% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case B is a significant model term. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.static model for roughness (Ra)

Std Dev.	**0.1079**
Coefficient of variation	14.53
Mean	0.7432
Adeq precision	5.2818
Predicted R^2	NA
Adjusted R^2	0.5285
R^2	0.8821

Case(s) with leverage of 1.0000: Pred R^2 and PRESS statistic not defined. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Yourratio of 5.282 indicates an adequate signal. This model can be used to navigate the designspace.Final model, for surface roughness given below

$R1 = +0.255203 - 0.001354*\text{cutting speed} + 10.0442*\text{feed rate}$

The equation in terms of actual factors can be used to make predictions about theresponse for given levels of each factor. Here, the levels should be specified in theoriginal units for each factor. This equation should not be used to determine the relativeimpact of each factor because the coefficients are scaled to accommodate the units ofeach factor and the intercept is not at the centre of the design space.

Residual plots

All the figures given below show the residual plots for surface roughness (Ra)

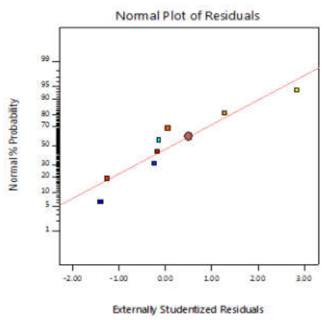


Fig. a

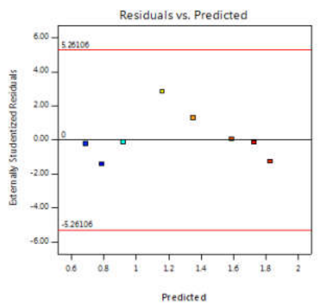


Fig. b

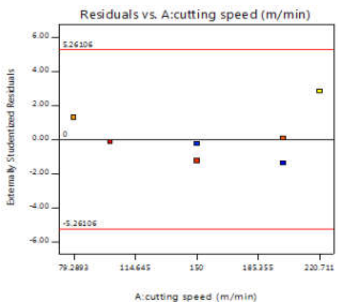


Fig. c

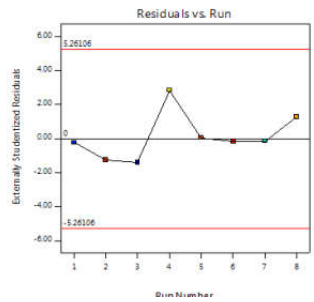
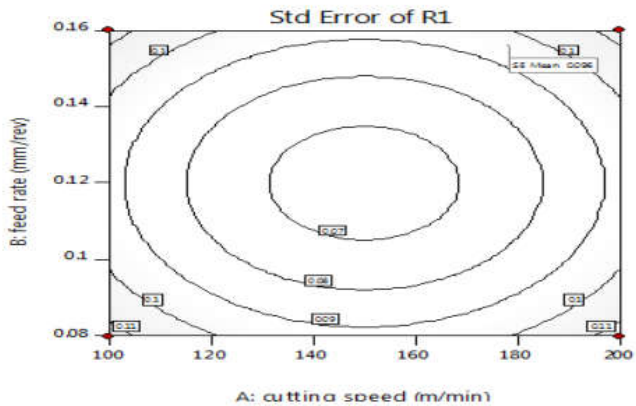


Fig. d

Above is shown plot of residual figure, all purposes of result are practically close to the straight line in this way this model is a satisfactory and this plot likewise indicates typical conveyance of blunders. In plot remaining versus anticipated figure (b), a few are far from the straight. In other language we can say that irregular pattern take place and some errors are find out.

Three dimensional surface and contour plots for average surface roughness of workpiece (Ra) are given below-



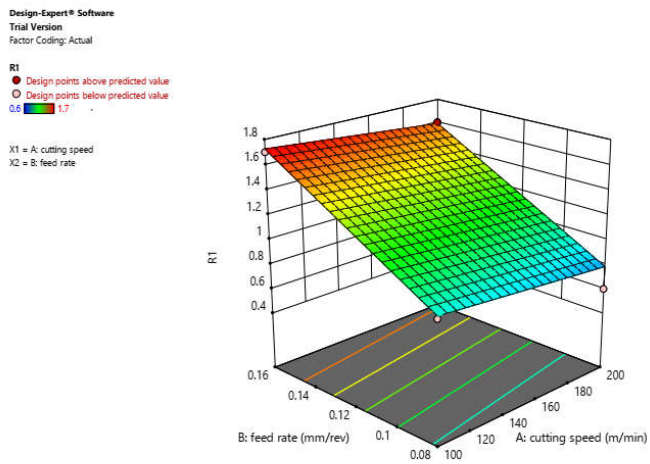


Fig 3D Plots

In above plots, cutting speed and feed rate are variables while depth of cut is kept constant throughout the this research Effect of feed rate and cutting speed at surface roughness of material are shown graphically by using of surface plot and contour plo.ActualR1Design points above predicted value Design points below predicted value0.6 1.7X1 = A: cutting speedX2 = B: feed rate0.08.

Some things are observed from above two figures that surface roughness decrease with increase in cutting speed when depth of cut is kept constant. And surface roughness increase with increase and decrease indeed rate from specific rage of feed arte when depth of cut is kept constant therefore feed rate are used in specific rang for better results of roughness for tool steel D3.After analysis for roughness by using ANOVA in design expert software, surface roughness of tool steel D3 are the most influenced by feed rate as compared to cutting speed. Therefore feed rate is most important factor for measuring the average surface roughness during the machining operation of tool steel D3.

Optimum values for Different Parameters

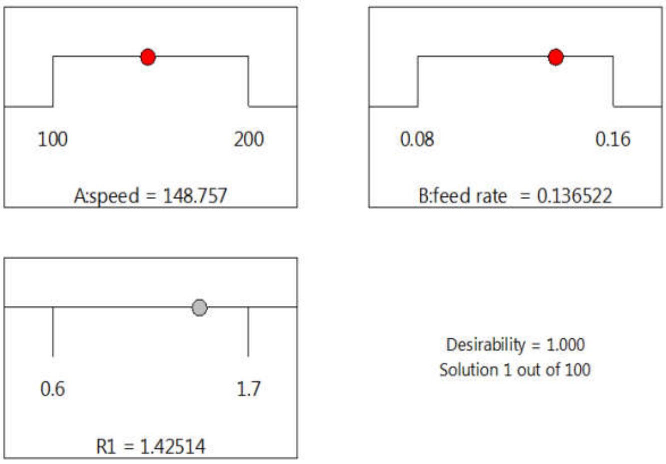


Fig Optimum Values

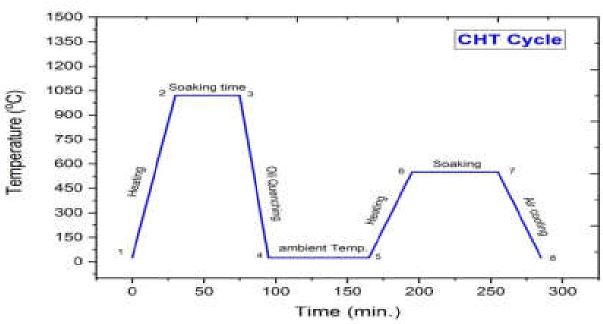
Fig shown above depicts the optimum value for A: Cutting speed, B: Feed rate & average R1: Surface roughness at given conditions. These values are finalized by me but surface roughness range is main output value which is obtained after performing the machining operation.

Optimum values for different parameters for optimum desirability.

Cutting speed(m/min)	Feed rate (mm/rev)	Surface roughness(Ra) (um)	Desirability
148.757	0.136	1.42514	1

Results of experiment after the Conventional heat treatment

Heat treatment cycle is shown in the fig. below. It shows primary temp conditions for material during the heat treatment process.



During the CHT of tool steel D3, first of all material was heated in muffle furnace whichis seen in above figure from point1 to point2, this time interval of heating is called timeTemperature of material reached the 1020 ºC then material was kept for 45 minutes, thistime interval is called soaking time, saw in above figure from point2 to point3. In this interval of time, crystal structure of material changes therefore we can say that propertiesof material changes. Heated material at point3 was cooled up to point4, by quenching in oil and then put intothe atmosphere. And then reach the point 5.After point 5, again heating, holding at high temperature but below lower critical temperature and cooling (cooling in air) are done which is seen in above figure frompoint 5 to point 8. Cycle form point 5 to point 8 is called tempering process which is usedto relieve the internal crack and internal stress

After heat treatment machining operation is performed and results obtained and input values of variable are given in below table.

Result Obtained after CHT Process

S.No	Speed (m/min)	RPM	Depth of cut	Feed rate (mm/rev)	Average surface roughness Ra (um)
1	100	637	0.3	0.16	1.22
2	100	637	0.3	0.08	0.83
3	150	955	0.3	0.0634	1.48
4	150	955	0.3	0.176	0.94
5	200	1274	0.3	0.16	6.1
6	200	1274	0.3	0.08	5.14
7	220	1401	0.3	0.12	5.32
8	80	509	0.3	0.12	5.80

All input values of variable and output values obtained during the machining process aregiven in above table. And this data is analysis by ANOVA application which is given indesign expert software.

Anova for Linear Model

Analysis of the variance were used for studying significance and the effect of cuttingparameter on response variable (Ra)

Response 1: R1

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	9.10	2	4.55	0.7165	0.5326	not significant
A-cutting speed	9.06	1	9.06	1.43	0.2859	
B-feed rate	0.0430	1	0.0430	0.0068	0.9376	
Residual	31.74	5	6.35			
Cor Total	40.84	7				

The Model F-value of 0.72 shows that the model is not significantly relative to the noise. Thereis about 53.26% chance that an F-value of this much value could occur due to noise. P-values of 0.0500 indicate model terms are significant. In this case there are no significant modelterms. Values greater than 0.1000 indicate the model terms are not significant. Static model for roughness (Ra)

Std Dev.	2.52
Coefficient of variation	75.13
Mean	3.35
Adeq precision	1.9502
Predicted R^2	-0.9897
Adjusted R^2	-0.0881
R^2	0.2228

This negative Predicted R^2 implies that overall mean may be a better predictor of your response than the current model. In some cases, a higher order model may also predict better.

Adeq Precision measures the signal to noise ratio. A ratio of 1.95 indicates an inadequate signal and we should not use this model to navigate the design space.

Final Model, for Surface Roughness Given Below

R1 = - 0.057813 + 0.021278*cutting speed + 1.83226*feed rate The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

Residual plots for Conventional heat treated Tool Steel D3

All the figures given in following page shows the residual plots for surface roughness (Ra)

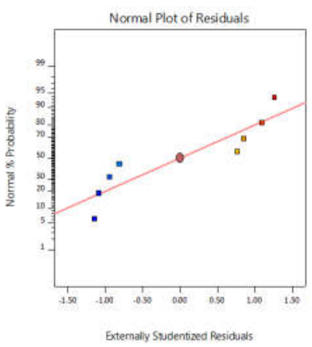


Fig. a

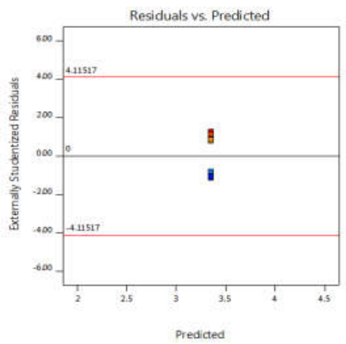


Fig. b

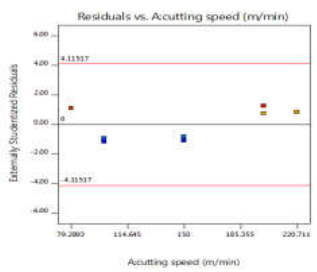


Fig. c

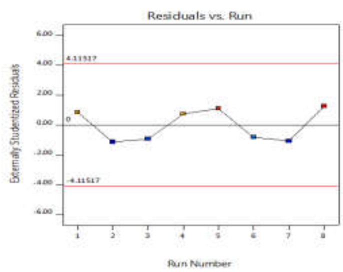


Fig. d

Three Dimensional Plots

Three dimensional plot for average surface roughness, feed rate and cutting speed ofworkpiece (Ra) is shown below

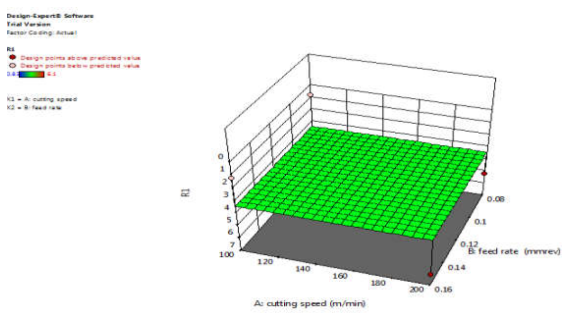


Fig 3D Plots

The above figure shows the three dimensional plot of cutting speed, feed rate and average surface roughness.

In three dimensional plots, cutting speed and feed rate are variable while depth of cut is kept constant throughout this research. Effect of feed rate and cutting speed at surface roughness of material are shown graphically by using of three dimensional plots. Some things are observed from above figure that surface roughness decrease with increase in cutting speed when depth of cut is kept constant. And surface roughness increase with increase and decrease in feed rate from specific range of feed rate when depth of cut is kept constant therefore feed rate are used in specific rang for better results of roughness for tool steel D3 during machining.

Optimum Values

Optimum Value of all Factors are Given Following

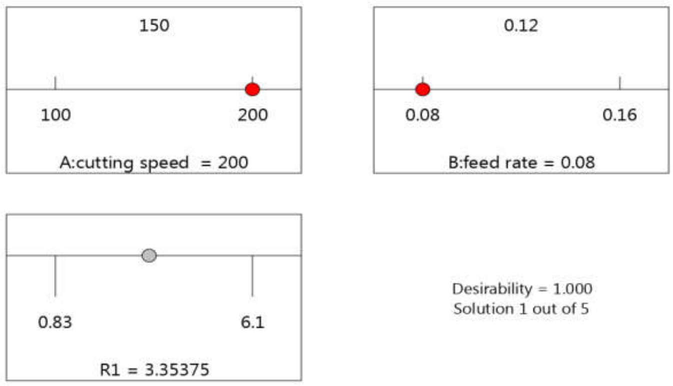


Fig. Optimum Values

Figure given above shows the optimum values of cutting speed, feed rate andsurface roughness at given conditions of all factors.

Optimum values of all factors are given in table below

Cutting speed(m/min)	Feed rate (mm/rev)	Surface roughness(Ra) (um)	Desira bility
200	0.08	3.353	1

Comparison among roughness taken in different condition Roughness of tool steel D3 after machining at CNC machine (turning operation is used) at different condition are measured, and also measured before and after the conventional heat treatment process. And then in each case, optimum values of roughness are obtained by using the design expert software, these optimum values of roughness are compared by using of these optimum values. Optimum values taken are given below

Comparison of Roughness

S.No	Conditions	Optimumcut ting speed (m/min)	Optimum feedrate (mm/rev)	Optimum roughness (um)
1	No heat treatment	148.757	0.136522	1.42514
2	Cryogenic and Conventionalheattr eatment	200	0.08	3.35375

During the study of roughness it was observed that roughness decrease with increase in cutting speed, and roughness increase with increase in feed rate, when depth of cut was kept constant. From above table, quality of roughness case of above table is better than other case, whereas feed rate is more. Therefore we can say that quality of roughness in machining of Heat treated treated material is the better.

Comparison among chip Morphology Obtained Atseveral Conditions

Material used Chip information	Material without heat treated	Conventional heat treated material
Type of chips	Semi segment chip	Segment chip
Color of chips	Black	Dark blue
Height of tooth in chips	Less	More than previous
Temperature of chips during the machining	Less	Highest

Compare between the tools wears at different conditions

Comparison of tool wears given at different conditions in table is given below.

Cutting speed (m/min)	Material without heat treated	Material after CHTprocess
100	Little abrasive wear	abrasive wear and heating of cutting tool
150	Less abrasive wear	High abrasive wear, little creature wear and less amount of heat was generate.
200	High abrasive wear and some amount of heat was generate	Cracking of cutting edge, and large amount of heat was generate.

CONCLUSION

In above study, effect of different parameters like depth of cut, feed rate, cutting speed on chip morphology, wear of tool and surface roughness are analyzed before and after conventional heat treatment. Some results which are seen throughout the machining are-

1. Cutting seed and feed rate, both of them are highly effective parameter during this process of orthogonal machining of Tool Steel 3D.
2. At constant depth of cut, feed rate is more effective than cutting speed.
3. As cutting speed increases, average surface roughness increases & vice versa.
4. Chip morphology suggests that segmented dark blue chips are obtained for CHT when compared to semi segmented black chip for no heat treated material.
5. Tool wear shows abrasive wear and cracking of tool.

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