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Effect of Cryogenic Treatment of Cutting Tool on Surface Roughness in Machining of Stainless Steel (304 H)

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ABSTRACT

The increasing importance of machining operations is gaining new dimensions in the present industrial age, all the efforts to be directed towards the economical and quantitatively acceptable manufacture of machined parts. Surface finish is one of the most crucial quality measures in manufacturing products. Customers now have increasingly high demands on quality, making surface roughness one of the most competitive dimensions in today's manufacturing industry. Stainless Steel (304H) is extensively used material for engineering components. Tungsten carbide tool is common tool used for machining operation of Stainless Steel (304H). Present work is a study of the surface roughness of work specimen during turning operation. The machining is performed with deep & shallow cryogenically treated and untreated tool bits used in turning process. In present work full factorial experimentation approach is applied to study the impact of machining parameters on the surface roughness of turned workpieces using cryogenically treated and untreated tool. The study presents a comparison between the machining performances of deep, shallow cryogenically treated and untreated tool bits with a methodology to achieve optimum selection of machining parameters and bit nose radius for CNC turning operations and describe the interrelationships between machining parameters and surface roughness during operation. The results indicate the treatment done cryogenically on the material improves the hardness of the material. In this work, a comparison has been done for the machining performance of deep & shallow cryogenically treated, and untreated tool bits.

Keywords : Cryogenic, stainless steel, CNC Turning Operation

I. INTRODUCTION

Machining of metal is the process by which the components are brought into the desirable shape & size by removing the extra material from the parent metal in the form of chips. There are various machining processes like turning, milling, drilling, shaping, planning and broaching etc. Turning is most common among above processes. The increasing importance of turning operation is gaining new dimensions in the present industrial age because of the development of CNC machines for manufacturing industries.

To optimize the output of material from CNC machines a detailed study regarding the various process variables is required. The machining process variables are categorized into three categories they are tool variables, work-piece variables, and set-up variables. The variables include tool material, nose radius, tool wear, tool geometry, tool vibration, machine tool rigidity and tool overhang etc. Workpiece variables cover work material, material hardness, length & diameter of the work–piece. Set-up variables include cutting speed, feed & depth of cut. All the above variables interact and are generally dependent. That is why it is necessary to obtain optimal value of different process variables so as to fulfill the efficient & economical machining.

As the technology has been rapidly advancing, newer cutting tool materials such as cemented carbides, cermets, and ceramics, are needed to machine many difficult to machine at higher cutting speed and higher MRR with performance reliability. The commonly used cutting tool material in machine tools for machining of steels is tungsten carbide.

Cryogenics

In last few years, concern about low-temperature effects on tool & die materials have increased, and in particular on tools like HSS. Machining with hardened tools improves the surface finish of machined parts. Cryogenic treatment has been said to improve the wear resistance of steels and has been implemented in cutting tools. Although it has been confirmed that cryogenic treatment improves wear resistance and tool life, the process has not been standardized with inconsistent results (Babu, 2005). Cryogenics is the study and use of materials at very low temperature. The cryogenic treatment may double the service life of tools (Encarta, 2005).

II. METHODS AND MATERIAL

2.1 Literature Review

There are several studies conducted by many researchers and engineers regarding the optimization of machining parameters and to enhance surface roughness in machining.

2.2 HSS Carbide

Sreerama et al. (2009) found the machinability of C45 steel with deep cryogenically treated tungsten carbide cutting tool inserts. They concluded that the flank wear of the cryogenically treated inserts is less when compared to untreated inserts. It is observed that the main cutting force for the cryogenically treated inserts is less when compared to untreated inserts. The surface finish of the workpiece is better when the work piece was machined with cryogenically treated inserts in comparison with untreated inserts at all the cutting speeds.

Amini et al. (2010) found the influence of different cryo-treatments on tribological behavior of 80CrMo12.5cold work tool steel. They found that the cryogenic treatments decrease retained austenite, which is more effective in the case of the deep cryogenic treatment (DCT). They observed that the cryogenic treatments increase the wear resistance and hardness of the tool material. Senthil and Rajendran (2011) studied the influence of shallow and deep cryogenic treatment on tribological behavior and wear resistance of En-19 Steel. A comparative 10 (SCT, -80 *0C*) and conventional heat treatment (CHT) was performed through dry sliding wear testing. They found that deep cryogenic treatment and shallow cryogenic treatment promote the transformation of retained Austenite to Martensite, thereby causing a significant increase in wear resistance. Wear resistance has been increased by 118.38% for SCT samples and 214.94% for DCT samples as compared to CHT samples. In addition, the increase in wear resistance of DCT samples is 44.39% with respect to SCT samples. They observed that the magnitude of wear increases linearly with respect to load at constant sliding velocity. The wear increases linearly with respect to sliding velocity at constant applied load. They measured the coefficient of friction during machining and the lowest value of the coefficient of friction is observed in DCT samples.

Yong et al. (2006) studied the effects of cryogenic treatment on tungsten carbide. They found that the cryogenic treatment increases the tool life of tungsten carbide tools.

Bensely et al. (2008) observed the effect of cryogenic treatment of cutting tool on the distribution of residual stress in the case carburized steel (En-353). Two types of cryogenic treatment: shallow cryogenic treatment (-80 ^{o}C) and deep cryogenic treatment (-196 ^{o}C) were adopted, as a supplement to conventional heat treatment. The amount of retained Austenite in conventionally heat-treated, shallow cryogenically treated and deep cryogenically treated samples was found to be 28%, 22% and 14% respectively. They found that there was an increase in the compressive residual stress in En-353 that was subjected to cryogenic treatment prior to tempering.

Zhirafar et al. (2007) investigated the effects of cryogenic treatment on the mechanical properties and microstructures of AISI 4340 steel. Mechanical tests including rotating fatigue, impact and hardness were carried out for various heat treating conditions and the results were compared. Fracture features of specimens were also compared. It was observed that in general, hardness and fatigue strength of the cryogenically treated specimens were a little higher whereas the toughness of the cryogenically treated specimens was lower when compared to that of the conventionally treated steel.

Coated/Uncoated Carbide

Nikhil et al. (2010) investigated the wear behavior of uncoated carbide inserts under dry, wet and cryogenic cooling conditions in turning C-60 steel, They concluded that in machining steels, by carbide inserts, application of conventional method and type of cutting fluid like soluble oil does not help in reducing wear or improving tool life. But proper application of cryogen like liquid nitrogen in the form of jets provides substantial improvement. Such benefit of cryogenic cooling may be attributed mainly to reduction of abrasive and chemical wear at the tool flanks and also possible control of chip-tool interaction and thereby built-up edge formation which not only adds flaking wear but also accelerates chipping of the cutting edges by induced vibration.

Gill and Singh (2009) performed a study on wear behavior of cryogenically treated TiAlN coated tungsten carbide inserts in turning. They found that the shallow cryogenic treatment can significantly enhance the cutting life of TiAlN coated tungsten carbide turning inserts. The recorded maximum tool life enhancement over untreated inserts in the study was 25.53% for shallow cryogenically treated inserts. It was observed that the deep cryogenic treatment has destructive effect on the performance of TiAlN coated tungsten carbide inserts especially at lower cutting speeds, however, at higher cutting speeds, marginal gain in tool life was observed. Deep cryogenic treatment weakens coating–substrate interfacial adhesion bonding. It was found that the deep cryogenic treatment is not recommended for TiAlN coated tungsten carbide inserts as the benefit gained is not significant.

Other Material

Aggarwal et al. (2008) performed a study to optimize the power consumption for CNC turned parts. They used response surface methodology (RSM) with Taguchi technique for the study. They concluded that cryogenic environment is the most significant factor followed by cutting speed and depth of cut. Vadivel et al. (2002) compared the cryogenically treated and untreated inserts for finding the effect of machining parameters on the surface roughness, power consumption, and 12 flank wear. They found that there is an improvement in the surface finish off work specimen, reduction in power consumption and flank wear with cryogenically treated inserts in turning. They had shown the effect of cryogenic treatment on microstructure by performing the SEM analysis and micro structural analysis.

Sidhu et al. (2010) investigated life enhancement of single point cutting tool by cryogenic treatment and hard facing and observed minimum change in nose radius of single point tool when compared with hard faced HSS tool and with untreated HSS tool bit. They carried out the micro structural analysis and micro hardness analysis on these tools and observed the improvement in the wear resistance of the cryogenically treated tool.

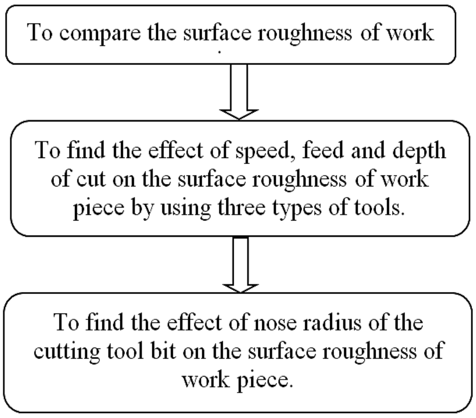
Yakup et al. (2008) studied cryogenic cooling in machining processes. In this work, the effect of liquid nitrogen, as a cryogenic coolant, was investigated in terms of application methods in material removal operations and its effects on cutting tool and work piece material properties, cutting temperature, tool wear/life, surface roughness and dimensional deviation, friction and cutting forces.

2.3 Research Gap

From the literature, it is found that a not a very substantive work has been performed on the comparison of deep cryogenically treated, shallow cryogenically treated as well as untreated Tungsten-Carbide cutting tool bits. Further, it is observed that a very less study has been performed on the effect of surface roughness of the work-piece for the nose radius of the tool in particular. Also the effect of machining parameters on the above said variables for turning of stainless steel (Grade 304H SS), using cryogenically treated tungsten carbide tool on CNC machine has been done only to a small extent.

2.4 Problem Identification and Research Objective

The main objectives of this research are to compare the effect of deep cryogenically treated, shallow cryogenically treated and untreated Tungsten-Carbide cutting tool bit on the surface roughness of the Stainless steel (Grade 304H SS) in turning operation. The experiments are performed using full factorial design as per Design of experiments, with three parameters (speed, feed, and depth-of-cut) at two levels (low and high level) each. In the present work, set-up variables (speed, feed and depth-of-cut) and the tool nose radius of 0.4 mm and 0.8 mm are considered. Other set up and workpiece variables are kept constant. The main objectives of the present study are:



III. DESIGN OF EXPERIMENT

Design of experiment is a formal structured technique for studying any situation which involves a response that varies as a function of one or more independent variables. Design of experiment is specifically designed to address complex problems where more than one variable may affect a response and the two or more variables may interact with each other. It is used wherever experimental data are collected and analyzed. It can provide answers to specific questions about the behavior of a system, using the optimum number of experimental observations. It also gives the answers that one seeks with minimum expenditure of time and resources. The design of experiment is a procedure of selecting the number of trials and conditional running them, essential and sufficient for solving a problem that has been set up with the required precision. Following are some of the advantages of designs of experiments (Montgomery, 2009)

- Numbers of trials are significantly reduced.
- Identification of important decision variables, which control and improve the performance of the product or process.
- Determination of experimental error can be made.
- Optimal setting of the parameters can be found out.
- Inference regarding the effect of parameters on the characteristics of the process can be made.

Experimental design is a strategy to gather empirical knowledge i.e., knowledge based on the analysis of experimental data. Building a design means, carefully choosing a small number of experiments that are to be performed under controlled conditions. There are four interrelated steps in building a design:

i. Design an objective i.e. effect of process variables or find optimal parameters.
ii. Define the process variables that will be controlled during experimentation and their working range.
iii. Define the variables that will be measured to describe the outcomes of the trials.
iv. Among the available standard designs, choose the one that is compatible with the objective, number of design variables and precision of measurements and has a reasonable cost.

Experimental Design Techniques

To investigate the effect of machining parameters, mathematical models are required. To collect the data required for the development of the models, experiments have to be conducted. For conducting the experiments, processing the data in cost effective and efficient manner, the design of an experiment, on scientific basis rather than on commonly employed trial and error method, is essential. Apart from trial and error method of investigation, the various techniques generally employed by the researchers with varying degree of success are:

- Theoretical approach.
- Qualitative approach.
- Dimensional analysis.
- General quantitative approach (statistical approach).
- Factorial design.
- Fractional factorial design.
- Response surface methodology.
- Taguchi method.

IV. EXPERIMENTATION

4.1 Introduction

In the previous chapter, a study on experimental design and construction of design matrix is described with the help of process variables. In this chapter, the selection of tool & work piece materials is described. The observations on surface roughness ,according to the design matrix are listed.

4.2 Experimental Setup

For this work, the experiments are performed on CNC lathe at Institute for Auto Parts & Hand Tool Technology, Ludhiana. Experimentation was done on CNC lathe as per the design matrix.

4.2.1 Selection of Tool

Tungsten-Carbide (WC) cutting tool inserts are available in different geometries and material grades. The tool inserts are purchased in the form of bit having nose radius 0.4 mm and 0.8 mm. A total of 03 number of tool bit for each nose radius of 0.4 mm and 0.8 mm are purchased. The chemical composition of inserts, as provided by the manufacturer, is as follows:
Homogeneous Co-bonded WC 92% Co 7% Others 1% (e.g. Ta, C, etc)

4.2.2 Cryogenic Treatment of Tungsten Carbide Inserts

The cryogenic treatment of the tool inserts has been carried out at the Institute of Auto Parts Ludhiana. One tool bit for each nose radius is subjected to shallow and deep 22 cryogenic treatments respectively. One tool bit for each nose radius is kept as untreated. The details of the cryogenic treatment are as follows:

Shallow Cryogenic Treatment

- Gradual lowering of temperature from room temperature to -85°C for 12 hours.
- Holding the temperature at -85°C for 7 hours.
- Gradual rising of temperature back to room temperature for 12 hours.

Deep Cryogenic Treatment

- Gradual lowering of temperature from room temperature to -185°C for 12 hours.
- Holding the temperature at -185°C for 24 hours.
- Gradual rising of temperature back to room temperature for 12 hours.

4.2.3 Selection of work material and preparation

As elaborated in problem formulation the work material for performing the turning operation is SS 304HH.

Table 4.1 : Chemical composition of the material

Work Materials	% age of composition							
Elements	C	Cr	CO	Si	Mo	W	Mn	Ni
	0.42	19	0.13	0.54	0.49	0.17	1.48	7.28

Observation Tables

Variation in the surface roughness of the work samples against different combination parameters viz. cutting speed, feed given to tool and depth of cut provided for machining, are measured after conducting the machining experiment. The center line average value of surface roughness i.e. Ra is obtained. The response variable (surface roughness) recorded against each set of parameters are shown in Tables 4.2-4.3 for nose radius of 0.4 mm and 0.8 mm respectively.

Table 4.2 : Observations for surface roughness (μm) for nose radius 0.4 mm

S.No	Speed	feed	DOC	UT	SCT	DCT
1	147	0.22	1	1.583	1.401	1.340
2	148	0.22	0.53	1.555	1.399	1.300
3	149	0.11	1	1.483	1.380	1.296
4	149	0.11	0.50	1.466	1.365	1.281
5	52	0.22	1	2.083	1.786	1.663
6	52	0.22	0.51	2.000	1.765	1.635
7	53	0.12	1	1.790	1.630	1.555
8	53	0.12	0.52	1.654	1.580	1.487

Table 4.3 : Observations for surface roughness (μm) for nose radius 0.8 mm

S.No	Speed	feed	DOC	UT	SCT	DCT
1	149	0.22	1	1.560	1.402	1.333
2	149	0.22	0.53	1.545	1.390	1.299
3	149	0.11	1	1.481	1.378	1.282
4	149	0.11	0.50	1.460	1.343	1.263
5	53	0.22	1	2.083	1.780	1.662
6	53	0.22	0.51	1.985	1.700	1.634
7	53	0.12	1	1.802	1.680	1.583
8	53	0.12	0.52	1.782	1.582	1.466

V. RESULTS AND DISCUSSION

A In this paper, mathematical model were developed using Design Expert® software for the data recorded on surface roughness for machining with cryogenically treated tool bits. Later, the effect of individual machine and tooling parameter and the effect of interaction between different machining parameters on the surface roughness are demonstrated and discussed.

5.1 Measurement of Surface Roughness

Experiments have been conducted for different combinations of parameters as per design matrix. Six set of specimen viz. two sets for untreated tool bit, two sets for shallow cryogenically treated and two sets for deep cryogenically treated tool bits corresponding to 0.4 mm and 0.8 mm nose radius respectively are machined. Surface roughness is measured by Surfcorder SE-1200. The observed values for surface roughness are tabulated in Tables 4.2-4.3 for nose radius of 0.4 mm and 0.8 mm respectively. The recorded values have been considered herewith for the development of mathematical model using Design Expert® software.

5.1.1 Surface roughness with UT tool bits for nose radius 0.4 mm. The surface roughness values are recorded for cylindrical work pieces of SS304H machined with the help of untreated Tungsten-Carbide tool bits having nose radius of 0.4 mm. ANOVA table is constructed based on the recorded observations tabulated in Table 4.2 and a mathematical model is developed for the surface roughness.

Table 5.1 ANOVA for surface roughness with UT tool bit for nose radius 0.4 mm

Source	Sum of square	DOF	Mean square	F-value	P-valve Prob>F	
Model	0.36	5	0.075	564.98	0.0017	Significant
A-speed	0.25	1	0.26	2008.01	0.0004	
B-feed	0.077	1	0.078	585.7	0.0015	
C-doc	6.96E-03	1	6.96E-03	52	0.0188	
AB	0.022	1	0.020	165.01	0.009	
AC	2.66E-03	1	2.66E-03	19.8	0.0493	
Residual	2.7lE-04	2	1.35E-04			
Cor total	0.37	7				

Table 5.1 shows the ANOVA for the surface roughness with untreated tool bits of 0.4 mm nose radius. It is observed that the cutting speed have a statistically significant effect on the surface roughness. Further, the interaction between cutting speed and feed is the significant factor which affects the surface roughness. Other parameters and the other interaction effects do not have much statistically significant effect on the surface roughness for the current levels of the process parameters.

Final Equation in Terms of Coded Factors:
Surface roughness = 1.70 – 0.18(A) + 0.09(B) + 0.029(C)-0.053(AxB)-0.018(AxC) …..(1)
Final Equation in Terms of Actual Factors:
Surface roughness =1.25701+ 5.98958E-004(speed) +3.50825(feed)+0.27160(doc)-.018316(speed*feed)-1.52083E – 003(speed*doc).. (2)

5.1.2 Surface roughness With SCT Tool Bits for Nose Radius 0.4 mm

The surface roughness values are recorded for cylindrical work pieces of SS304H machined with the help of shallow cryogenically treated Tungsten-Carbide tool bits having nose radius of 0.4 mm. AONVA table is constructed based on the recorded observations tabulated in Table 4.2 and a mathematical model is developed for the surface roughness.

Table 5.2 ANOVA for surface roughness with SCT tool bit for nose radius 0.4 mm

Source	Sum of square	DOF	Mean square	F-value	P-valve Prob>F	
Model	0.3	6	0.030	511.89	0.0330	Significant
A-speed	0.18	1	0.18	2618.75	0.0122	
B-feed	0.05	1	0.03	300.90	0.0366	
C-doc	1.77E-03	1	1.77E-03	26.73	0.1210	
AB	8.00E-03	1	8.00E-03	120	0.0570	
AC	3.00E-04	1	3.00E-04	4.50	0.2790	
BC	1.01E-05	1	1.01E-05	0.16	0.7600	
Residual	6.61E-05	1	6.61E-05			
Cor total	0.25	7				

5.3 **Influence of Cryogenic Treatment on Surface Roughness**

The comparison of surface roughness recorded on the cylindrical work-pieces turned with deep cryogenically treated, shallow cryogenically treated and an untreated cutting tool bits is shown in Figs. 5.1-5.2 for nose radius of 0.4 mm and 0.8 mm respectively. It is observed that the cryogenically treated tool bit provide improved surface finish than that of the untreated tool bit for both types of cutting tools. It is evident that the cryogenic treatment improves the wear resistance of the material and modifies retained Austenite which improves the cutting ability of the tool and improves upon the surface roughness.

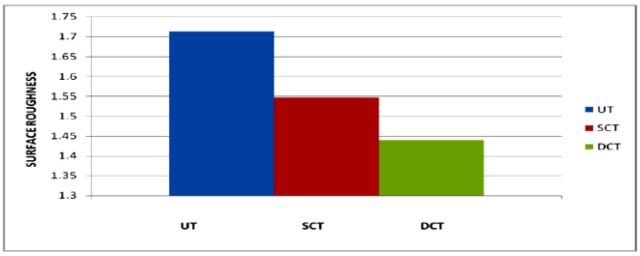


Figure 5.1 Comparison of surface roughness by UT, SCT and DCT for nose radius 0.4 mm

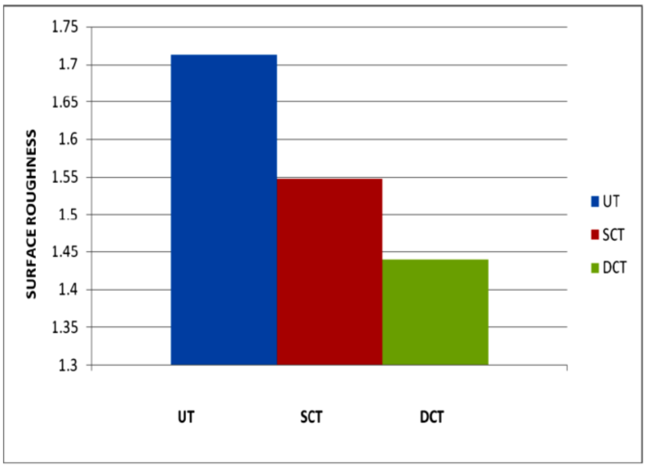


Figure 5.2 Comparison of surface roughness by UT, SCT and DCT for nose radius 0.8 mm

5.4 **Influence of Machining Parameters on Surface Roughness**

The influence of various parameters on surface roughness during turning operation has been observed. In this section, the plots showing the effect of speed, feed and depth of cut on surface roughness obtained due to turning by a single point Tungsten-Carbide cutting tool bit have been presented. Separate plots are displayed for nose radius of 0.4 mm and 0.8 mm respectively.

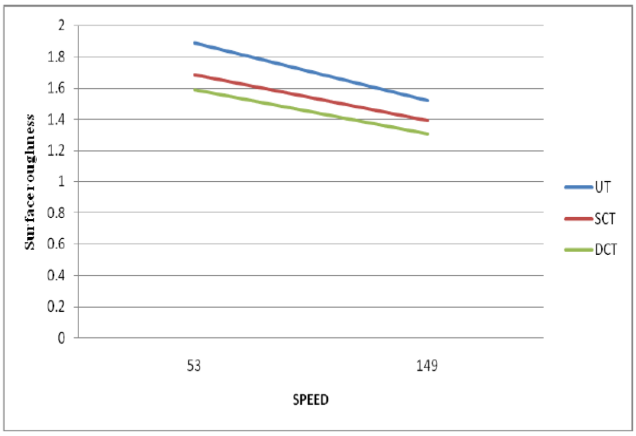
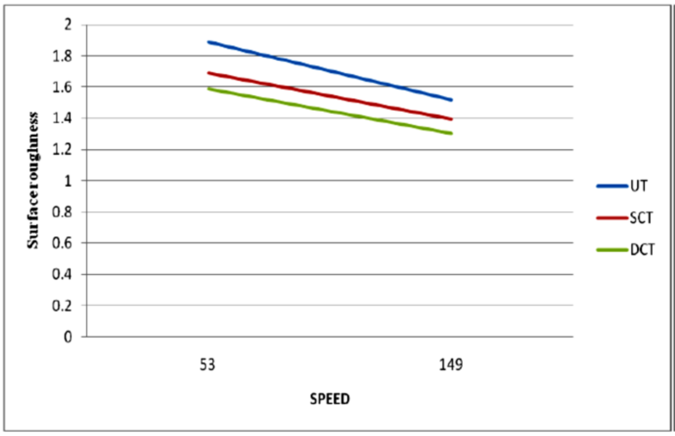


Figure 5.4 Effect of speed on surface roughness for nose radius 0.8 mm



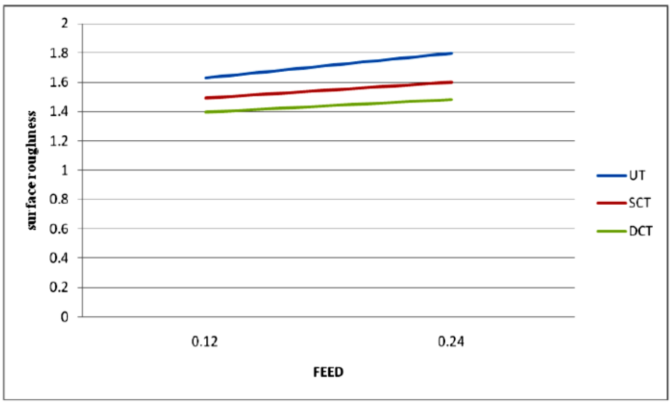


Figure 5.8 - Effect of feed on surface roughness for nose radius 0.4 mm

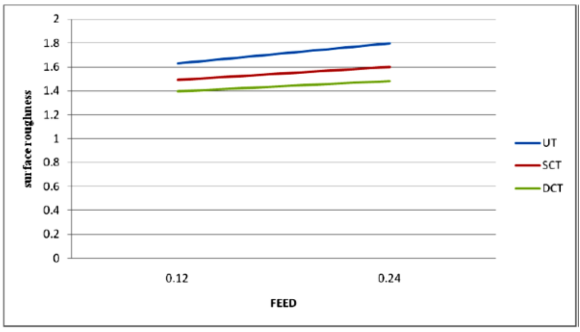


Figure 5.6 - Effect of feed on surface roughness for nose radius 0.8 mm

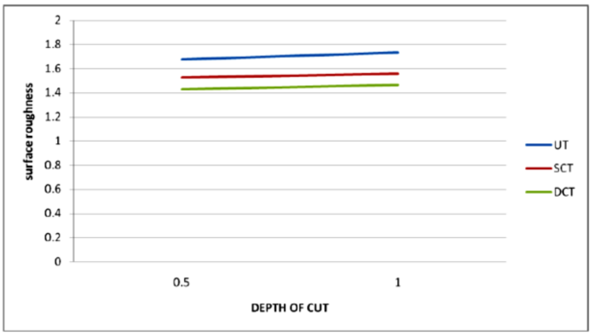


Figure 5.7 - Effect of depth of cut on surface roughness for nose radius 0.4 mm

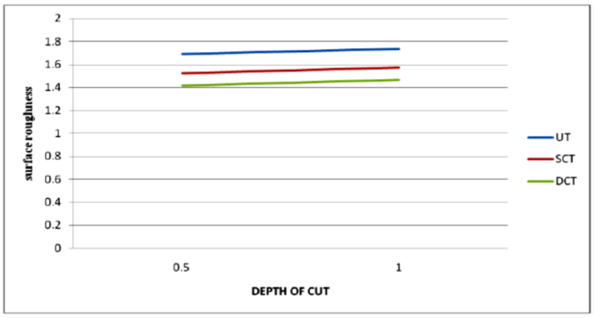


Figure 5.8 Effect of depth of cut on surface roughness for nose radius 0.8 mm

5.5. Effect of Nose Radius on Surface Roughness

To find the effect of the change in nose radius of the cutting tool, a study was performed by varying the nose radius. Based on the availability two types of tool were used having nose radius of 0.4 mm and 0.8 mm. Both types of the cutting tool were subjected to the respective cryogenic treatments as mentioned earlier. The material was machined using 47

UT, SCT and DCT tool bit with both types of nose radius. Figure 5.21 shows the effect of variation of nose radius with cryogenic treatment on the surface roughness in turning operation of SS304H material. It is observed that there is an anticipated reduction in surface roughness with the increase in nose radius of the tool bit. From the figure it is observed that the relative improvement in the surface roughness with increase in nose radius becomes better with the cryogenic treatment.

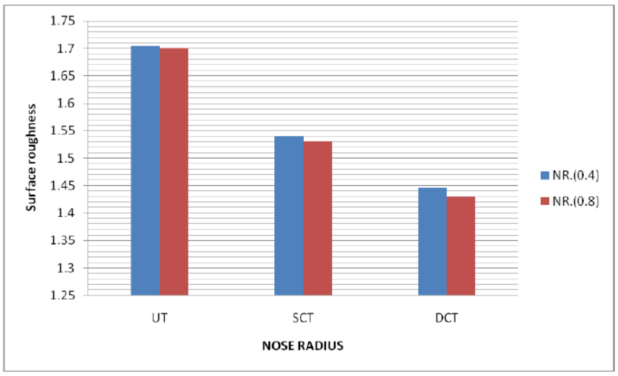


Figure 5.9 Effect of nose radius on surface roughness

VI. CONCLUSION

In this material machining the tool material hardness should always be higher for the effective cutting of the work-piece. It is found that the cryogenic treatment improves the material hardness. In this work, a study of comparison is done for the machining performance of deep & shallow cryogenically treated and untreated tool bits. The performance of machining has been in terms of the surface roughness of the machined surface. Study and analysis of experimental data, mathematical models are developed by using three machining parameters i.e. speed, feed and depth of cut as variables for calculating surface roughness for cutting tool.

Following conclusions have been drawn from this study

- The machined surface of the work piece improves when the work pieces are turned using cryogenically treated tool instead of untreated tool.
- Surface roughness of the deeply cryogenic treated bit gives better results as compare to shallow & untreated bit.
- With increasing cutting speed the surface roughness improves in all three cases of the tool.
- With decreasing feed the surface roughness decreases with all the three types of treated tool.
- With decreasing depth of cut the surface roughness decreases with all the three types of treated tool. The effect of depth of cut is not very significant on improvement in surface roughness

in comparison to cutting speed and feed during machining operation.

- There is reduction in surface roughness with the increase in nose radius of the tool bit. The bit with 0.8 mm nose radius gives less surface roughness as compare to bit with 0.4mm nose radius.
- The relative improvement in the surface roughness with increase in nose radius becomes better with the cryogenic treatment.

VII. REFERENCES

[1] Aggarwal A., Singh H., Singh M. and Kumar P. 2008 "Optimizing power consumption for CNC turned parts using response surface methodology and Taguchi technique. A comparative analysis", Journal of Material Processing Technology, Volume 200, pp 373-384.

[2] Amini K., Natesh S. and Shafyei A., 2010 "Influence of different Cryo treatments on Tribological behavior of 80CrMo12.5 cold work tool steel", Materials & Design, Volume 31(10), pp 4666–4675.

[3] Babu P.S, Rajendran P. and Rao K.N. 2005 "Cryogenic treatment of M1, EN19 and H13 tool steels to improve wear resistance", IE(I) Journal-MM, Volume. 86, pp 64-66 ,

[4] Bensely A., Venkatesh S., Lal D.M., Nagarajan G. Rajadurai A. and Junik K. 2008 "Effect of cryogenic treatment on distribution of residual stress in case carburized En 353 steel", Materials Science and Engineering, Volume 479, pp 229-235,.

[5] Degarmo P. 2003 "Materials and Process of Manufacturing", Prentice Hall of India.

[6] Dhar N.R., Islam S., Kamruzzaman Md and Paul S. 2006, "Wear behavior of uncoated carbide inserts under dry, wet and cryogenic cooling conditions in turning C-60 steel", Journal of the Brazilian society of Mechanical Sciences and Engineering, Volume 28, pp 146-152.

[7] Encarta, 2005 Microsoft Encarta Encyclopedia, ISBN No. 99994-533-075-367.

[8] Gill S. S. and Singh H, 2009. "Wear behavior of cryogenically treated tungsten carbide inserts under dry and wet turning conditions", International Journal of Machine Tools & Manufacture, Volume 9, pp 256-260,

[9] Kalpakjian 2002 "Manufacturing Engineering and Technology", Pearson Education Ltd.

[10] Mohan L.D., Renganarayanan S. and Kalanidhi A. 2001 "Cryogenic treatment to augment wear resistance of tool and die steels". International Journal on Cryogenics, Volume 41, pp 149-155,

[11] Montgomery D.C., 2009, "Design and Analysis of Experiments", John Wiley.

[12] Nalbant M. and Yildiz Y. 2011 "Effect of cryogenic cooling in milling process of AISI 304H stainless steel", Journal of Transactions of Nonferrous Metals Society of China, Volume 21, pp 72-79,.

[13] Ramji B.R., Krishna M. and Murthy H.N. 2010 "Performance study of cryo-treated HSS drills in drilling cast iron". International J. of Engineering Science and Technology, Volume 2(7), pp 2530-2536,

[14] Ramji B.R., Krishna M., and Murthy Narasimha H .N. 2010 "Analysis of Roughness and Flank Wear in Turning Gray Cast Iron Using Cryogenically Treated Cutting Tools", Journal Applied Sciences, Engineering and Technology Volume 2(5), pp 414-417.