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Characterization and Performance Evaluation of HSS Cutting Tools under deep Cryogenic Treatment

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ABSTRACT: *Cutting tool materials are high quality steels made to close compositional and physical tolerances. In service, most cutting tools are subjected to extremely high and fluctuating loads. That is, the tool materials must withstand loads for long times without breaking and without undergoing excessive wear or deformation. For a tool steel at a given hardness, wear resistance may vary widely depending on the heat treatment used and wear mechanism involved in the process. Low temperature treatment is one of the most promising methods to enhance the performance of tool materials. Thus, the influence of cryogenic treatment (CT) on the performance of high speed steel (HSS) cutting tool is studied in this paper. The study was conducted on untreated and cryogenically treated HSS tools under the machining process of turning mild steel (MS) specimens. The tests on turning process were conducted at constant depth of cut (1mm) for a combination of five different cutting speeds and three different feed rates. The cutting tool parameters such as hardness and tool life, and the surface roughness of MS test specimens were measured. Also the microstructure characterization and chemical composition of the cutting tools are studied with the help of Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS). It was found that the cryogenically treated HSS tools are superior to non treated ones in all the test conditions.*

Key words: Materials: *Steel,*
Applications: *Cutting tools, Low temperature,*
Techniques and methods: *Electron microscopy,*
Physics and mechanics of materials and contact: *Hardness*

I. INTRODUCTION

In recent years, increased interest in the effects of low temperature on tool materials, particularly HSS tools, has been demonstrated. Actually when the cutting tools are heat treated, i.e., during quenching, the total austenite is not transformed in to martensite, and the austenite retained at room temperature is unstable. This untransformed austenite makes the tool brittle and causes loss of strength and hardness. Therefore cryogenics or deep freezing is necessary to make sure that there is no retained Austenite during quenching.

Cryogenic treatment of tool steels is a new technology to increase the wear resistance and extend intervals between replacements for blades, bits, machining mills etc., and hence improves surface quality of the machined parts. Mohan Lal et al., [1] studied the improvement in wear resistance and the significance of treatment parameters in different tool and die materials. They found that cryogenic treatment imparts nearly 110% improvement in tool life. Cohen et al. [2] proved that the power consumption of cryogenically treated HSS tools is less when compared to the untreated HSS tools.

Although it has been conformed that cryogenic treatment improves the wear resistance and tool life, the process has not been standardized, with the results being inconsistent by varying from researcher to researcher [3]. Flavio J. Da Silva [4] studied the effect of cryogenic treatment on M2 high speed steel tools after using them in either laboratories or shop floor tests in an automotive industry. Singh [5] conducted experimentation on the effect of cryogenic treatment on machining characteristics of Titanium alloy (Ti-6A1-4V). In his experimentation, he predicted the best rpm range for conventional milling of Titanium alloy using HSS tool material. The mechanical properties, viz., surface roughness, surface hardness, metal removal rate and tool wear rate were observed to find out the best range of machining characteristics. Vadivel et al. [6] studied on cryogenically treated carbide cutting tools and showed micro structural changes in the material that can influence the life of the tools significantly. Cajner et al. [7] studied the effect of deep cryogenic treatment on impact and fracture toughness, erosion wear resistance and the material microstructure has been tested on test pieces made of PM S390 MC HSS.

Podgonik et al. [8] investigated the influence of deep CT parameters, viz., treatment time and temperature on the tribological performance of powder-metallurgy (P/M) HSS. Tribological tests indicate that deep cryogenic treatment contributes to improved abrasive wear resistance and better galling properties of P/M HSS. Jo J. Braz et al. [9] stated that cryogenic cooling is an efficient way of maintaining the temperature at the cutting interface well below the softening temperature of the cutting tool material. This technology is exploited mainly in the grinding industry because of the high specific energy requirements which results in high grinding zone temperature. Gill et al. [10] concluded the deep CT 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 can be obtained.

The present study focuses on the effect of CT on hardness and tool life, and microstructure characterization and chemical composition of HSS cutting tool during the turning operation on MS work piece specimens. It also studies the surface roughness changes on the test specimens.

II. EXPERIMENTATION:

In the present study the performance evaluation of untreated and treated HSS tools is done during turning of MS test specimens. The machining conditions are given in Table 1. All the tests are carried out on a heavy duty lathe fitted with variable spindle drive.

Table 1: Machining conditions

Work piece material	Mild steel specimen
Tool type	V tool (zero rake angle)
Cutting velocity	88,150,250,420 , 710rpm
feed	0.06,0.07 , 0.1mm/rev
Depth of cut	1mm
Experiment condition	Dry

2.1 CRYOGENIC TREATMENT:

The HSS tools are cryogenically treated under dry condition using liquid nitrogen. During the treatment, the tool is placed in a container and the temperature is slowly decreased to -193^{0}c. At this temperature the cutting tool is held for a period of 36 hours before the process was reversed. Then the cutting tools are slowly brought to room temperature. The cryogenic treatment curve is shown in Fig.1.

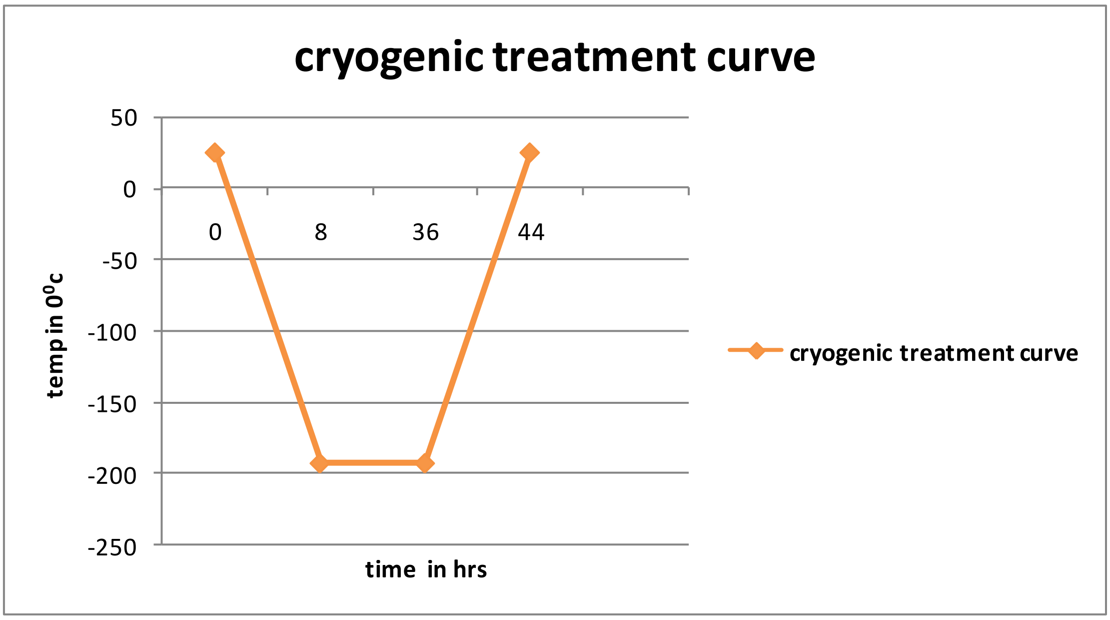


Fig. 1: Cryogenic treatment curve

2.2 MEASUREMENT OF CUTTING TOOL AND WORK PARAMETERS:

The surface morphology and microstructure of untreated and cryo treated HSS cutting tools are studied using a high resolution Scanning Electron Microscope (SEM). Also the compositions of the top surface of both the untreated and cryo treated HSS tools are examined by using Energy Dispersive Spectroscope (EDS). Then the hardness of untreated and cryo treated HSS cutting tools is measured by a Rockwell hardness tester having a diamond indenter. The tool life is also determined by measuring actual cutting time between two regrindings. After the machining operation, the surface roughness of the work-piece is measured by using a talysurf surface measuring tester.

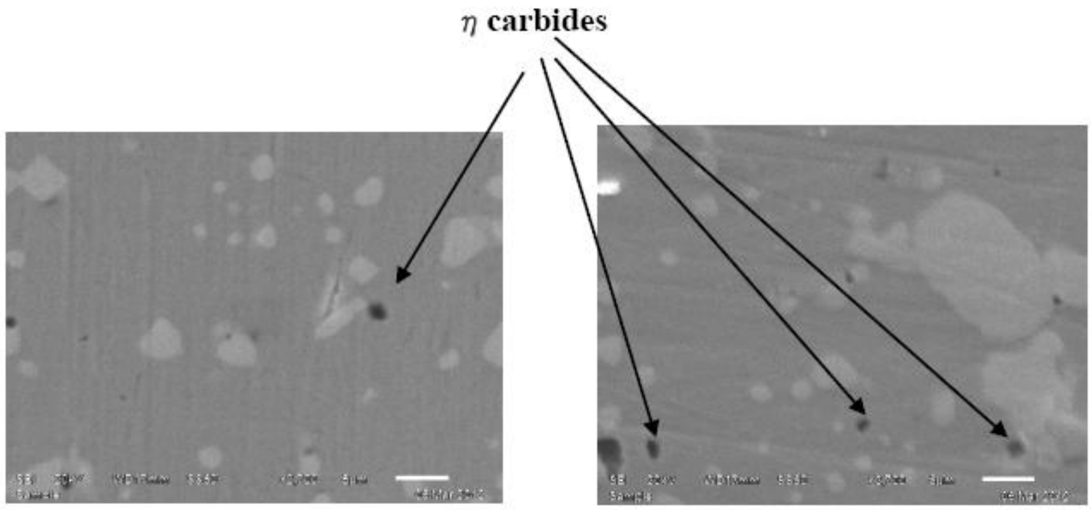
III. RESULTS AND DISCUSSION:

The effects of cryogenic treatment (including the subsequent tempering treatment) on the performance of both the HSS cutting tools & MS test specimens are studied and discussed in this section.

3.1. SEM ANALYSIS:

The SEM images of untreated and cryo treated HSS tools (Fig.2a and b) clearly reveal the presence of several black spots in the cryo treated tools. These are identified as η-carbides. The formation of η-carbides increases hardness of cutting tool and provides greater wear resistance. Literally it is accepted that the major contribution for improvement in properties is due to the transformation of retained austenite to martensite [11]. Still it is suggested that CT makes a contribution to increase in hardness due to fine η-carbide precipitation rather than transformation of retained austenite to martensite.

It is observed that the volume fraction of carbides in the CT sample was found higher, and the main reason for improving fine carbide precipitation is super saturation of martensite. Decrease in temperature during CT leads to lattice distortion and thermodynamic instability of martensite. Hence both carbon and alloying elements migrate to the nearby defects and segregate, resulting in the formation of fine carbides on tempering. The formation of high carbide contraction will increase wear resistance, reduce friction, and improves stability [12-16]. It is also observed that the cryogenic treatment refined the grain size and changed the state of energy absorption in the fracture process of metal and resulted in increased toughness of steel.



(a) (b)

Fig.2: SEM Micrographs of HSS tool (a) before CT (b) after CT

3.2. EDS ANALYSIS:

The composition of the top surface of both untreated and cryo treated HSS tools are examined using EDS through X-ray. Fig.3 and 4 depict EDS spectra of HSS tools. The chemical composition demonstrates that, some change in composition took place on the surface of the tool after cryo treatment. The peaks in figures indicate the percentage composition of elements. The corresponding compositions are shown in Table 2. It is revealed that the percentage of Molybdenum in CT tool is increased from 6.65% to 8.02%. This increase in Molybdenum percentage enhances the red hardness and stability of the tool.

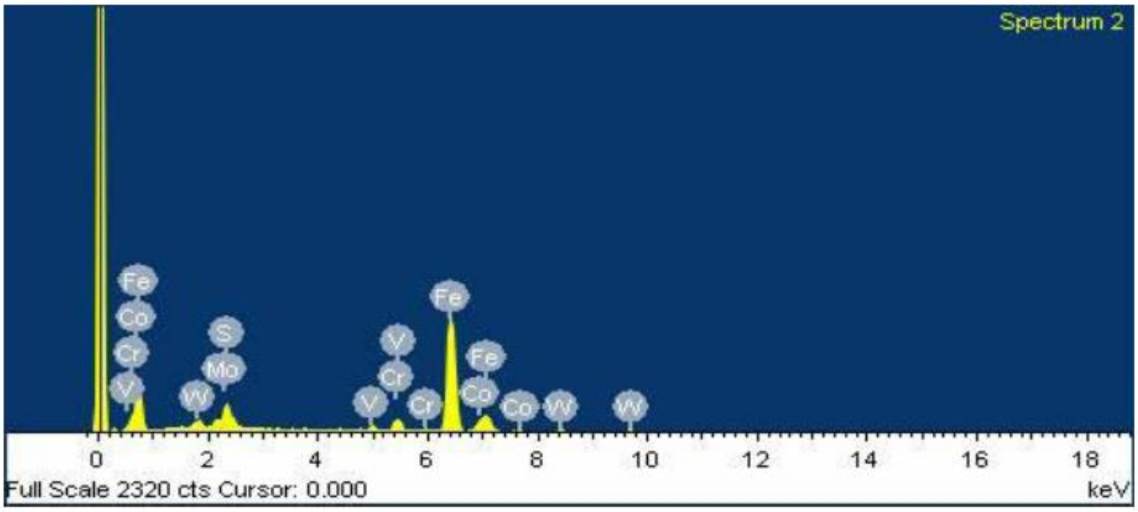


Fig. 3: Representative EDS spectra for untreated HSS tool

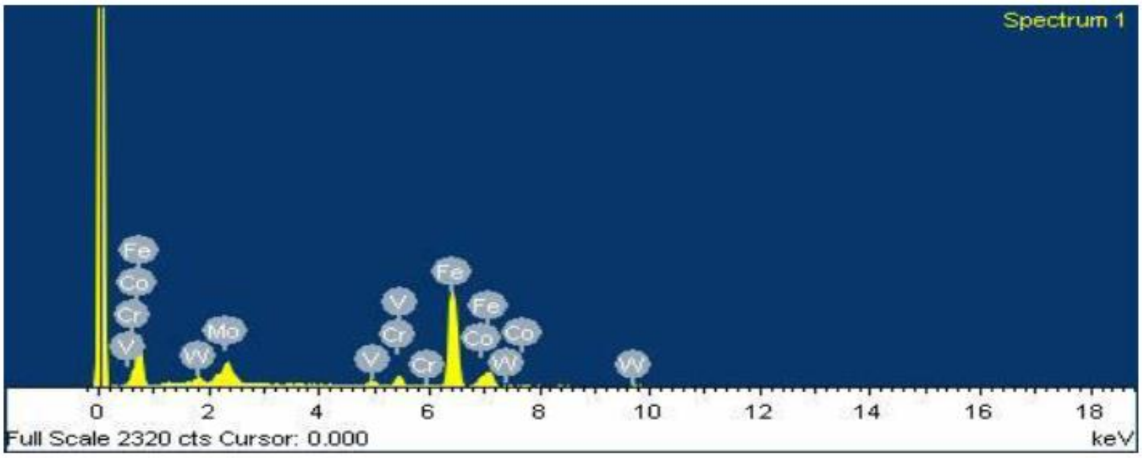


Fig. 4: Representative EDS spectra for cryo treated HSS tool

Table 2: Percentage composition of (a) untreated HSS tool (b) cryo treated HSS tool

Element	% weight of element in	
	untreated tool	cryo treated tool
S	0.81	-----
V	3.77	4.49
Cr	10.28	9.72
Fe	44.45	45.66
Co	4.88	3.59
Mo	6.65	8.02
W	2.25	1.94
O	26.90	26.58
Total	100.00	100.00

3.3 HARDNESS AND TOOL LIFE:

The results of hardness tester for untreated and cryo treated HSS tools are shown in Fig.5. It indicates that the average Rockwell hardness number of untreated tool is 66 and that of cryo treated tool is 68.

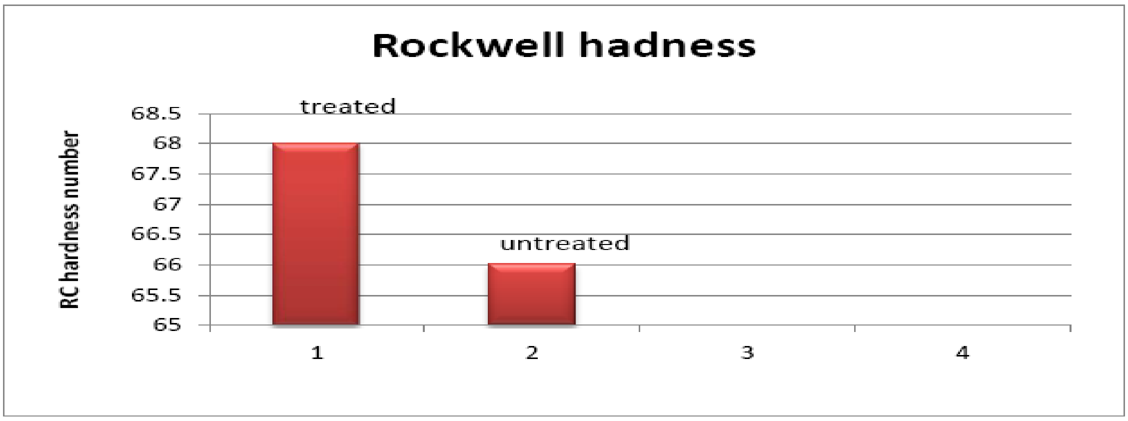


Fig. 5: Comparison of Rockwell hardness of untreated and cryo treated tools

During the performance evaluation in machining, tool life test is conducted for different values of speed, viz., 88, 150, 250, 420 and 710 rpm with feeds of 0.06, 0.07 and 0.1 mm/rev at constant depth of cut of 1mm. It is found that the tool life of untreated HSS cutting tool is 102.68 minutes and that of cryo treated tool is 105 minutes.

3.4 SURFACE ROUGHNESS OF WORK PIECE:

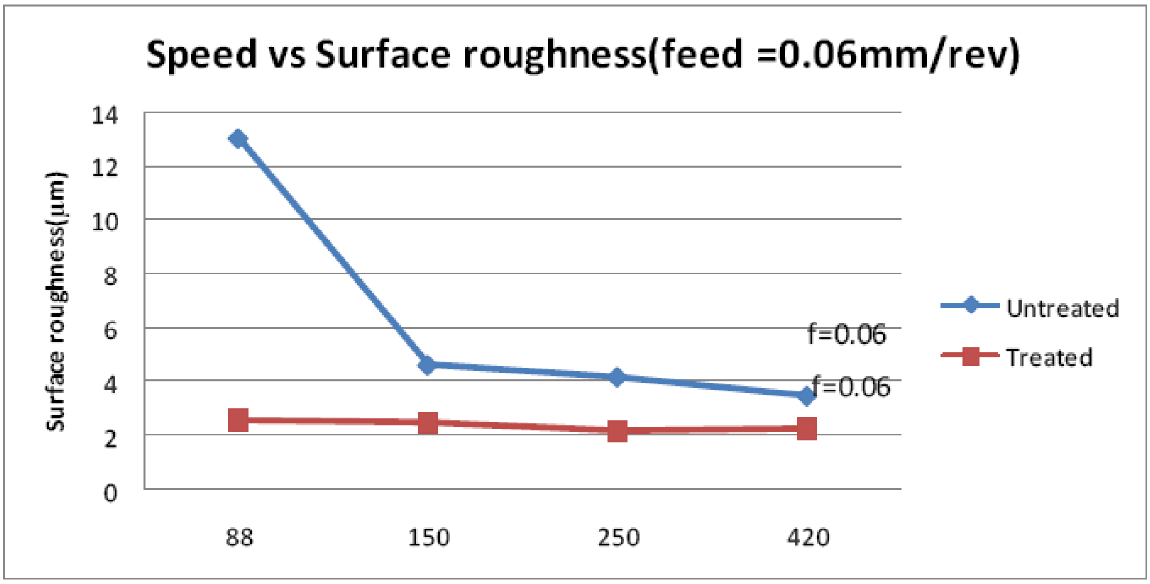
After the comparative evaluation of the characteristics of untreated and cryo treated HSS cutting tools, an attempt is made to investigate the machining performance of them in turning of MS test specimens in dry condition. The surface roughness of MS machined specimens is measured under different combinations of speeds and feeds when machining is done with constant depth of cut of 1mm. The results with respect to untreated and cryo treated HSS tools are shown in Table 3. It is observed from the average results that, surface roughness improves as the speed increases, whereas it increases as the feed increases. Thus while making a choice of cutting process parameters for surface finish, it is desirable to have high cutting speed and small feed rates.

The variation of surface roughness with cutting speeds has been comparatively shown for untreated and cryo treated HSS tools in Fig.6. It is noticed that the CT tool produces superior surface when compared to the untreated tool for the entire range of cutting speeds and feeds.

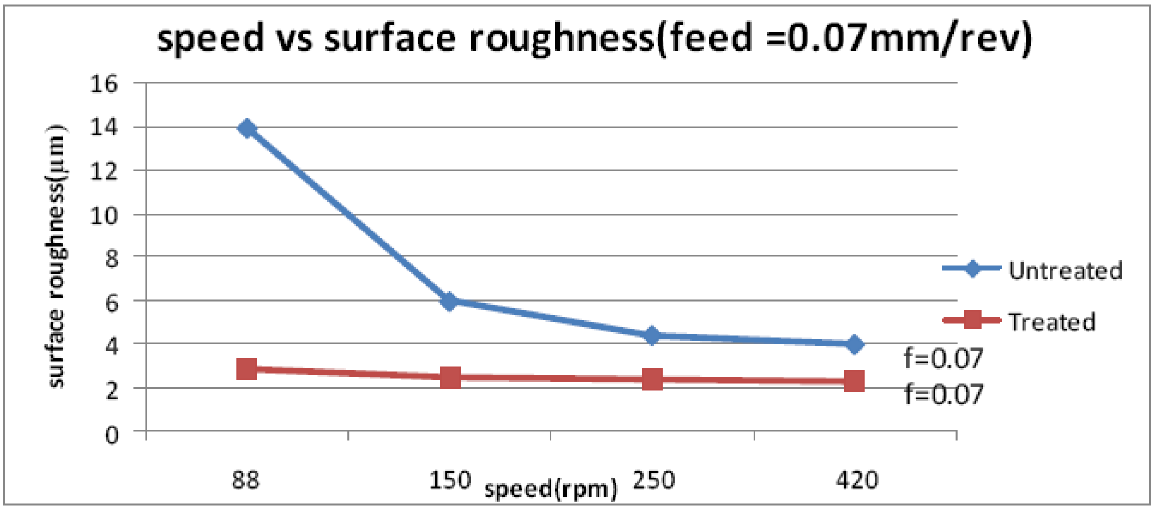
Table 3: Surface roughness of MS test specimens for untreated and cryo treated HSS tools

				UN TREATED						**TREATED**					
Specimen no No	**Speed (rpm)**	**Feed (mm/rev)**	**Depth of Cut (mm)**	**Machining time (min)**	**Surface roughness (µm)**				**Average**	**Machining Time (min)**	**Surface roughness (µm)**				**Average**
1	88	0.06	1	18.93	14.48	12.25	11.67	13.87	13.067	18.93	2.23	2.66	2.67	2.4	2.545
2	88	0.07	1	16.23	18.46	11.16	10.16	15.82	13.9	16.23	2.65	2.66	2.69	3.33	2.832
3	88	0.1	1	11.36	10.59	17.63	14.48	14.23	14.232	11.36	3.27	3.42	3.37	3.85	3.474
4	150	0.06	1	11.11	4.85	4.5	4.81	4.65	4.612	11.11	2.46	2.83	2.27	2.37	2,485
5	150	0.07	1	9.52	5.07	4.96	4.7	6.44	5.925	9.52	2.46	2.69	2.08	2.5	2.432
6	150	0.1	1	6.66	6.32	7.29	7.96	7.33	7.225	6.66	2.53	2.23	2.58	2.61	2.332

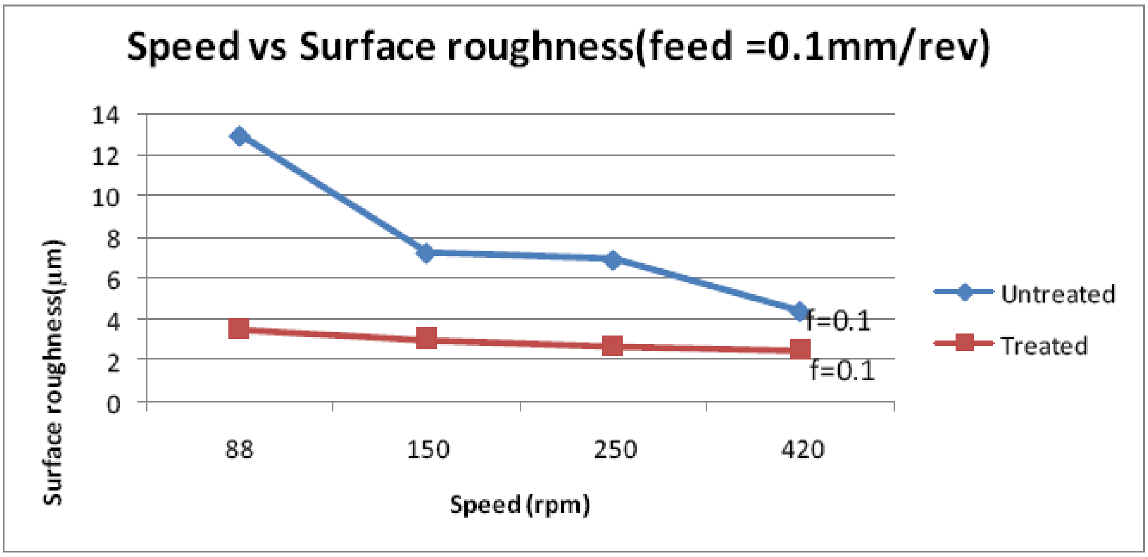
7	250	0.06	1	6.66	5.02	3.01	4.74	3.91	4.17	6.66	2.45	2.19	2.15	2.14	2.16
8	250	0.07	1	5.71	4.5	4.7	4.2	4.06	4.365	5.71	2.88	2.67	2.37	2.46	2.67
9	250	0.1	1	4	7.1	7.17	6.32	6.95	6.885	4	2.84	2.23	2.02	2.9	2.68
10	420	0.06	1	3.96	3.93	3.11	3.6	3.23	3.467	3.96	2.91	2.29	2	2.46	2.225
11	420	0.07	1	3.40	4.86	3.76	3.12	3.21	3.97	3.40	2.79	2.9	2.88	2.69	2.54
12	420	0.1	1	2.38	4.67	4.55	4.0	4.27	4.372	2.38	2.79	2.75	2.11	2.89	2.5
13	710	0.06	1	2.34	3.95	3.06	3.7	3.63	3.585	2.34	2.52	2.65	2.96	2.54	2.66
14	710	0.07	1	0.424	5.45				5.45	2.01	3.68	3.86	3.86	3.96	3.775



(a) Ra vs. speed for feed = 0.06 mm/rev



(b) Ra vs. speed for feed = 0.07 mm/rev



(c) Ra vs. speed for feed = 0.1 mm/rev
Fig.6: Surface roughness (Ra) variation of MS specimens for untreated and cryo treated HSS tools

IV. CONCLUSIONS:

This paper focused mainly on the characterization and performance evaluation of HSS cutting tool under deep cryogenic treatment. It is observed that, the cryogenic treatment of HSS cutting tool resulted in change in microstructure and formation of η phase carbides rather than in the removal of retained austenite. As a result the hardness of CT HSS cutting tool is marginally increased when compared to that of untreated HSS tool. Also the tool life of the CT tool is found to be more when compared to that of untreated tool during the turning operation of MS work pieces under the different combinations of speed and feed rates at constant depth of cut. It is also to be noted that the surface roughness of MS test specimens is more superior when machined with cryo treated HSS tool rather than untreated HSS tool (Table 3) under all the test conditions.

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