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Experimental Investigation and Comparison of Tool Wear of Cryo-Treated HSS M35 and Untreated HSS M35 Tool During Machining of C18000 By Using Optimized Cutting Parameters.

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ABSTRACT

Tool life enhancement has always been an area of research. To achieve that, along with the optimization of machining parameters, heat treatments are also done to increase the cutting tools' mechanical properties. In cryogenic processing, the materials get treated at sub-zero temperatures. The productivity, efficiency, durability, wear resistance, abrasion resistance and erosion resistance increases with cryogenic treatment. In this paper, CNC turning operation using optimized machining parameters is performed on C18000 copper alloy, using Cryo treated and untreated zero back rake HSS cutting tool, to investigate and compare the tool life. Deep cryogenic treatment is done at – 196˚C with a cooling rate of 0.5˚C per min. Optimum speed, depth of cut and feed are obtained using the Taguchi method. The surface roughness of the workpiece is measured using Taylor Hobson-PGI-120contact-type mechanical profiler. The workpiece surface degradation is considered as an indication of the tool failure. Quantification of the tool wear is done through Taylor Hobson-Coherence Correlation Interferometer (3D Optical Profilometer). This is a new technique that can be used to capture and measure the tool wears. Both the cutting tools worked on the same optimized machining parameters, and It has been observed that the performance of cryo treated cutting tool is far better than the untreated tool in terms of life and MRR. During experimentation, there are no apparent changes observed on the surface finish of the workpiece.

Keywords: Cryogenic treatment, tool tip wear, Surface topography, CNC Machining.

1. INTRODUCTION

In recent years, fewer articles have been devoted towards machining of material C18000, an alloy of copper, chromium, nickel and silicon alloy, also known as Beryllium Free Copper alloy. The applications of C18000 are found in the machining scenario where high mechanical strength is combined with moderate thermal and electrical conductivities. C18000 can also replace other copper-beryllium alloys such as C17500 and C17510 in terms of machining applications. C1800 is fabricated through the casting process and further, finishing processes such as grinding and coating are used. .

The heat treatment processes are employed to give rise to a coarse grain structure and increase various mechanical properties such as strength, hardness, ductility, along with a significant increase in thermal and electrical conductivity. In this experimentation, the tool used is high-speed steel. The hardness of high-speed steel cutting tools

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are about 60 to 65 RC, and they easily work under the temperature range of 600 to 650°C. These cutting tools are the logical choice of many cutting industries because they are available at economical prices. A different application of High-speed steel is that it can be used as a turning tool, taps, twist drills, dies, counter bores, milling cutter, hobs, saws, reamers, etc. High-speed steel possesses excellent hardness and wears resistance properties along with good toughness as it goes thought different heat-treatment process. The high-speed steel tool samples considered in this work are DOUBLE-H (M35) 5%Co steels procured from Matrix with dimension 6.35×101.60 mm. The selection of parameters of cryogenic treatment is of great importance to achieve the desired results.

T.V. Sreerama Reddy et al. (2009) studied the deep cryogenic treatment on WC cutting tool inserts during machining of C45 steel. The flank wear of untreated carbide during machining is found to be greater than the deep cryo treated carbide tool and also found that the surface finish of the deep treated tool is better in comparison. Reduction in cutting forces is observed. Cryogenic treatment resulted in better machining and increased the hot hardness of cutting tools.

Simran Preet Singh Gil (2012) investigated the machining effect on cryogenically treated AISI M2 HSS tools. The performance of deep cryogenically treated (-196° C) HSS is found to be far better than that of shallow treated one (-110° C). Cryogenic treatment increased the service life significantly. In the case of shallow cryogenic treatment, the tool life has been improved by 35%, and with the in-depth cryo-treatment, 50% tool life was increased.

Amrita Priyadarshini (2007) studied the effect of cryogenic treatment on the performance of the HSS tools and carbide insert. The life of HSS increased by 12% and the carbide insert by 17%. Uniform carbide distribution is found in cryo treated HSS as compare to untreated tools.

T. V. Sreerama Reddy et al., (2009) investigated the effect of deep cryogenic treatment on P-40 tungsten carbide cutting tool insert during turning operation. After cryo treatment, the tool life factor increased by 1.27%. Cutting forces decreased in the cryo treated insert by 11% as compared to untreated insert. Due to increased thermal conductivity and red hardness, tool wear reduction is found.

K. N. Pandeet et al. (2012) examined the influence of the cryogenic treatment on polyamide on optimized parameters for the enhancement of wear performance. The abrasive wear performance of the polymer rose because of the transformation of the crystal structure.

Fanju Meng et al. (1994) investigated the wear resistance and microstructure of the cryogenic treated Fe-I.4Cr-IC bearing steel. Wear resistance and microstructure of cryo treated, and untreated tool material is checked. It has been found that there is a significant improvement in resistance to sliding wear of bearings. It increased in the range of 110% to 600%. Comparison is also done by doing conventionally heat treatments. The wear volume in the case of conventional heat treatment is more in untreated material than that of cryo treated materials. Due to the formation of refined carbide precipitate, the wear resistance increased.

Franjo Cajner et al. (2009) scrutinized the impression of the deep-cryogenic treatment on HSS characteristics. There is an increase in wear resistance; toughness, erosion wear resistance and abrasion by the deep cryogenic treatment. The microstructure also changed due to cryogenic treatment, and there is the formation of refined grained

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particles. Refined grained particles result in improved wear resistance. The thermal conductivity and hot hardness also increased. The tool can be resharpened again and again without any noticeable change.

A. Y. L. Yong et al. (2006) considered the performance of cryogenically dosed WC tools in milling processes. The soak section grasp at the heat of -300^{o} F for a time near about 8 to 40 hour. There is a change in the crystal structure due to soaking periods. There is the formation of the refined grained carbide precipitates in the material due to soaking. More the socking time more will be the improvement of the properties of the material. During the soaking period, the energy comes out from the crystal lattice, and crystal lattice becomes a more perfect and stronger structure occurs.

B. Podgornik et al. (2009) studied the importance of the Deep cryogenic treatment on the tribological properties of P/M high-speed steel. The researcher examined the galling resistance and abrasion wear resistance under dry sliding machining. The results are evaluated in terms of the coefficient of the sliding friction and wear volume of the tool. Tribological characteristics of the P/M high-speed steel improved by the deep cryogenic procedure. The abrasive wear resistance and galling properties became better though deep cryogenic treatment. Austenite temperature played a crucial role in enhancing the mechanical properties of the HSS tool.

S. D. Bhole et al. (1990) developed a prototype for abrasive wear testing of tillage tool materials. It is found that Feed, depth of cut, tool material, heat treatment of the tool, heat treatment of the work piece material, nature of the cutting oblique/ orthogonal affect the tool life of the material. Wear resistance, thermal heat conductivity, strength, abrasion resistance, impact resistance, surface roughness and red hot hardness are the main characteristics of the cutting tools. The heat generation and cutting velocity make the maximum effect on the life of the tool. Feed rate, depth of cut and cutting velocity are a factor of heat generation. Tool geometry also plays an important role in tool life.

J. Tang. Et al. (2016) heightened the exterior integrity and corrosion resistance of Ti-6Al-4V titanium alloy by cryogenic burnishing. The cryogenic processing enhanced the corrosion resistance of the Ti-6Al-4V titanium alloy. It also improved the surface roughness and refined the grain structure. In the cryogenic burnishing, the Nanocrystalline layer is formed over the Ti-6Al-4V titanium alloy. It is concluded that more the cryogenic burnishing passes on titanium alloy more will be the surface refinement. Due to the high density of grain boundaries and dislocation formed on the titanium alloy caused a positive effect. Mott-Schottky, electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization curves are used to determine the corrosion behaviour using 0.9% NaCl solution.

Mozammel Mia (2016) studied the effect of cryogenic on the machinability of hardened steel. Cryogenic machining decreased the wear rate of the tool. Flood machining, dry machining and cryogenic machining are done in the experimentation. The heat generation on the tool tip is very small in the case of the cryogenic machining and increased tool life.

A. H. Kheireddine et al. (2014) study the experimental and numerical study of the effect of cryogenic cooling on the surface integrity of drilled holes in AZ31B Mg alloy. The experiment study examines the in-process cryo cooling on the drilled hole on the AZ31B Mg alloy. Investigation of the parameter like surface roughness, cutting force, grain size, surface hardness, layer thickness and torque, is done. FEM model was generated to simulate the cryo processing effect with the corresponding work-study.

Hadi Ghasemi Nanesa et al. (2015) examined cryogenic process parameters on the microstructure and hardness development of AISI D2 tool steel. The microstructure and hardness of the cutting tool are checked after cryo processing. The heating rate, surface density, microstructure are the parameter used for statistical analysis. There are two different phases for the processing of the material, cryogenic process and tempering process. In both processes, the phase transformation takes place. WC is produced in the tempering process at 473K and begin a reduction in the hardness by 40HV. At 773K phase, change from transition carbides to martensite and cementite.

In this paper, CCI-3D optical profilometer is used to check the tool wear of cryo treated and untreated cutting tools. Machining parameters like spindle speed, depth of cut and feed rate are optimized using the Taguchi method, orthogonal L9 array. The tool wear of treated and untreated cutting tool is checked on the optimized machining parameters. Mainly the discussion will be on the comparison of both the tools. Comparison is done on the parameters like MRR, Total volume removed, Surface finish, total length covered. Graphs are also plotted for the same parameters for investigating the machining performance of both the tools. Various levels selected for the depth of cut, feed rate and spindle speed are also discussed further along with the whole experimentation.

2. EQUIPMENT DETAILS

2.1. FORM TALYSURF PGI-120:

Taylor-Hobson Form Talysurf's surface profiler shown in Figure 1 is used to analyze the surface roughness. Surface roughness was examined with the help of the profiler’s conical diamond tip stylus. The angle of the diamond tip varies from 60 to 90 degrees, and the radius of the cutting tip ranges from 1 to 10µm. The motion of the tip of the mechanical profiler is in linear motion, which ranges from 1 to 10 mm, and the direction of motion is perpendicular to the direction of machining.

It gives the various values like Ra (Average Roughness), Rz (Maximum depth of a valley) Rq (Root mean square of Ra) Rt, (Peak to valley distance) Rp, (Maximum peak distance) and Rpc. (Number of peaks and valleys in a particular scan). But in this study, only Ra (Average Roughness)value is required to examine the surface roughness to optimize the machining parameter. During the working of the stylus, no external force and the disturbance is acting on the stylus. It moves over the work piece surface with the constant speed, and it is a two ways motion forward and backward motion. There is a transducer that reads the upright deflection of the stylus tip and transforms the mechanical signal to the electrical signal. There is an amplifier that converts the analog signal into a digital signal.

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Further, this digital sign is concocted by a computer to monitor roughness and surface waviness.

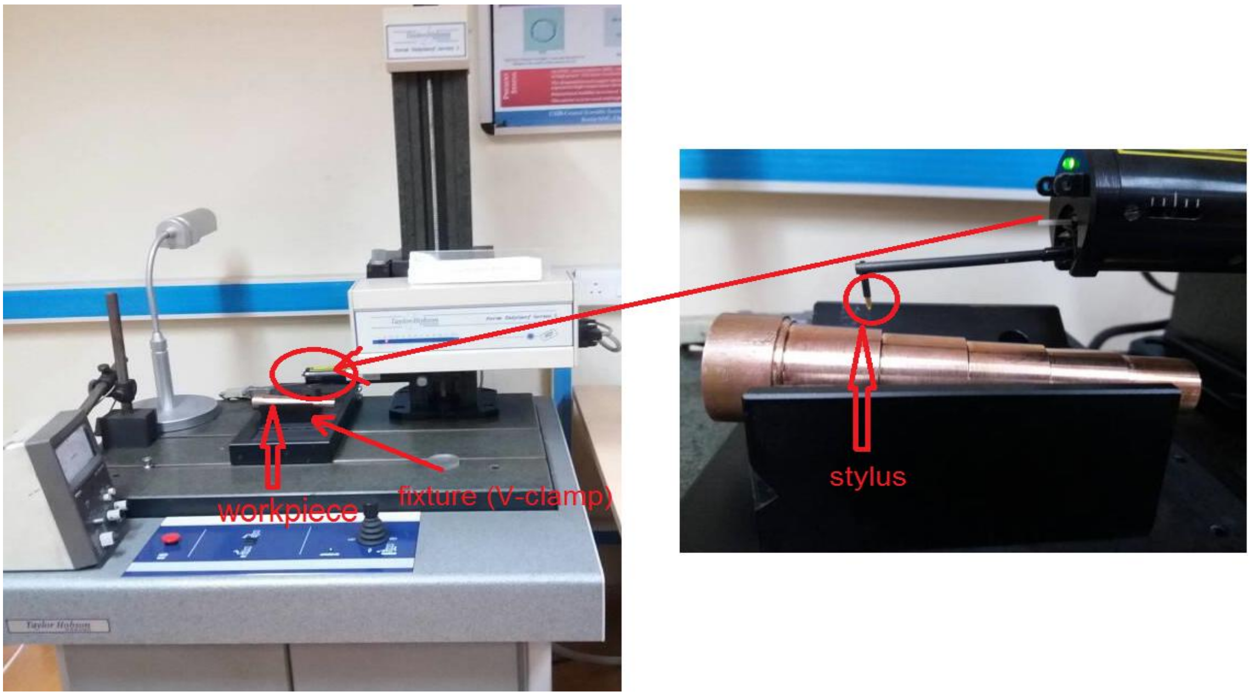

Figure 1. Form Talysurf PGI-120

The stylus glides over the surface at a steady speed, and the transducer produces an electric signal. The electrical signals are exaggerated and then pass through analog-to-digital regeneration. The rdigital profile is then collected in a computer & can be investigated afterward for syrface topographical information.

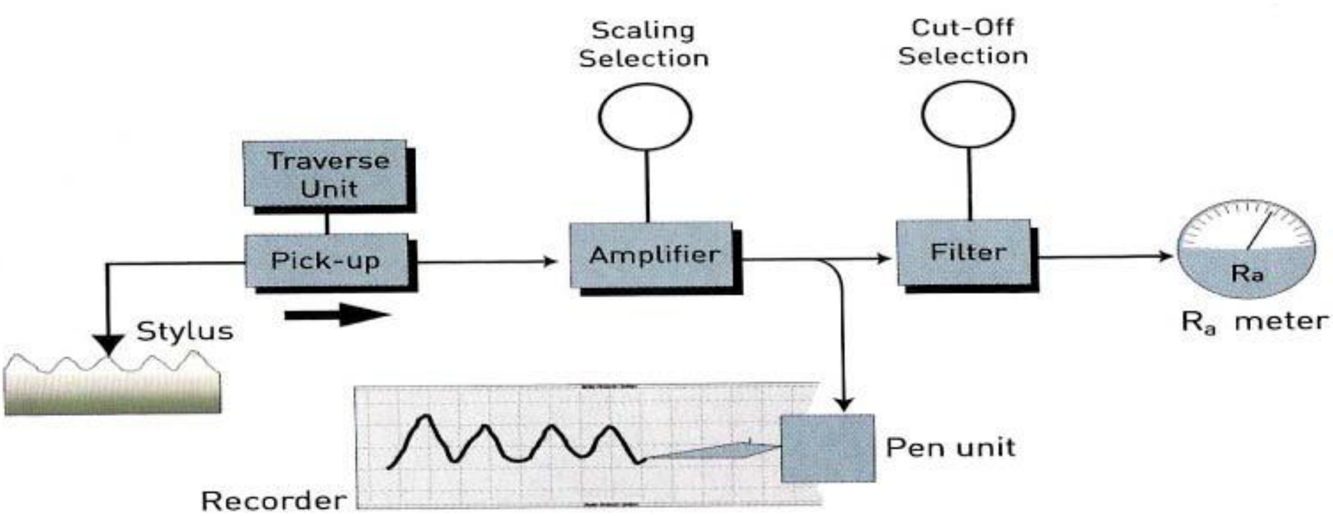

Figure 2. Schematic Diagram of Stylus Instrument

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2.2. IMAGING

The apparatus CCI (Coherence Correlation Interferometer) shown in Figure 3 is used to measure tool wear on HSS M35.

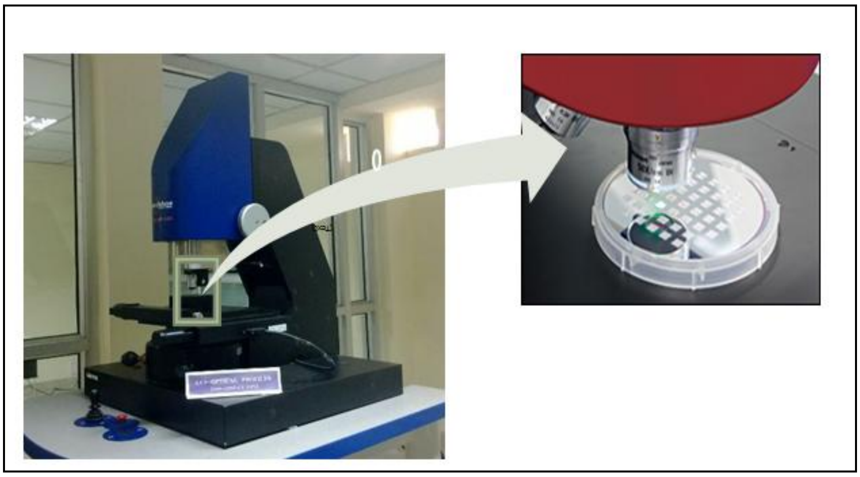

Figure 3. Taylor Hobson CCI-6000

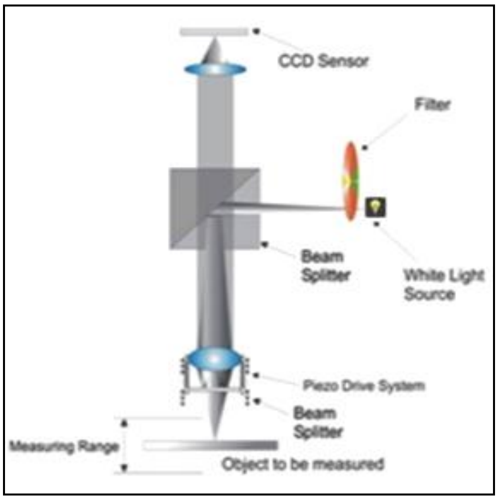

Figure 4. Schematic of CCI-6000 (Ref: Taylor Hobson CCI-6000 manual)

Table 2. Technical Specification of CCI6000 Optical profiler (**Taylor Hobson CCI-6000**)

Technical specifications of CCI 6000 optical profiler	
Measurement technique	Coherence correlation interferometery
Vertical range(Z)	100µm (400µm optional)

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Vertical resolution	0.1 nm [1.0Å] (over full 100µm range)
Measurement area (X,Y)	0.36 mm^2 – 1.8 mm^2
Optical resolution (X,Y)	0.4 – 0.6 µm (surface dependent)
Surface reflectivity	0.5% -100%
Measurement time	5-20 seconds (typical)
Measurement capabilities of CCI 6000	
Measurable Material	Glass, Metals, Polymers, Photo-Resist, Liquid Inks, Pastes
Evaluation parameters	Roughness, shape deviations, step height, critical dimensions.

3. MACHINING PARAMETERS OPTIMIZATION TECHNIQUE:

Using Taguchi design, different levels of process parameters are generated, which are to be used for performing the experimental work, which is then analyzed using the signal to noise ratio. In this study, L9 orthogonal array is used for attaining optimal results is calculated with a good confidence level. Where these process parameters get affected by two factors known as controllable and uncontrollable, also known as signal and noise, respectively. Thus, with the help of the S/N ratio, we found the parameters less affected by noise and can be easily controlled. Henceforth model developed is satisfactory to signify the relation between machining parameters and surface roughness. The levels for spindle speed are 1200, 1500 and 1800 rpm, for the depth of cut: 0.03, 0.05 and 0.07 mm and for feed rate 0.03, 0.06 and 0.09 mm/revolution, as shown in Table 3. The optimized machining parameters with an untreated cutting tool were found to be spindle speed: 1800 rpm, depth of cut: 0.03mm, and feed rate 0.03 mm/revolution.

Table 3. Machining parameter levels

Level	Spindle Speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)

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1	1200	0.03	0.03
2	1500	0.05	0.06
3	1800	0.07	0.09

MACHINING AND TOOL WEAR MEASURING DETAILS

The wear on the cutting tip of a single point cuttinghigh-speed steel M35 tool and cryo-treated HSS M35 tool is measured based on a number of machining cycles performed. A copper-alloy (C18000) having the length of 120mm and a diameter of 28.5 mm is taken. 20 mm is held in chuck and the rest of the work piece is divided into five steps of 20 mm length. The other end of the work piece is supported by the tailstock of the machine. In this study, the tool is considered to be worn out at that point when it provides an unsatisfactory surface finish in comparison to the previous surface finish.

A comparison of tool wear between standard and cryogenated HSS tool is done when both the tools started degrading the surface finish of the component. The tool wear is further studied based on the micro images produced by CCI (Coherence Correlation Interferometer) - non-contact type mechanical profiler.

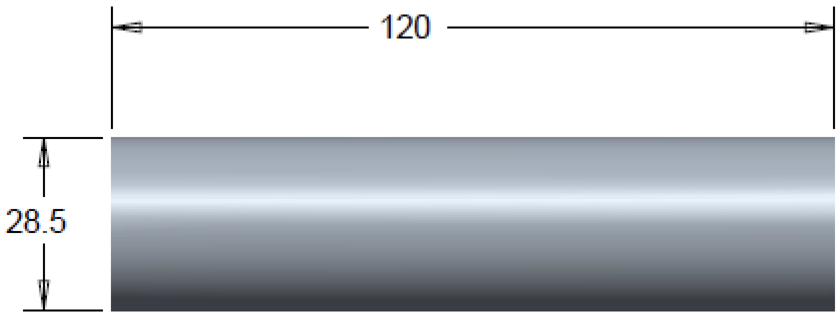

Figure 5. Raw material design, units 'mm'

Figure 6. C18000 (Copper alloy)

1.1. MRR CALCULATION

A. N= rotational speed of work piece rpm

B. F= feed, mm/rev

C. L= length of the cut, mm

D. D_o= work piece original diameter, mm

E. D_f = final diameter of workpiece, mm

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F. D_{avg} = average dia of work piece, $(Do + Df)$/2, mm

G. D= depth of cut, mm

H. T= cutting time, sec/min $\{L \div (F * N)\}$

I. MRR= material removal rate, mm^3/min $(\pi * Davg * D * F * N)$

2. EXPERIMENTATION

2.1. STANDARD HSS M35 TOOL

Machining conducted using untreated HSS tool on the copper alloy (C18000) yielded the following results:

Table 4. Machining data of untreated C18000

Sr. no	D_o (mm)	D_f (mm)	Machining cycles	R_a (µm)	T(min)	Material Removal (mm3)	Cutting Length in (km)
1	28.5	27.99	17	0.1996	6.3	905.32	1.005
2	27.2	26.69	17	0.2494	6.3	863.66	0.964
3	24.1	23.59	17	0.2869	6.3	764.13	0.848
4	22.1	21.59	17	0.31	6.3	700.22	0.777
5	20	19.1	30	0.3182	11.1	1104.42	1.29

A. Total number of machining cycles= 98

B. Machining time for one cycle= L/F*N = 20/0.03*1800 = 0.37 minute

C. Total machining time of untreated HSS tool= 98*0.37 = 36.30 min

D. Total Material Removed by standard HSS tool = 4337.75 mm^3

2.2. SURFACE TEXTURE ANALYSIS OF UNTREATED HSS TOOL

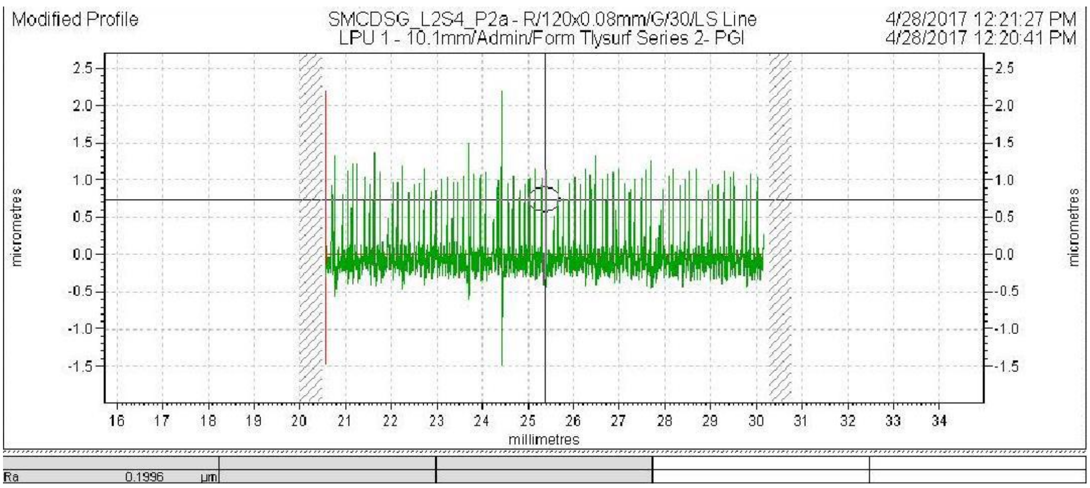

Figure 7. Taylor Hobson-Form Talysurf image (R_a = 0.1996µm, after 17 machining cycles)

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It is evident that the first 17 machining cycles resulted in 0.1996μm surface finish at the optimized machining parameters.

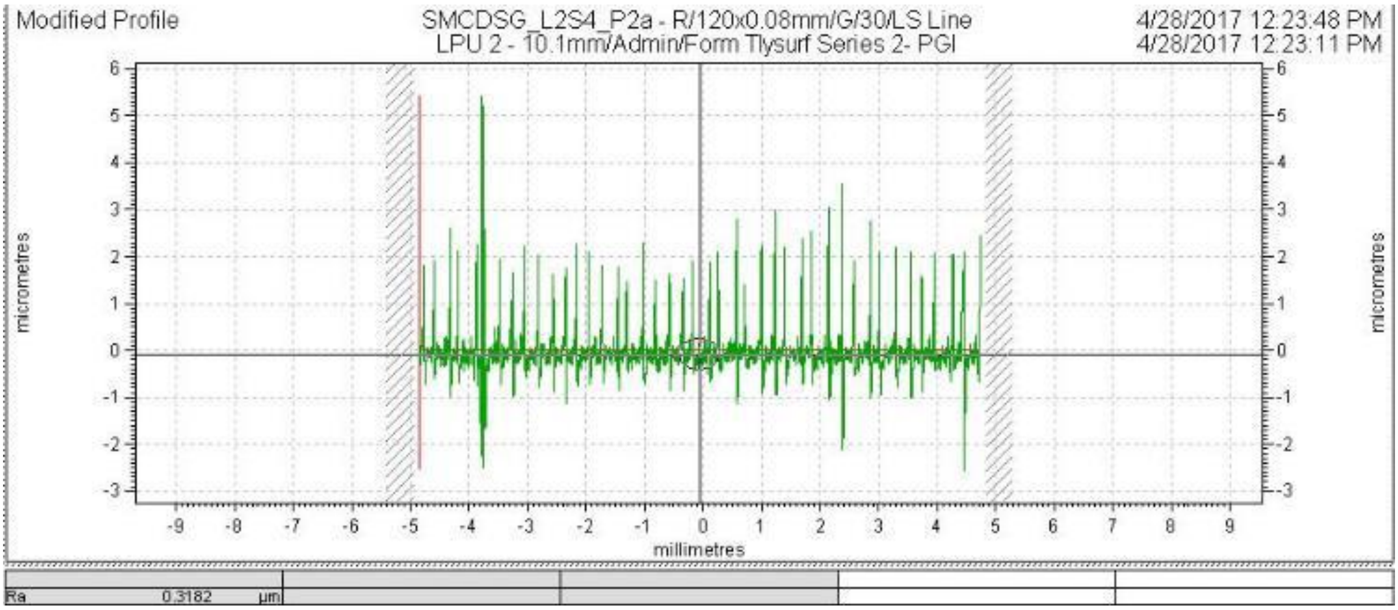

Figure 8. Taylor Hobson-Form Talysurf image (R_a = 0.3182μm, after 98 machining cycles)

Measurement after 98 machining cycles yielded an average surface finish of 0.3182μm on C18000. This R_a value is unacceptable for material like C18000 as it is mostly used for making moulding dies in which the average surface finish below 0.3μm is ideal.

2.3. STANDARD HSS TOOL WEAR AFTER MACHINING

The images of the standard HSS tool having a 4μm tool tip radius under different magnifications are taken in this experiment. Figure 9 shows the images of the tool which has not gone under any process; this was done to compare the results of the standard HSS and cryogenic HSS tool.

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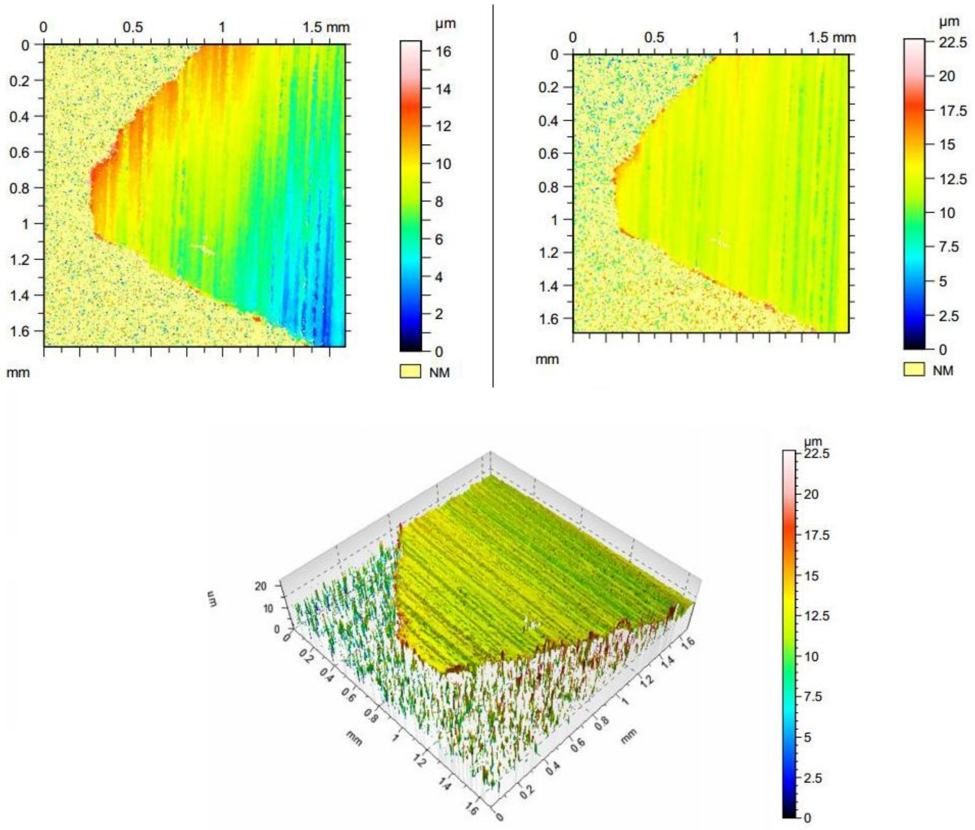

Figure 9. CCI Image of untreated unused HSS M35

Figure 10 shows the non-cryo treated blunt tool used to machine C18000. The tool tip is studied at different magnifications to understand the effect of machining on the cutting tool. The tool used to machine the work piece has 4µm tip radius, and after 98 cycles of machining, which took about 36.30 min, it was observed that the tool is providing bad surface finish due to the tip of the tool, which got flattened to 8µm due to wear.

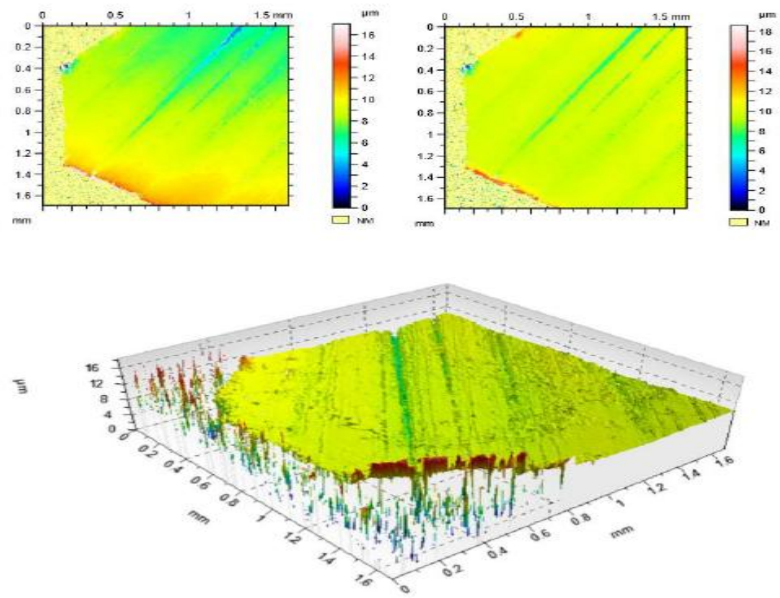

Figure 10: CCI Image of untreated HSS M35

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2.4. CRYOGENICALLY TREATED HSS M35 TOOL:

Machining conducted using the treated HSS tool on the copper alloy (C18000) yielded results shown in table 5.

Table 5: Machining data of cryo-treated HSS M35 tool

Sr. no	D_o (mm)	D_f (mm)	Machining cycles	Ra (µm)	T(sec)	Material Removal (mm3)	Cutting Length in (km)
1	28.61	28.1	17	0.2348	6.3	909.149	1.008
2	26.61	26.1	17	0.244	6.3	845.023	0.937
3	24.61	24.1	17	0.2479	6.3	780.896	0.937
4	22.61	22.1	17	0.268	6.3	716.769	0.795
5	20.78	18.8	66	0.5906	24.44	2461.567	2.733

A. Total Number of Cycle= 134

B. Machining Time for One Cycle= L/F*N = 20/0.03*1800 = 0.37 min

C. Total Machining Time of standard HSS tool= 134*0.37 = 49.58 min

D. Total Material Removed by standard HSS tool = 5713.40 mm^3

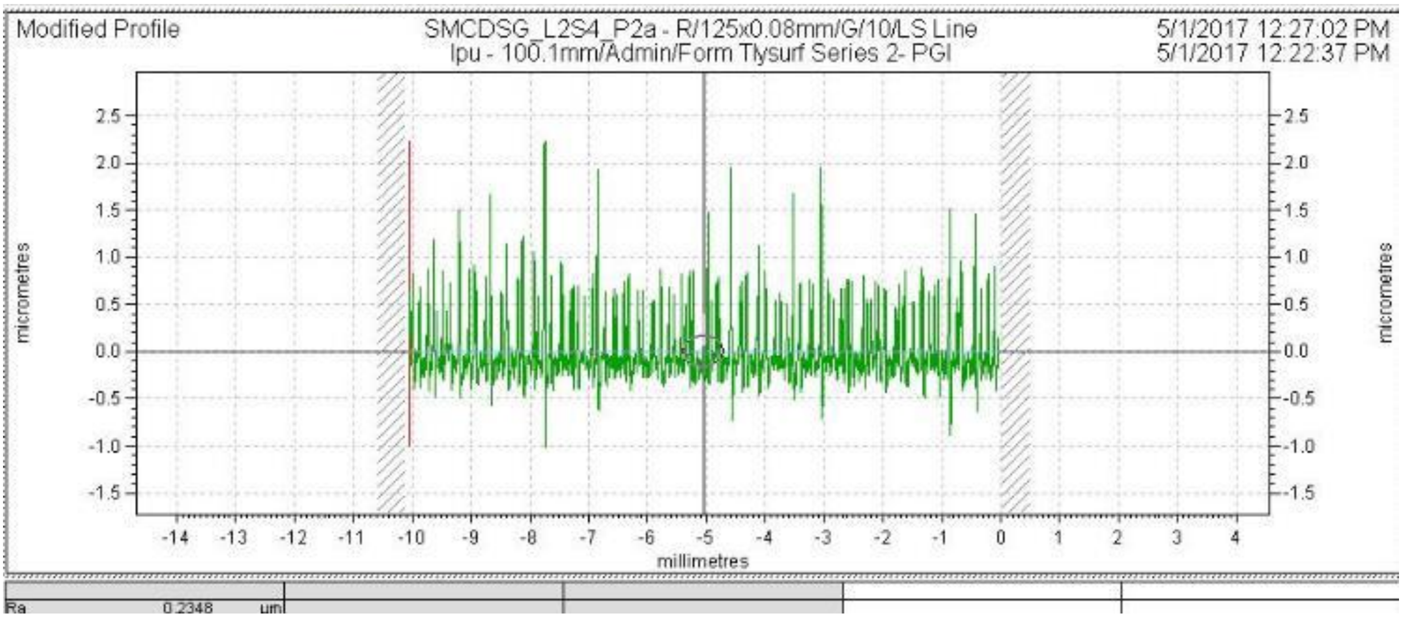

Figure 11. The surface roughness of Cryo-treated HSS after 17 cycle

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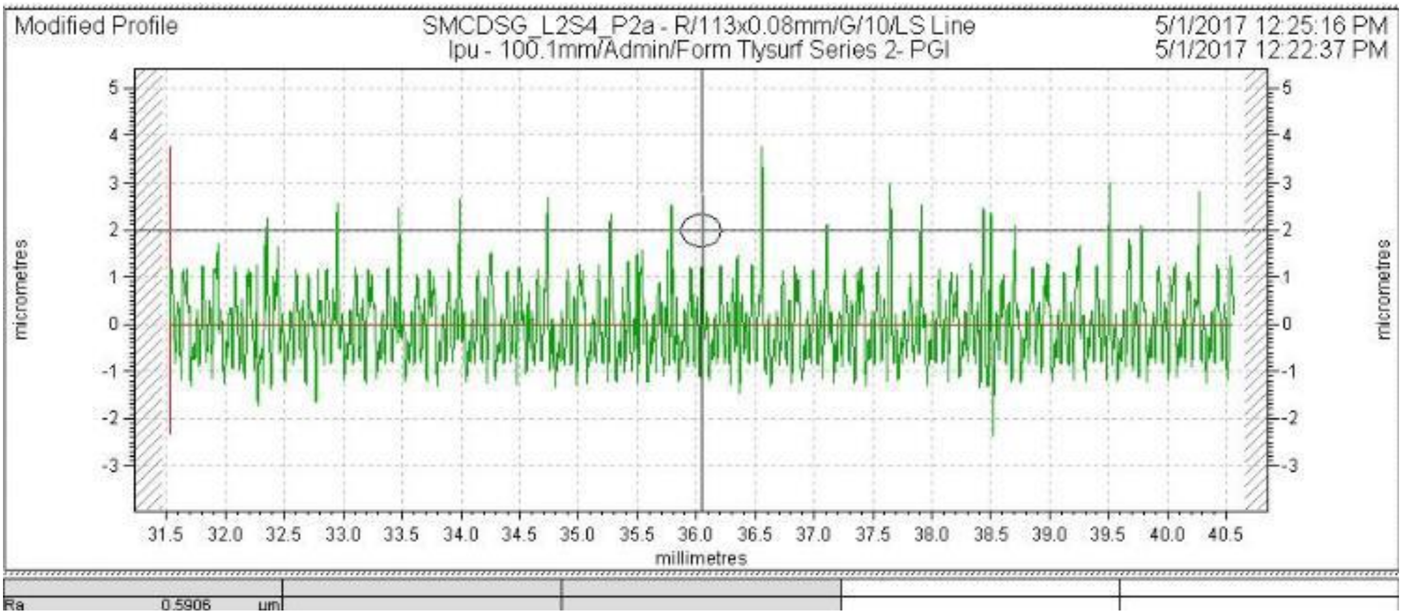

Figure 12. The surface roughness of Cryo treated HSS after 134 cycle

The above image of the surface roughness of the C-18000 material surface with cryo treated HSS tool. In Figure 11 the value of Ra is 0.2348 µm after 17 cycles with the optimized parameter. And in the second Figure 12, the value of Ra is 05906 µm after completion of the 134 cycles. After the 134 cycles the machined surface becomes rough means the tool becomes worn out.

Figure 13 shows the CCI Images of the Cryo treated tool, which is used for machining of C18000. The tool tip was studied at different magnification to understand the effect on the tool after machining of the workpiece. The tip of the tool has a 4µm radius, and the 134 machining cycle consumed 49.58 min. It was observed that the tool is providing bad surface finish because of the sudden wear in tool tip, which was studied with the help of CCI HD non-contact image profiler

2.5. STANDARD HSS TOOL WEAR AFTER MACHINING

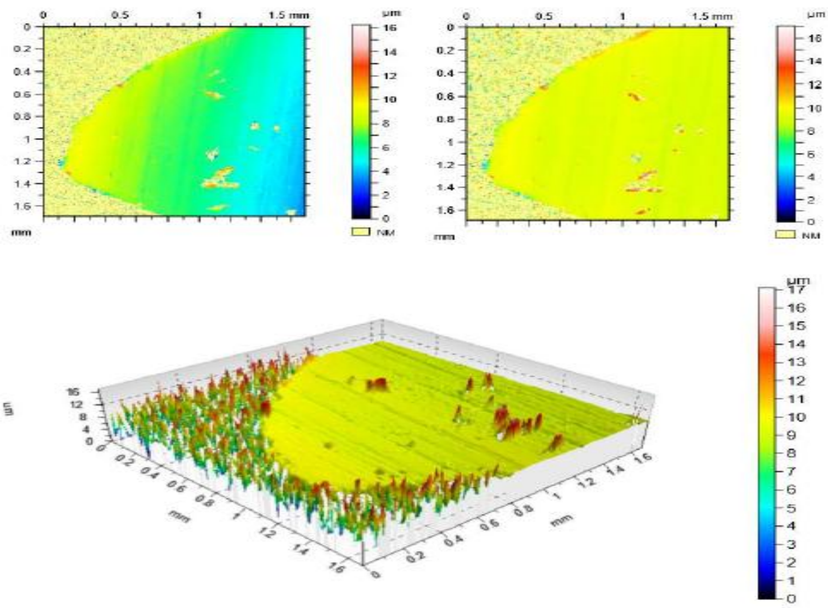

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Figure 13. **CCI Image of cryo-treated HSS M35**

3. COMPARISON OF PERFORMANCE OF TREATED AND UNTREATED HSS M35

The factors considered to examine the cutting tool performance are machining time, the number of the machining cycles performed by the cutting the tool, tool travel length and amount of material removed As per the study, it has been found that the cryo treated cutting tool machining time for the same level of surface finish was 26.78 percent more than that of the untreated cutting tool.

Tool	Time	No. of cycles	Tool travel length (Kms)	Amount of material removed
Untreated HSS	36.3	98	4.884	4337.75
Cryo Treated HSS	49.58	134	6.339	5713.4
Comparison (% change)	26.78	26.86	22.95	24.08

4. CONCLUSION

1. C18000 alloy was used in this study because less of work has been done on it, and it is widely used in industries because of its major acceptability criteria that is a strength. The following conclusion is drawn from this study.
2. The optimized cutting parameters for finishing machining of C-18000 are 1800 rpm, 0.03mm depth of cut and 0.03mm/rev feed rate.
3. Feed rate seems to be the most significant factor affecting the tool life followed by spindle speed and depth of cut respectively during the machining of C-18000 alloy with HSS M35 tool
4. The tool life of cryo treated cutting tool increased by 24% for M35 single-point cutting tools in comparison to the non-cryo treated tool.
5. The factors weighed to examine the performance of the tool are machining time, a number of the cycle performed by the tool, tool travel length and amount of material removed by the tool. All these factors positively increased in the case of cryo-treated HSS tools. Further, it has been observed that the machining time, tool travel Length and amount of material remove withing a similar range of surface finish increased within the range of 22 to 26%
6. No significant difference in hardness between cryogenically treated and untreated M35 tool is found.

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