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A Comparative Study of the Effect of Various Cryogenic Treatments on the Performance of Tungsten Carbide Inserts

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Abstract— In this work aims to study the performance of the cryogenic treatment on the tungsten carbide inserts tools (Shallow cryogenic treated and Deep cryogenic treated) compared to the untreated tool for machining the AISI 1020 Bright rod (workpiece). From that machining, the tool wear and surface roughness values of the workpiece material was determined. At the same time cutting zone temperature and chip formation methodology were observed. From the tool wear tests deep cryogenically treated tool revealed the less amount of weight loss (10mg). The reason behind that, the formation of ήphase particles precipitated on the carbide inserts after the cryogenic treatment. The SEM images and EDX images shows the formation of fine grains. After the machining the surface roughness test was conducted. In this test, the deep cryogenically treated tungsten carbide tool affords the less surface roughness value (2.483µm) compared to others. The cutting zone temperature was observed for each machining operation. The deep cryo treated tool affords the less temperature (130 deg C) compared to others. The chip formation was analysed for each machining operation. The deep cryo treated tungsten carbide tool affords the discontinuous chips.
Keywords— An effect of cryogenic treated Tungsten carbide, SCT and DCT Tungsten carbide inserts

I. INTRODUCTION

Cryogenics is defined as the branches of physics and engineering that study very low temperatures, how to produce them, and how materials behave at those temperatures. Rather than the acquainted temperature scales of Fahrenheit and Celsius, cryogenicists use the Kelvin and Rankine scales. The word cryogenics literally means "the production of freezing cold"; however the term is used today as a synonym for the low-temperature state. It is not well-defined at what point on the temperature scale refrigeration ends and cryogenics begins. The workers at the NIST at Boulder, Colorado have chosen to consider the field of cryogenics as that containing temperatures below –180 °C (93.15 K). This is a logical dividing line, since the normal steaming points of the so-called permanent gases (such as helium, hydrogen, neon, nitrogen, oxygen, and normal air) lie below -180 °C while the Freon refrigerants, hydrogen sulphide, and other common refrigerants have steaming points above -180 °C. Cryogenic temperatures are achieved either by the rapid evaporation of volatile liquids or by the expansion of gases confined initially at pressures of 160 to 210 atmospheres. The expansion may be simple, that is, through a valve to a region of lower pressure, or it may transpire in the cylinder of an engine, with the gas driving the piston of the engine. The method is more efficient but is also tougher to apply. Cryogenic treatment is a one-time enduring treatment process and it disturbs the entire cross-section of the material usually done at the end of predictable heat treatment process but before tempering. Also it is not a substitute process but rather a supplement to conventional heat treatment process. It is believed to expand wear resistance as well the surface hardness and thermal stability of various materials. This treatment is done to make sure there is no recollected austenite during quenching. When steel is at the seasoning temperature, there is a compact solution of Carbon and Iron, known as Austenite. The amount of martensite formed at quenching is a function of the lowermost temperature encountered. At any given temperature of quenching there is a certain amount of martensite and the balance is unreconstructed austenite. This unreconstructed austenite is very brittle and can cause loss of strength or hardness, dimensional instability, or cracking.

II. EXPERIMENTAL SETUP

A. Cryogenic treatment Procedure

The liquid nitrogen as generated from the nitrogen plant is stored in storage bowls. Through the help of transfer lines, it is directed to a closed vacuum displaced chamber called cryogenic freezer through a nozzle. The fund of liquid nitrogen into the cryo-freezer is operated with the help of solenoid valves. Exclusive the chamber gradual cooling occurs at a rate of 2º C /min since the room temperature to a temperature of -196º C. On one occasion the subzero temperature is stretched, specimens are transferred to the nitrogen chamber or soaking chamber wherein they are stored for 24 hours with uninterrupted supply of liquid nitrogen. Then the preparation of SCT and DCT tungsten carbide inserts were placed in 12 hours and 24 hours cryogenic environment respectively. Formerly the treated tools were gradually transformed into the room temperature for 12 hours soaking of both tool inserts.

B. Effect of cryogenic treatment on the tungsten carbide inserts

The tentative study of microstructural distinctions of α (tungsten carbide), β (cobalt ring binder), γ (carbide of cubic lattice) and ɳ (numerous carbides of tungsten and at least one metal of the binder) phases within the tungsten carbide tools produced by the cryogenic treatment, and links these changes to the corresponding enhanced tool life. From the literature and with the help of EDX and SEM (Fig; 4.1.1. shows the untreated and Cryo treated SCT and DCT images in 50µm with X1000) study showed the formation of complex phases like W_3Co_3C and W_6Co_6C after cryogenic treatment. These phases are known as ɳ phase. These multifarious phases growth in hardness due to experience of skeleton carbide matrix due to later pole treatments. In this carbide matrix along with the cobalt binder, provides the rigidity to the shallow and deep cryogenic treated tungsten carbide inserts. The cryogenic treatment of tungsten carbide, noted that there were substantial improvements in the hardness of tungsten carbides after they were subjected to cryogenic treatment. I found that the hardness of the cryogenically treated tools increased with increasing cobalt content as well. The situation should also be well-known that the decrease in hardness of the raw tool as the cobalt pleased increases is much greater in degree compared to the increase achieved with cryogenic treatment. The machining was carried out for the following cutting conditions in Table 1.

III. RESULTS AND DISCUSSION

A. Tool wear

After the machining the weight loss of the each tool inserts were measured (UTT, SCT, DCT). By measuring the weights of tungsten carbide inserts were before and after the machining. From the experiment the DCT and SCT tool insert has the less wear compared to the UTT. The DCT has the improved tool life for 66% and 46.6% than UTT and SCT respectively. Because the cryogenically treated tools are retained its hardness during cryogenic treatment. The EDX experiment showed (fig 11, 12, 13) the increment in the carbon and cobalt percentage. So it provides the rigidity and hardness of the tungsten carbide inserts. The SCT and DCT tool inserts has the stronger carbon and cobalt binding were exercised after the cryogenic treatment.

B. Surface roughness

The machined surface of the workpiece were examined after the machining. From that, the SCT tool insert affords 17.5% improved surface roughness than UTT tool. Then the DCT tool insert also provides 24.5% and 6% improved surface Roughness value than UTT and SCT tool inserts. Because the DCT and SCT tool inserts the ή phase complex particles are precipitated on its surface. In this fine particles provides the less surface roughness value. The fine particle size were measured by using the SEM images and also determine the intermolecular distance between the atoms.

C. Chip morphology analysis

After the machining, the chips were collected and examined. From that the UTT tool insert offers the continuous chips (fig 14) formed during the machining. The reason behind that, the heat transfer rate across the tool insert and workpiece were minimum. By the way the, the heat is transferred through the chip only. So gradual cooling doesn't break the chips. So the chips were stickened on the workpiece. It increases the surface value of workpiece and reduce tool life. The SCT tool inserts offers the partially continuous chips (fig 15) due to the partial heat transfer across the tool chip interface. The few amount of fine grains of the complex particles ($C_3W_3CO_3$ and $C_6W_6CO_6$) were absorbs the heat. The DCT tool inserts offers the discontinuous chips (fig 16) due to the complete heat transfer across the tool chip interface. The improving grain structure access the heat transfer through the tool and workpiece itself. The less amount of heat generation during DCT tool insert machining has the sufficient time to eliminate the less amount of heat.

D. Cutting Zone temperature

The cutting zone temperature were measured during machining of the bright rod for UTT and SCT and DCT tool inserts. The SCT tool insert generates the 6% less cutting temperature than the UTT tool inserts. The DCT tool insert generates the 8% and 3% less cutting zone temperature than the UTT and SCT tool inserts. Because the fine grain distribution across the cryogenic treated tungsten carbide inserts were generates the less heat. At the same time the heat transfer across the tool has the sufficient time to

Volume 4 Issue XII, December 2016
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evacuate the heat during machining. So the discontinuous chips were formed during DCT tool machining on the bright rod.

E. Figures and Tables

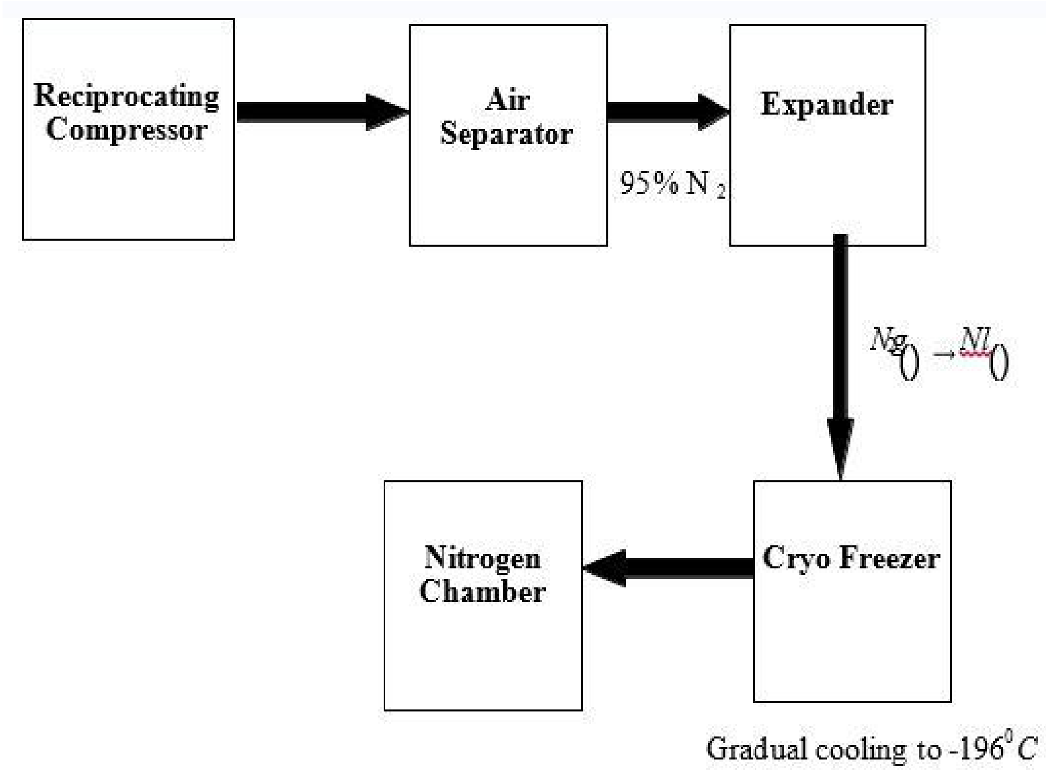

Fig1: cryogenic treatment setup

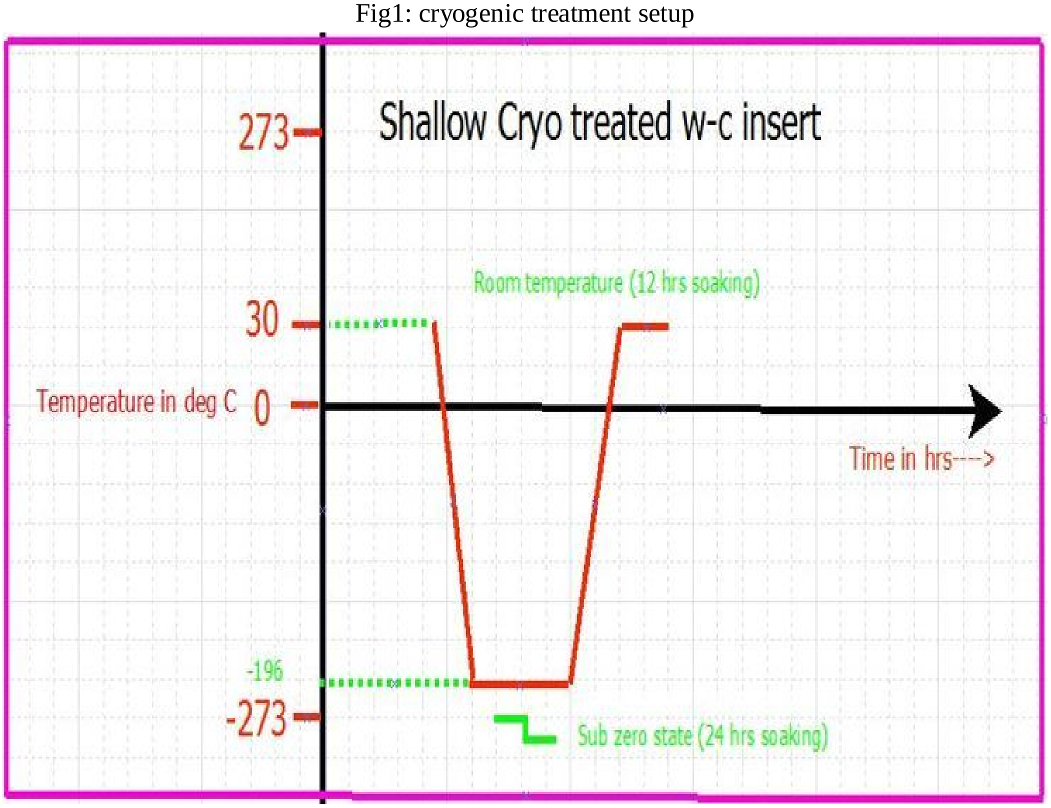

Fig 2: Preparation of SCT tool inserts

Volume 4 Issue XII, December 2016
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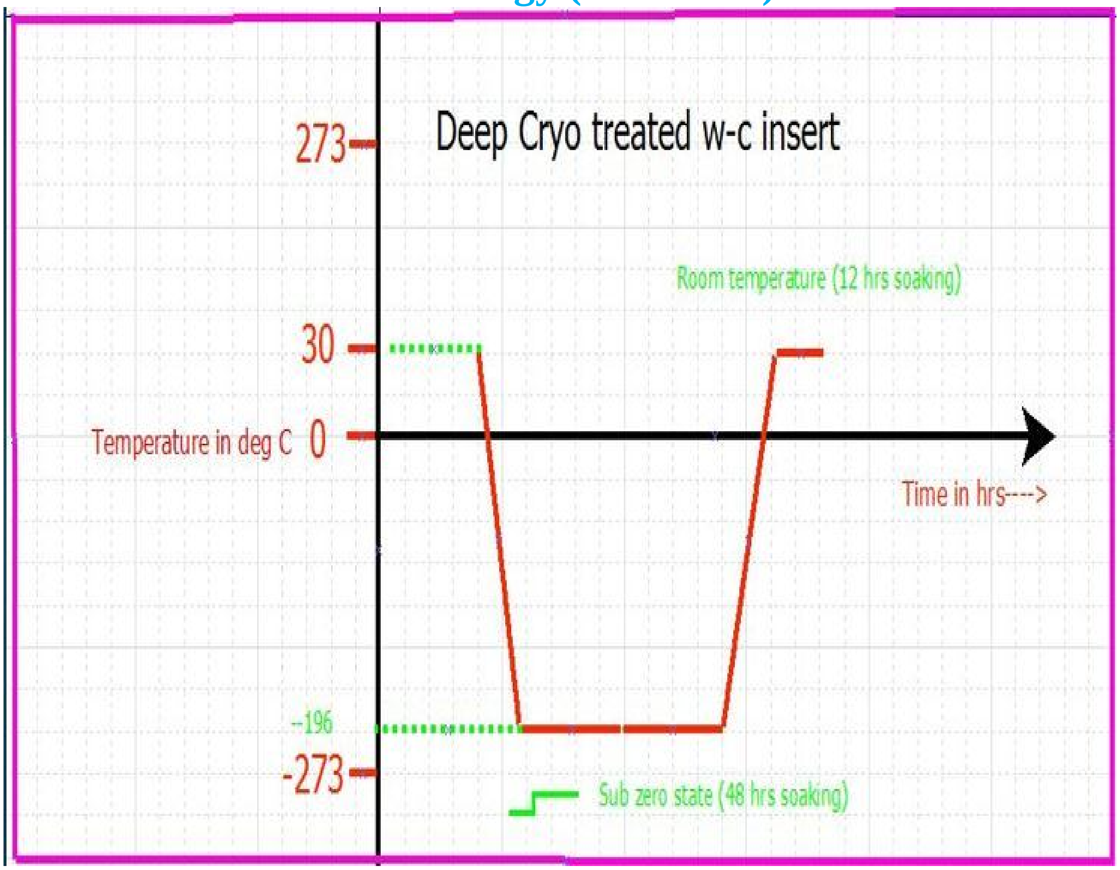
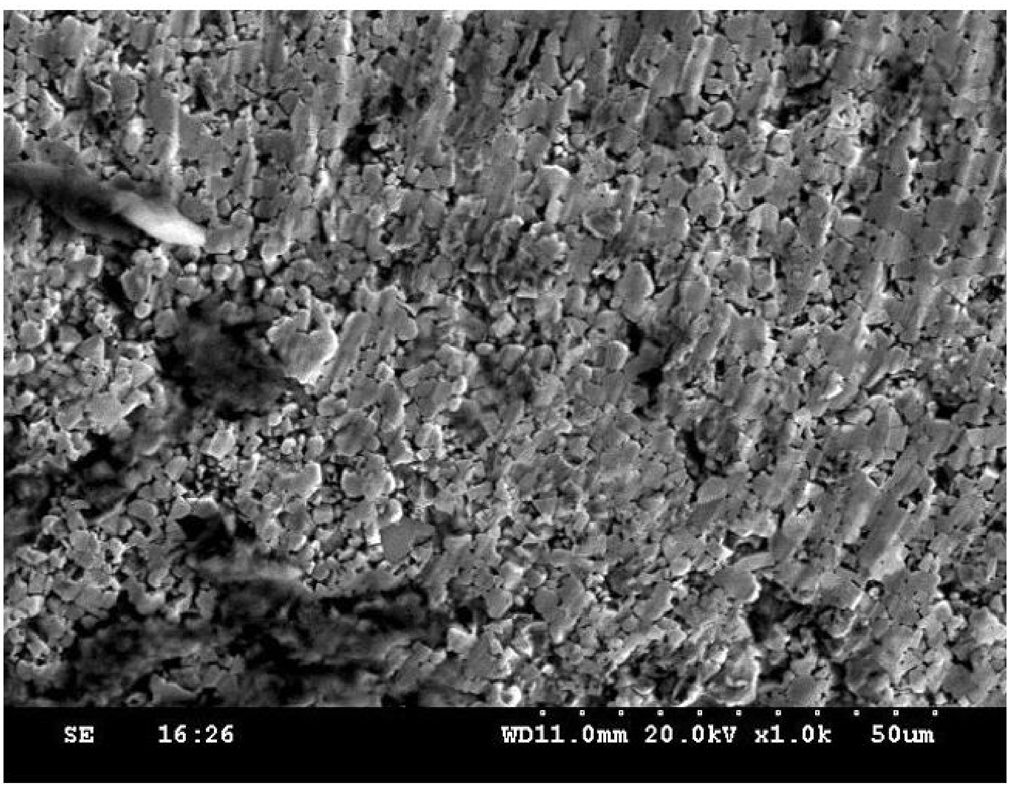
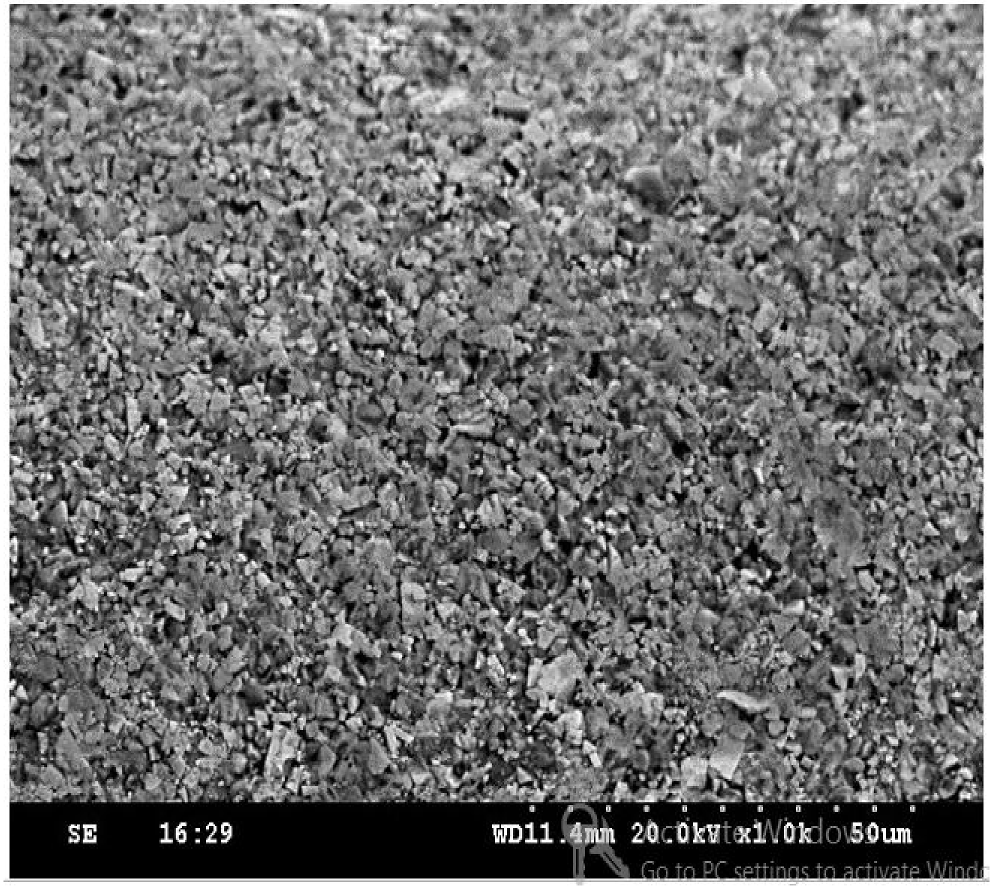


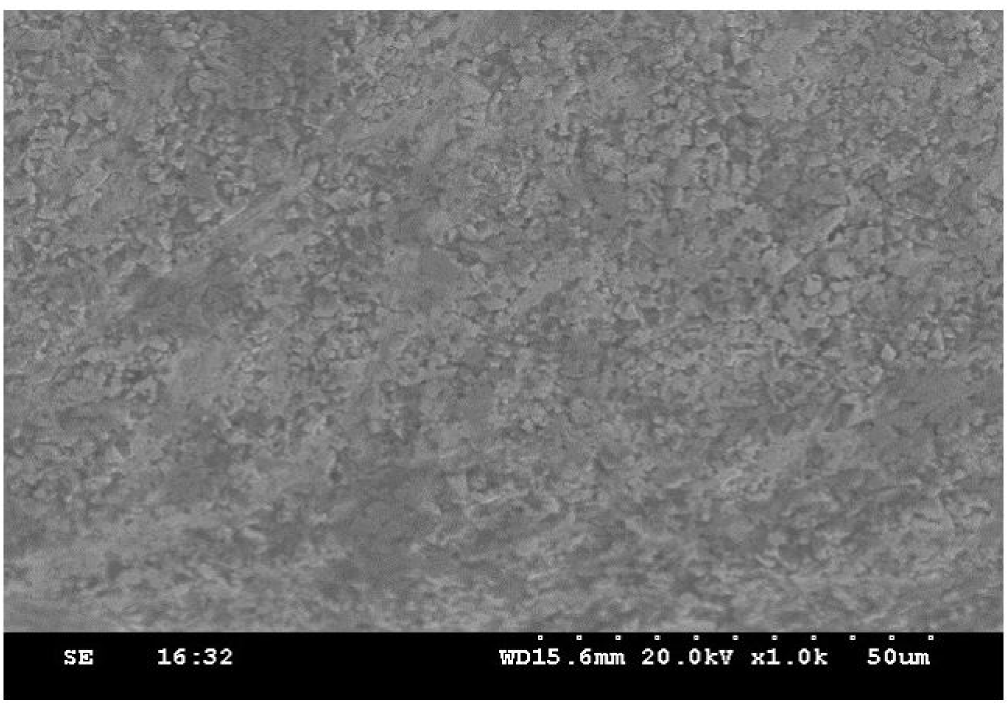
Fig 3: Preparation of DCT tool insert



Fig, 4: SEM image for UTT



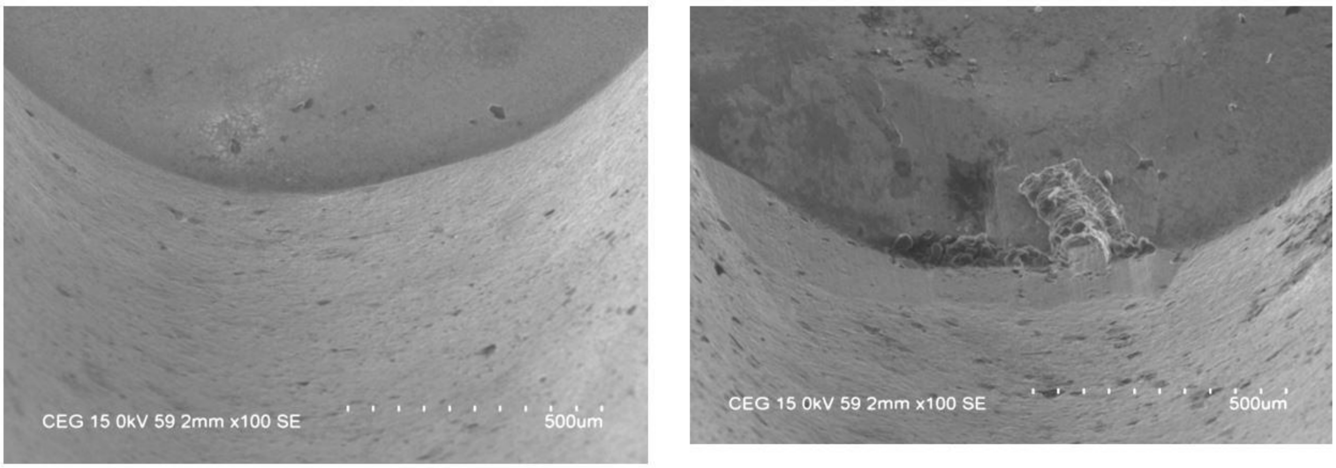
Fig, 5: SEM image for SCT



Fig, 6: SEM image for DCT

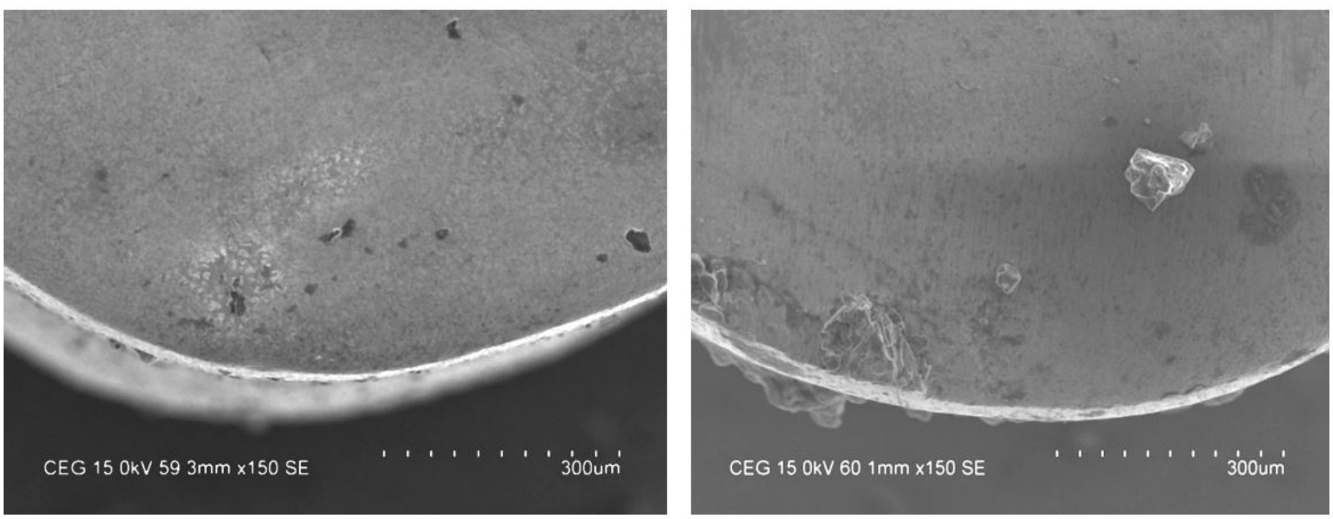
Volume 4 Issue XII, December 2016
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Fig 7: NAGMATI-175 turning lathe



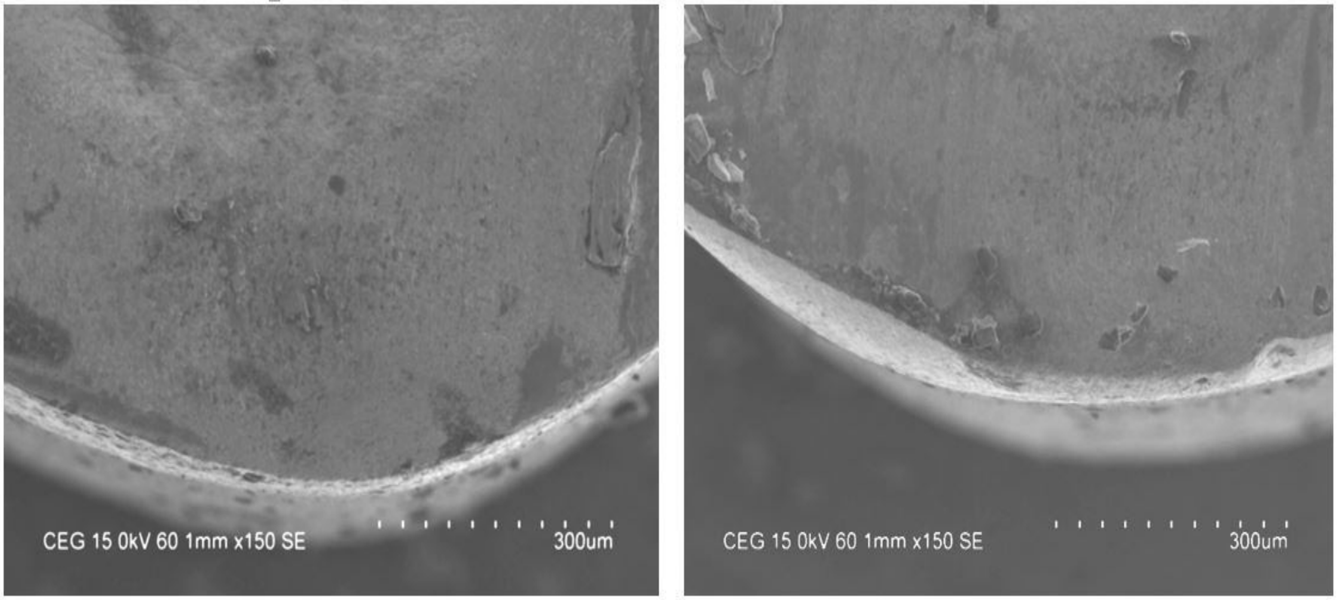
(a) (b)

Fig 8: SEM image for UTT tool inserts before (a) and after (b) machining



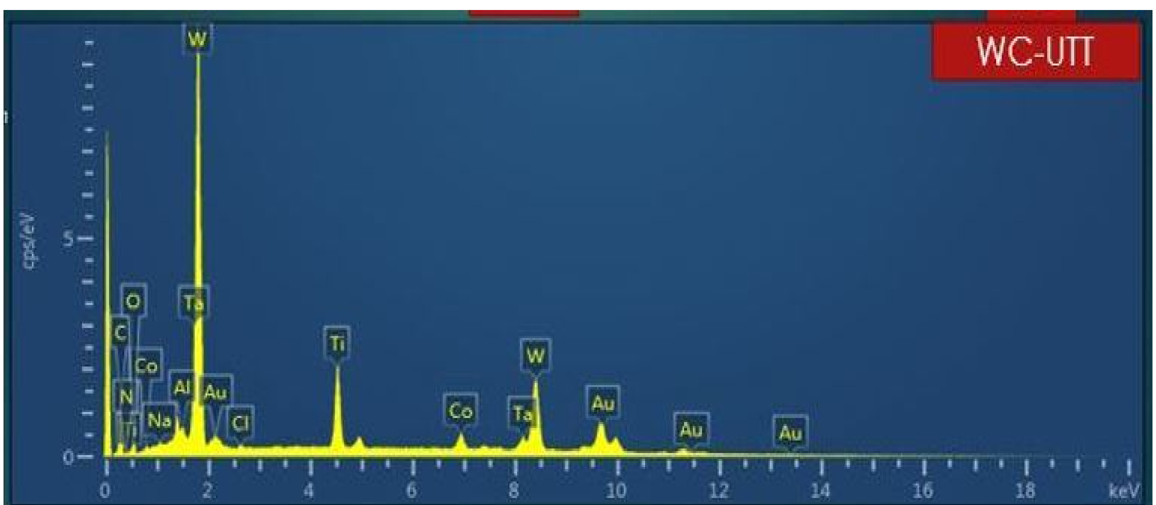
(a) (b)

Fig 9: SEM image for SCT tool inserts before (a) and after (b) machining



(a) (b)

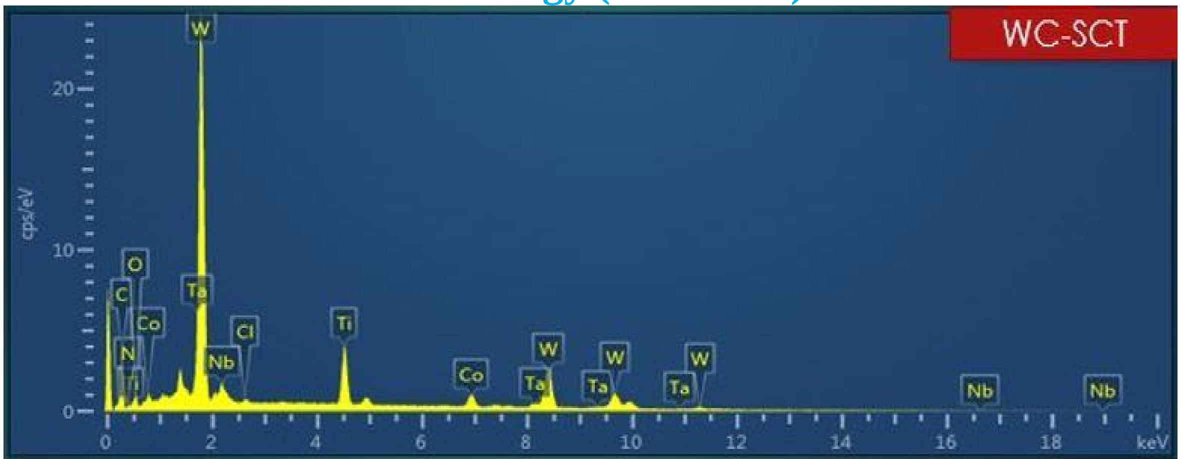
Fig 10: SEM image for DCT tool inserts before (a) and after (b) machining



Spectrum 5 Element	Line Type	Weight %	Weight % Sigma	Atomic %
Ti	K series	7.27	0.13	7.08
N	K series	0.00	0.50	0.00
C	K series	15.47	0.39	60.07
W	L series	58.56	0.55	14.86
Ta	L series	8.69	0.47	2.24
O	K series	4.02	0.24	11.73
Co	K series	2.63	0.12	2.08
Au	M series	2.56	0.23	0.61
Cl	K series	0.24	0.05	0.31
Al	K series	0.40	0.04	0.69
Na	K series	0.17	0.05	0.34
Total		100.00		100.00

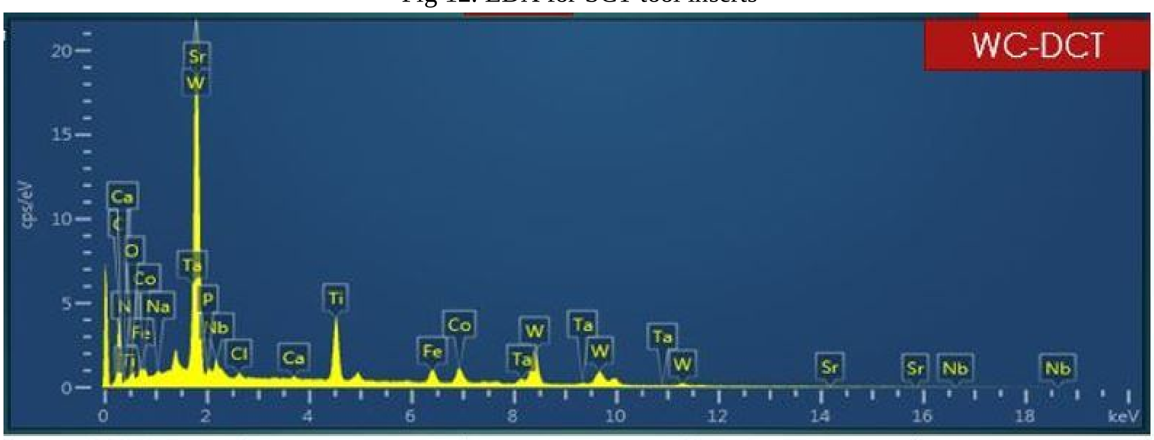
Fig 11: EDX for UTT tool inserts

Volume 4 Issue XII, December 2016
ISSN: 2321-9653



Spectrum 4				
Element	Line Type	Weight %	Weight % Sigma	Atomic %
Ti	K series	7.97	0.15	5.59
N	K series	0.00	0.85	0.00
C	K series	23.73	0.52	66.41
Co	K series	3.30	0.14	1.88
W	L series	50.32	0.61	9.20
O	K series	6.97	0.37	14.64
Nb	L series	3.33	0.23	1.21
Ta	L series	4.05	0.47	0.75
Cl	K series	0.34	0.06	0.32
Total		100.00		100.00

Fig 12: EDX for SCT tool inserts



Spectrum 2				
Element	Line Type	Weight %	Weight % Sigma	Atomic %
Ti	K series	7.22	0.14	4.29
N	K series	0.00	0.89	0.00
W	L series	39.21	0.58	6.08
C	K series	27.81	0.59	65.96
O	K series	9.87	0.39	17.57
Cl	K series	0.40	0.05	0.32
Fe	K series	2.51	0.11	1.28
Co	K series	3.52	0.13	1.70
Nb	L series	2.60	0.19	0.80
Ta	L series	4.41	0.42	0.69
Ca	K series	0.24	0.05	0.17
Na	K series	0.28	0.06	0.34
P	K series	0.26	0.08	0.24
Sr	L series	1.67	0.40	0.54
Total		100.00		100.00

Fig 13: EDX for DCT tool inserts

Volume 4 Issue XII, December 2016
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

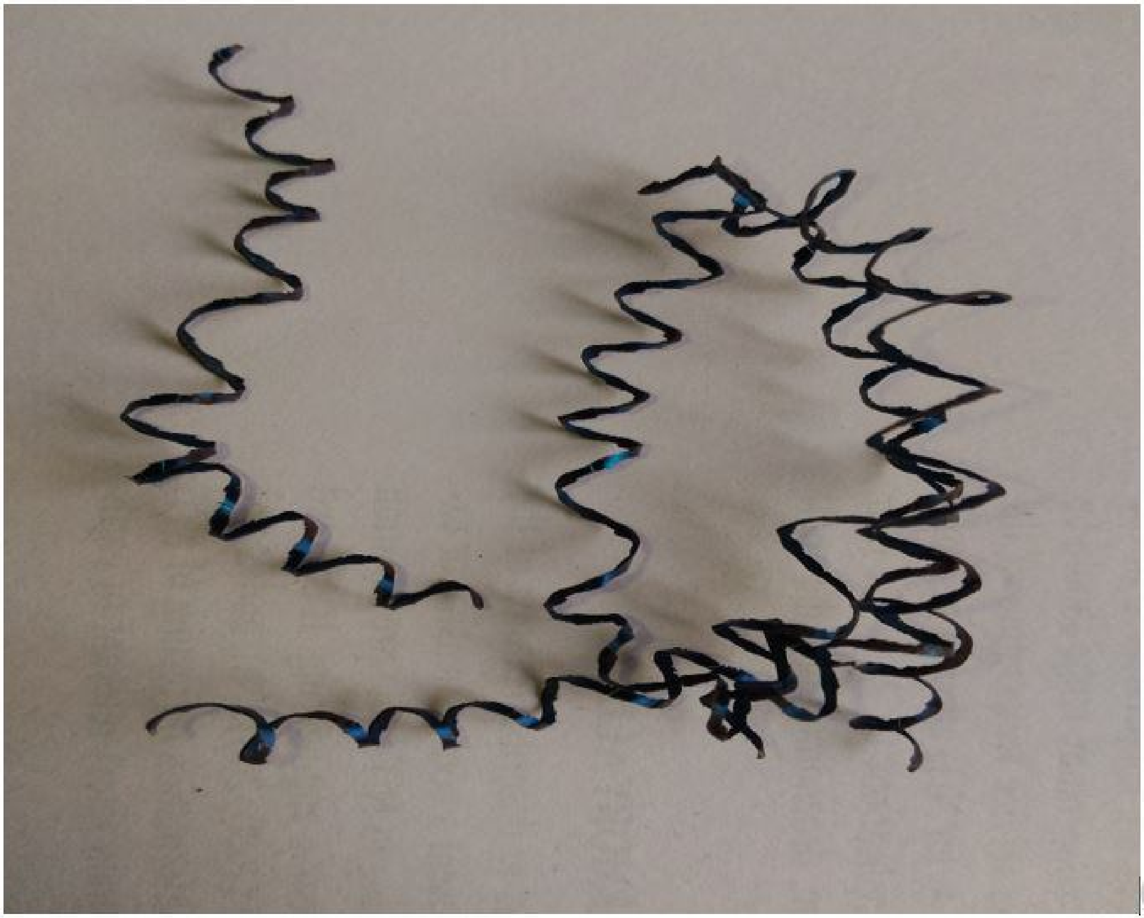


Fig 14: Continuous chips for UTT tool inserts

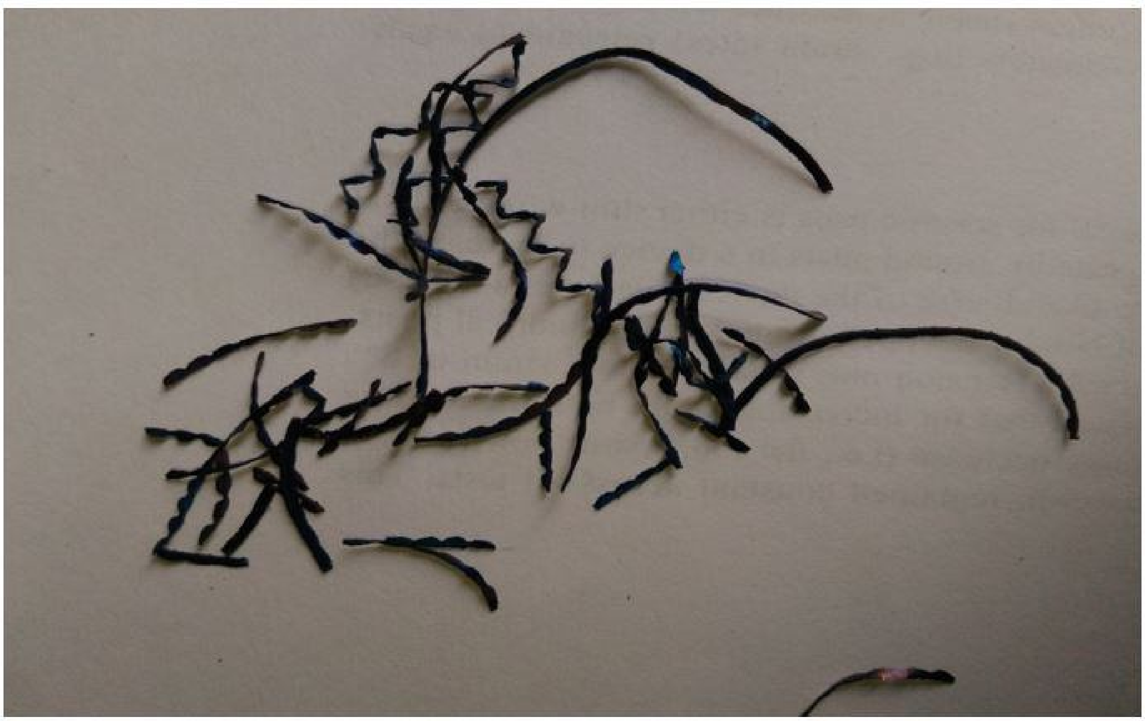


Fig 15: Partially continuous chips for SCT tool inserts

Volume 4 Issue XII, December 2016
ISSN: 2321-9653

Fig 16: Discontinuous chips for DCT tool inserts

Cutting Tool	Untreated Tungsten Carbide inserts	Shallow cryogenic treated Tungsten carbide inserts	Deep cryogenic treated Tungsten carbide inserts
Cutting speed (m/min)	94.2	94.2	94.2
Depth of cut (mm)	0.5	0.5	0.5
Feed (m/min)	0.096	0.096	0.096
Cutting condition	Dry	Dry	Dry
Work piece material	Mild steel	Mild steel	Mild steel

Table 1: Machining conditions on NAGMATI-175 Lathe

Volume 4 Issue XII, December 2016
ISSN: 2321-9653
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IV. LITERATURE SURVEY FOR REFERENCES

Cryogenic treatment of cutting tool materials such as tungsten carbide, have yet to be extensively studied. Tungsten carbide has been proven to be much more proficient than HSS when machining tough materials such as steel itself. If cryogenic treatments can binary the service life of HSS, it could doubtless do the same for tungsten carbide tools [1]. Unlike coatings that are only an apparent treatment, the cryogenic treatment is applied to the whole volume of the material, attainment the core of the tools. This assurances maintenance of their properties even after regrinding or re polishing. One of the most predominant claims in low-temperature treatment is an increase in wear opposition of certain steels [3][7][8] However, most researchers believe that cryogenic treatment promotes the complete conversion of retained austenite into martensite at cryogenic temperatures, which is credited to improved wear resistance [3[7]. Others assertion that cryogenic treatment facilitates the construction of fine carbides in the martensite, thus refining the wear resistance [10] [5]. However, the lack of communal sense in the literature regarding to the metallurgical features that cryogenic treatment confers better wear resistance and consequently higher tool lives as well as inconsistent results that are also encountered [3] [4][5] lead to many doubts and questions involving the practical use of this sort of treatment. Several different cryogenic progressions have been tested by researchers. These involve a combination of deep subzero and moderating cycles. Generally, they can be described as a controlled dropping of temperature from room temperature to the boiling point of liquid nitrogen (−196 °C), preservation of the temperature for about twenty four hours, followed by a controlled levitation of the temperature back to room temperature. Subsequent tempering processes may follow [3]. There are different levels of treatment temperatures. In order to evade confusion, cryogenic treatment has been classified into shallow cryogenic treatment (SCT) and deep cryogenic treatment (DCT) contingent upon the temperatures in which the material is treated [26].The common repetition for shallow cryogenic treatment is to keep the specimens in a automated freezer at 193 K for 5 h and then out to room temperature. But in deep cryogenic treatment the materials are slowly fetched down from room temperature to 77 K at 1.26 K/min, held at the same temperature for 24 h and subsequently brought back to room at 0.63 K/min. In order to accomplish deep cold temperatures, materials cannot be straight kept in freezer at 77 K related to that of shallow cryogenic treatment because the temperature difference is very high and fast cooling will prime to quench cracks. The orthodox heat treatment normally uses cooling situations only until room temperature, which may consent some retained austenite on the microstructure. This information must be considered during heat treatment of tool steels. This retained austenite is soft and unsteady at lower temperatures that it is likely to transform into martensite under certain advantageous conditions. It should be noted that recently formed martensite is also brittle and only tempered martensite is acceptable. To further aggravate this problem the transformation of austenite to martensite yields a 4% volume growth causing distortion which cannot be unnoticed. Thus retained austenite should be relieved to the maximum possible before any component or tool is put into service. The degree of undercooling decides the latent to transform retained austenite to martensite absolutely [3]. In this situation cryogenic treatment is accessible. It also causes the hail of finely dispersed carbides in the martensite. It would be the interest of investigators to quantify the benefits and also know the conditions at which the treatment derives maximum assistances. The freezing treatment will transform a great contract of this retained austenite by reaching the M_f line, giving more dimensional stability in the tool microstructure. The chief variables during heat treatment [7] have a great deal of influence on the results. A research done in steels corresponding to M2, varying the cryogenic cycles has quantified the occasioned particles and verified their influence onto the material assets [3]. Their research tangled seven steel samples, each of them submitted to different heating and cooling (up to −70 °C) phases. The microstructure was analysed and the carbide particles quantified using SEM, X-ray diffractometer, quantifiable metallography and variance dilatometer. The outcomes confirmed an increase in carbide hail (from 6.9% to 18.4%), a discount of the retained austenite (from 43.6% to 0.9%) and an increase in the martensite content (from 66.6% to 82.7%). The machining experiments carried out with minutes in turning AISI M35 steels showed a momentous increase in tool lives of cryogenically treated tools. These results can be credited to minimum quantity of retained austenite, higher amount of martensite content, higher density of fine carbides (smaller than 1 μm) and a more favourable distribution of the alloying elements among the carbide of the matrix.

Yakup yildiz et al. [1] did a thorough study on the effects of varying the deep freezing and moderating cycles on high speed steel and confirmed that in tool steels, this treatment affects the material in two ways. Firstly, it rejects retained austenite, and hence increases the hardness of the material. Secondly, this treatment recruits nucleation sites for hail of large numbers of very fine carbide particles, resulting in an increase in wear opposition.

Simranpreet Singh gill [3] also certified the presence of fine occasioned carbide units and their significance to the material properties. The precipitated carbides reduce internal tension of the martensite and diminish micro cracks exposure, while the uniform distribution of fine carbides of high hardness enhances the wear opposition

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

S.N.Choudhary et al [7] certified changes in the microstructure of M2 high speed steel when this material was submitted to diverse sequences of cryogenic treatment at −196 °C. Relating the conventional quenching cycle with other cryogenic cycles it was observed increases the strength, as well as toughness and also variations in the room temperature and hot hardness. The results were again attributed to transformation of the retained austenite into martensite and drizzle of ultrafine carbides, with this latter being considered the key point for the changes in the properties.

D. **Candane et al [8]** the orthodoxly heat-treated and cryogenically treated specimens exhibited the largest and smallest wear volume at all sliding distance, respectively. From the microstructure of the steel it is conveyed that the improvement in wear resistance after cryogenic treatment can be recognized to η-carbide precipitates.

So far, few investigators have proposed other apparatuses that explain the effect of cryogenic treatment on tungsten carbide. He features the wear resistance, and hence the increase in tool life, of carbide tools to the upgrading in the holding strength of the binder after cryogenic treatment. He trusts that cryogenic treatment also acts to sack the stresses announced during the sintering process under which carbide tools are formed. Though, he also cautioned that under certain conditions, cryogenic treatment would have little or no effect on carbide tools, such as when reclaimed carbides are recycled.

In a more modern work it was tested that cryogenic treatment no doubt improves the resistance to chipping of tools and to a less significant extent, improves flank wear resistance but however, under assured conditions, such as lengthy exposure to high temperatures during long continuous cutting procedures, cryogenically treated tools can lose their grander properties. Trendy light of the fact that cryogenically treated tools perform preeminent when the tool temperature is kept low, their effectiveness can be extended if coolants or suitable methods of cooling are used to keep the tool temperatures truncated. Later, the rationality of claims that cryogenic treatment can improve the lifetime of cutting tools would depend a lot on the cutting situations. Apparatuses under minor cutting conditions stand to gain from cryogenic treatment, but heavy duty cutting operations with long periods of heating of the cutting tool will not advantage from it.

Kyung -Hee Park et al [2015] examine the machining performance of a variety of cooling methods, cryogenic, minimum quantity lubrication (MQL), and flood cooling are performed on solid end milling of titanium alloy, Ti-6Al-4V. In particular, the effect of interior and exterior spray methods on cryogenic machining is analysed with a specially considered liquid nitrogen spraying system by gauging tool wear and cutting force at cutting circumstances. The cutting force is also analysed for tool breakage recognition. As a result, the combination of MQL and internal cryogenic cooling improves tool life by up to 33% compared to conventional cooling methods. The cutting force is also reduced significantly by this grouping of cooling and lubrication strategy of cross end milling. The real appliances which guarantee superior tool performance after cryogenic treatment are still questioning. This implies in the need of further investigation in order to control the technique more systematically.

V. CONCLUSIONS

The comparative study of the cryogenic treated Tungsten carbide inserts (shallow and deep) and untreated cutting inserts for turning the AISI 1020 Bright rod and the major conclusions and the results of the experimental work conducted can be summarized as follows.

A. From the comparative study of the deep cryogenic treated tungsten carbide (DCT), tool life is 66% and 46.6% increase compared for Untreated and shallow cryogenic treated tungsten carbide inserts when machining of a mild steel.
B. For Deep cryogenically treated tungsten carbide (DCT) inserts affords the less surface roughness compared to the Untreated (UTT) and Shallow cryogenic treated (SCT) tungsten carbide inserts, where the percentage was 24.5% and 6% respectively.
C. From SEM analysis, it is evident that refinement of ἠ-phase carbides is more in case of cryogenically treated tools (both SCT and DCT) in comparison to that of untreated tools. The EDX experiment shows the results increments in weight percentage of Carbon and Cobalt, after the cryogenic treatment.
D. The Deep cryogenically treated tungsten carbide inserts (DCT) affords the discontinuous chips for machining a mild steel. That tool also produce the less cutting zone temperature compared to Untreated (UTT) and shallow treated tool (SCT) for the percentage was 8% and 3% respectively.

VI. ACKNOWLEDGMENT

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