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Investigation on the Benefits of Cryogenic Treatment on Tungsten Carbide Tool Inserts in Machining C-45 Steel

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Abstract: -- Productivity of cutting tool inserts in machining high strength and high temperature resistance alloys is an issue of concern. This drawback persists in case of Sintered carbides also, that have machining capabilities comparable with HSS and Cast Steel alloys. Many innovative methods have been implemented in this regard, out of which cryogenic treatment appears to be a promising technique. In this technique tool inserts are soaked in a controlled atmosphere at beyond -150 0C for predetermined time and brought back to room temperature. This treatment normally leads to contraction of metal structure increasing hardness and related properties. In the present work untreated Tungsten carbide tool inserts have been subjected to Cryogenic treatment at -193 0C followed by tempering cycle to relieve stresses formed during cooling. The treated samples showed improved hardness and tool life when subjected to machining tests at different cutting velocities. The microstructure study showed the formation of complex carbide phases and further studies revealed the increased population of carbides and cobalt binder which have contributed towards improvement in properties.

Keywords: Cryogenic treatment, Surface Finish, Tungsten carbide, Tool life

I. INTRODUCTION

Cryogenic treatment has evolved as one of the promising techniques in improving life of tool inserts. This process when carried out at a controlled rate can produce not only improved wear resistance of tool inserts but also the surface finish of the machined part. The above benefits have been well demonstrated by Barron [1] who conducted wear tests on variety of steels and showed a significant improvement in tool life. This work is also supported by Molinari [2] and Mohanlal [3] who also justified the simultaneous improvement of both hardness and wear resistance in steels. Research works on effects of cryogenic treatment on tungsten carbide has been done but is limited to uninterrupted cutting operation like turning operation. Seah et al [4] have shown that cryogenic treatment improved the wear resistance and overall tool life of tungsten carbide tool inserts in turning. Recent works by AY.L. Yong et al [5] has shown that the cryogenic treatment of tungsten carbide inserts improves tool life performance to a certain extent but longer machining times diminish any beneficial effect of tool life that cryogenic treatment brings about. They also established the fact that cryogenically treated inserts performed better by lowering tool-tip interface temperatures by providing proper coolant at the interface. Experiment conducted by T.V. Sreerama Reddy et al [6] has shown that the main cutting force for the cryogenic treated inserts is less when compared to untreated inserts. The surface finish of the work piece is better, when the work piece was machined with cryogenic treated inserts, in comparison with untreated inserts at all cutting speeds. Subjecting tool to cryogenic treatment results in better machinability due to increase in thermal conductivity of the tungsten carbide, resulting in decrease in tool tip temperature during turning operation, which is a definite advantage. The cryogenic treatment also results in better machinability, due to increase in hot hardness of the tungsten carbide. This also indicates that cryogenic treated tool tips are subjected to lesser tool wear and increase in the tool life, lesser cutting force and gives better surface finish compared to untreated tool. Experimental analysis by J.Yong, C.Ding [7] showed that hardness and compression strength of the tool samples treated by cryogenic environment are higher than that of the untreated ones. The improvement of mechanical properties is highly dependent on the soaking time. Mechanism of cryogenic treatment process on WC–Co inserts mainly expresses two aspects. One is the increasing of residual compression stress band the other is phase transformation of cobalt. Research by Jagdev Singh et al [8] shows, that hard phase particles of tungsten carbide are refined into their most stable form via the phenomenon of spheroidization after shallow and deep cryogenic treatment. It also aligns the hard phase carbide particulate structure into a durable, stress-free crystallographic configuration.

II. METHOD & MATERIAL

In the present investigation Tungsten Carbide tool inserts uncoated with toll specification SNMG 120408-MR4 have been used. Initially these inserts were wire cut into 4 mm thick pieces and were subjected to Cryogenic treatment cycle. This treatment involved, cooling the inserts in a

Liquid Nitrogen atmosphere from room temperature to -193 0C in 14 hours at rate of 0.26 0C/min, followed by a soaking period of 24 hrs. at -193 0C. Finally the pieces were brought back to room temperature in 18 hours at a rate of 0.203 0C /min. Since the treatment induced large amount of residual stresses, tempering treatment was given and at two temperatures 250 0C and 300 0C. Tempering was carried out in a Muffle furnace and the process was followed by both air and furnace cooling. XRD analysis was carried out under Cuka radiation of wavelength 1.5418 mm to identify the phases in untreated and treated inserts. Hardness of the inserts was checked on a Micro Hardness Tester under a standard load of 1 kg in accordance with ISO 1501-2002, RA 2007, a diamond indenter of 1mm diameter and apical angle 1360 was used with a dwell time of 10 sec. The micro-structures of both as received and treated inserts were studied under an Optical Metallurgical Microscope test for analyzing the η-phase distribution. The detailed specimen preparation, polishing and etching procedure followed is given below. The initial grinding is done using a 220-grit resin bonded diamond lap. Final grinding was done in a two-step process: First with a 600-grit diamond lap and next with a 6 µm diamond lap. To find out the microstructure of η-phase of WC-Co, Murakami's reagent: 10 g of potassium hydroxide (KOH), 10 g of potassium ferric cyanide (k3 Fe (CN) 6) and 100 ml of distilled water. Optical microscopy was carried on Olympus make microscope with maximum magnification of 1000X.Scanning electron microscopy was carried at Carl-Zeiss make, Neon-40 FESEM with resolution 1.1nm. To find out the microstructure of η-phase of WC-Co, Murakami's reagent 10 g of potassium hydroxide (KOH), 10 g of potassium ferric cyanide (k3 Fe (CN) 6) and 100 ml of distilled water. Optical microscopy was carried on, Olympus make microscope at with maximum magnification of 1000X.Scanning electron microscopy was carried on Carl-Zeiss make, Neon-40 FESEM with resolution 1.1nm. The tool life tests were conducted by subjecting treated and un-treated tool inserts with face turning operation in machining C-45 Steel. Tool maker microscope used was Mitutoyo make with 1 micron accuracy. During tool life tests the inserts were withdrawn after each continuous cut and were studied under tool maker's microscope of least count 1 µm for the wear pattern and average width of the flank wear. Table 1 shows the tool life experiment conditions.

C-45 Steel work pieces machined with treated & un-treated tool inserts at cutting velocity of 65.94 m/min were subjected to surface roughness. Test. The surface roughness of all the work pieces was measured by Mitutoyo Tally surf TS-450, with a stylus of radius 10 in and angle 600.

Table 1. Experimental conditions

Work material	C-45 Steel
Cutting tool inserts	Uncoated Tungsten Carbide
Cutting Velocity	Vc= 45.35 m/min
Feed	0.1 mm/rev
Depth of cut	1 mm
Machining Environment	Dry

III. RESULT & DISCUSSION

Table 2 shows the values of micro hardness of treated and untreated samples. Cryogenically treated inserts show around 6.5% of improvement in hardness. The largest improvement is in case of inserts tempered at 3000c and furnace cooled.

Table 2. Hardness test results

SAMPLE	Average Hardness no. HV1	% Increase
1 As received	1591.00	---
2. Cryo-treated	1695.67	6.5
3.Air cooled at 250 ^{0}C,	1651.67	3.8
4. Furnace cooled at 250 ^{0}C,	1671.76	5.1
5. Air cooled at 300 ^{0}C	1783.46	12.1
6.Furnace cooled at 300 ^{0}C,	1859.43	16.8

XRD results of cryogenically treated inserts are shown in the figure 1. This shows the formation two phases that prevail over the other CO-WC phases: the Eta phase Co3W3C and Kappa phase Co3W10C3.4 in all the inserts. The Eta phase is a soft phase and the Kappa phase is a very unstable phase. The increase in hardness obtained with treatment can be attributed to stabilization of Kappa phase. Compared to as received samples, Cryo-treated samples show improved stabilization of Kappa phase and there is around 6% increases in the hardness as supported by hardness values. (Table .2).

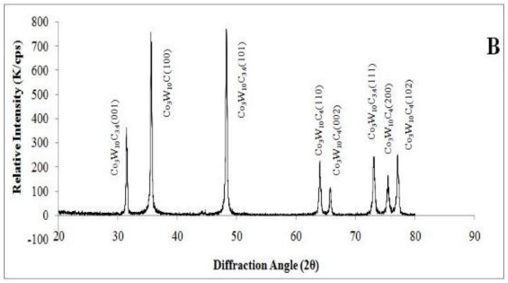

Fig 1. XRD results of Cryo-Treated inserts

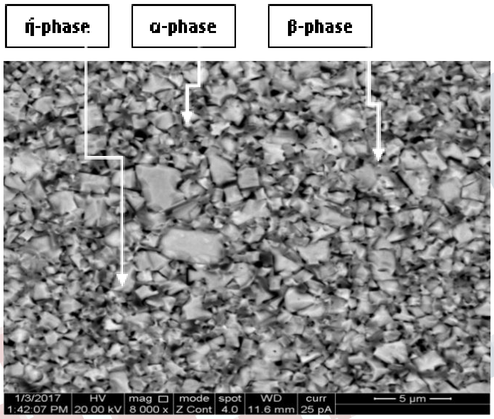

Fig 2 SEM Micrographs of as received inserts

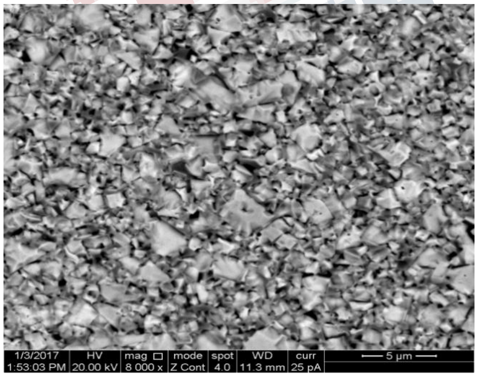

Fig 3 SEM Micrographs of Cryo-treated inserts

Fig. 2 and 3 show the microstructure of untreated insert and cryogenically treated inserts. The following phases are present in the microstructure as per ASTM B657-92 (2000) standard. The first phase is grey uneven angular shapes represent tungsten carbide (α-phase), the second phase which is white region signify cobalt binder (β- phase) and the third phase multiple carbide tungsten with at least one metal binder known as (ή-phase) appears as dark grey. Fig 4 shows the SEM images of flank wear on tool insert. The wear surface appears to be highly irregular as shown in Fig.5.

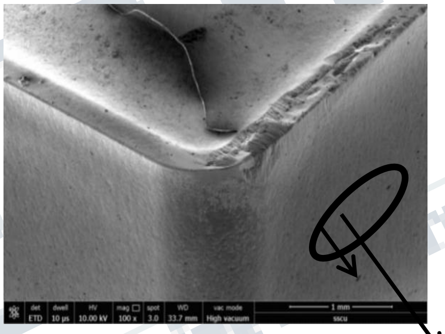

Fig. 4 Flank Wear on tool inserts

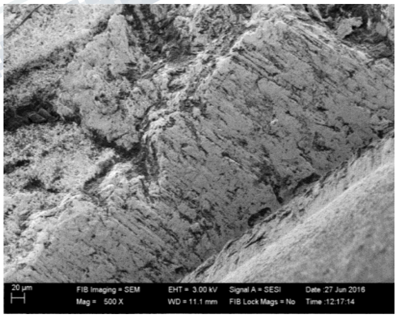

Fig. 5 Wear surface on higher magnification

Figure 6 shows graph of tool life vs. machining time. It is clearly observed from the experiment that in all the machining trials the growth of flank wear more or less showed the established pattern. It can be seen that all the treated samples show improved tool life than as received inserts. Inserts furnace cooled at 300 0C show the highest tool life. Also, as received inserts show the lowest tool life under at given cutting velocity. Untreated inserts and cryogenic treated inserts show the same trend. Initially flank wear of both types of inserts is same but with increase in production or near the end of tool life, cryogenically treated inserts showed less flank wear compared to untreated inserts. The cryogenically treated inserts show significant improvement in wear resistance. Flank wear of all the treated samples at given cutting speed was found to be lesser than that of untreated inserts, when machining was performed with feed of 0.1 mm/rev. There was a gradual improvement in tool life observed in samples after treatment.

Higher wear rate of untreated inserts during the machining can be attributed to coarse carbide structure. Gradual decrease in the wear of tempered inserts can be attributed to a better resistance of the inserts. Improvement in the performance of cryogenically treated and tempered inserts is due to the reduction in the brittle behaviour of cobalt binder. Also due to the creation of compact and tougher matrix of cobalt phase and uniform distribution of carbides, which impart wear resistance by forming complex carbides in ή-phase which are harder.

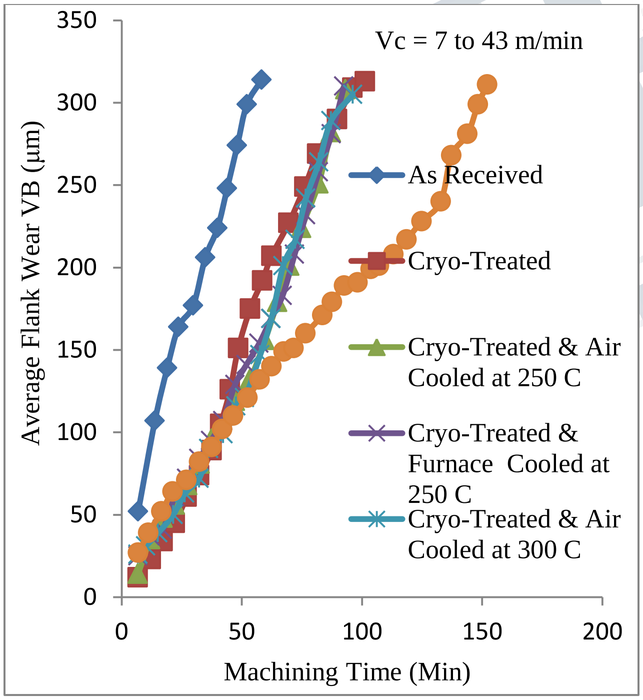

Fig. 6 Tool life of as received & treated inserts

The average atomic percentages of different phase elements in treated and untreated samples are shown in table 3. It is clear from the table that the percentage of Carbide and Cobalt has increased after treatment. Increase in carbide population of carbides has increase the wear resistance significantly in treated samples. This shows the controlled Cryogenic treatment followed by tempering can result improved flank wear resistance and consequently tool life of tungsten carbide tool inserts.

Table 3 Average Atomic Percentages of Different Phase elements

	C	**Co**	**W**
1 As received	18	10.82	63.49
2. Cryo-treated	23.25	12.92	63.25
3.Air cooled at250 ^{0}C,	21.02	12.75	65.56
4. Furnace cooled at 250 ^{0}C,	23.56	14.27	59.74
5. Air cooled at 300 ^{0}C,	24.33	11.96	60.82
6.Furnace cooled at 300 ^{0}C,	21.15	12.48	62.86

Table 4 shows the surface roughness values for treated and un-treated inserts. Since in most of the surface finish measurement applications Ra value is considered to be reliable, the comparison is made with the same value. It can be clearly seen that, after cryogenic and tempering treatments surface finish has improved considerably. The improvement in surface finish after cryogenic treatment can be assigned to the improved thermal conductivity and reduced cutting forces as supported by previous literature.

Table 4 Surface roughness parameters

	Surface Roughness Parameters (µm)			
	Ra	**Ry**	**Rz**	**Rq**
1 As received	3.86 3.54	30.95 29.97	30.69 29.87	5.09 4.98
2. Cryo-treated	2.96 3.34	29.53 28.96	29.53 28.96	4.93 4.53
3.Air cooled at 250 ^{0}C	2.83 2.34	26.51 22.94	26.51 22.94	4.36 3.95
4. Furnace cooled at 250 ^{0}C	2.61 2.78	20.27 19.18	20.27 19.18	3.52 3.32
5. Air cooled at 300 ^{0}C	2.73 2.71	17.52 17.13	17.52 17.13	3.39 3.33
6.Furnace cooled at 300 ^{0}C	0.95 1.29	6.09 8.87	6.09 8.87	1.19 1.61

CONCLUSION

1. Cryogenic treatment helps in stabilizing carbide phase and increasing hardness of Tungsten carbide tool inserts.
2. Tempering process following Cryogenic treatment reduces stresses induced during contraction and helps in improving wear resistance.
3. Tool life of cryogenically treated inserts found to be improved substantially compared to untreated inserts.
4. Cryogenically treated & tempered inserts show large improvement in tool life.
5. Improvement in carbide population and segregation can be attributed to the increased hardness and wear resistance in treated sample.
6. Cryogenic treatment has also influenced the surface finish of machined surface. C-45 Steel when machined with treated inserts show improved surface finish due to reduced cutting forces and improved thermal conductivity.
7. Controlled cryogenic treatment followed by tempering can improve strength, tool life of Tungsten carbide tool inserts and also surface finish of C-45 steel.

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