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Materials Today: Proceedings XX (2016) XXX–XXX

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PMME 2016

Machining With Cryogenically Treated Carbide Cutting Tool Inserts

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Abstract

With the development newer materials for aerospace, marine, automobile industries it became inevitable to develop new cutting tool materials with competitive performance and productivity. In this regard Sintered Carbide tools were developed to meet the modern machining requirements. But they failed miserably to due to rapid wear in machining high strength and temperature resistance alloy. This necessitated the need for bringing out innovative changes in machining process and controlling the various parameters associated. One such promising technique is subjecting the tool inserts to Cryogenic Treatment to alter the mechanical properties like hardness, strength and Wear resistance. Cryogenic treatment refers to process of exposing the metals to temperatures below -180^{0}c and soaking for a predetermined period and then allowing ascending back to room temperature at slow cooling rates. In the present work, uncoated Tungsten Carbide cutting tool inserts of geometry SNMG 120408-MR4 have been used. The inserts were cryogenically treated at -183 ^{0}C and were subjected to tempering in electric muffle furnace by placing on refractory brick at temperatures 250 ^{0}C and 300 ^{0}C for 120 minutes both followed by air cooling and furnace cooling. The samples showed appreciable improvement in hardness and microstructure study revealed that carbide phase distribution was fairly uniform with binder phase segregating slightly in few cases. Under all cutting velocities, Cryo-treated and tempered inserts showed the highest tool life and wear resistance. It was found that tempering has a significant influence on the phases present in WC+Co inserts and subsequently influences their machining performance. Cryogenic treatment significantly improved the mechanical properties of both the tested tool materials.

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Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

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Keywords: Cryogenic Treatment, Tempering, Carbide tool inserts:

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1. Introduction

Machining is a versatile technique of producing a wide variety of components from a wide range of materials with acceptable levels of dimensional accuracy and surface integrity. The advances in the field of Materials science and Technology have lead to development of new materials with improved engineering properties even for commonly used materials. Even the strength and hardness of a variety of conventional engineering materials has increased many fold to keep pace with development of new materials. Sintered carbides are extensively used as cutting tool material, a material in machining a wide variety of work materials in present day machining industry with proven machining abilities compared to HSS tool and Cast alloy. Cryogenic treatment is carried out at low temperatures to convert the retained austenite to martensite phase, thereby benefitting the improvements in tool life significantly. The cryogenically treated tool inserts become so hard that brittleness also creeps in.To reduce the brittleness by retaining hardness post treatment becomes necessary in terms of tempering. The tool inserts when subjected to low temperature tempering for predetermined time show the beneficial improvements. The process can be made more effective by subjecting the inserts to both air and furnace cooling. The combined effect of Cryogenic treatment and tempering would benefit the inserts by the removal of residual stresses and proper segregation of carbide particles that will increase the hardness significantly. Most of the research in this regard has been restricted steel and its alloys used as tool materials. Tungsten Carbide is on popular material of Sintered carbides, which are produced by powder metallurgy possess excellent properties in machining high strength alloys. Controlled Cryogenic treatment would greatly benefit carbide tool inserts by increasing the carbide population and its segregation. Microstructure analysis of treated and untreated inserts can reveal the above and co relate to property improvements. Phase identification with XRD would predict the prevailing phases responsible for the improvements tool life.

Nomenclature

τ	is the mean size of the ordered (crystalline)
K	is a dimensionless shape factor
λ	is the X-ray wavelength
β	is the line broadening at half the maximum intensity
θ	is the Bragg angle

2. Literature Survey:

Cryogenic treatment refers to the treatment of materials at very low temperatures generally around -183 ^{0}C which is much lower than cold treatment where temperatures are around -96 ^{0}C. The appreciable changes include the changes in the mechanical properties and in crystal structures of materials. However survey of literature shows that large part of the research work has been limited to cryogenic treatment on ferrous metals. Barron [3] performed abrasive wear tests on a wide variety of steel and concluded that metals which can exhibit retained austenite at room temperature can have the wear resistance significantly increased by subjecting them to cryogenic treatment. Collins [4] has explained in detail the process of austenite to martensite transformations and also explains how cryogenic treatment process can be used in combination with austeniting treatment to achieve either increase or decrease in hardness and increase or decrease in wear resistance for tool steels. Other related works show that both hardness and wear resistance of toll steels can improve simultaneously through cryogenic treatment. This was supported by Molinari

[5]. Mohanlal [6] who also justified the simultaneous improvement of hardness and wear resistance of tool steels upon cryogenic treatment. Microstructure analysis on cryogenically treated tool steels indicate that treatment has increased the carbide population and also distributed the carbides evenly throughout the structure, resulting in improved wear resistance. [7] C. Maranhao, J.Paul Davim predicted, in machining of AISI 316 steel, the frictional drag encounters in the tool rake (between the tool and the work piece). [8] Research efforts on the effects of cryogenic treatment on non-ferrous metals are few. Works by J. Indumathi et al [9] shows that cryogenic treatment has been improved to be an effective technique in enhancing abrasive wear performance of polymers and composites. And it was also concluded that Cryo-treatment is effective for the finished components. This led to the development of diamonds, ceramic, indexable inserts and coated tool materials. Research work on cryogenically treated [10] tool inserts exhibited better wear properties than untreated ones at low cutting speed and feeds.

3. Methodology

3.1 Cryogenic Treatment

In the present work, uncoated Tungsten Carbide cutting tool inserts of geometry SNMG 120408-MR4 have been used. The cryogenic treatment is as follows: 1.Descend: A gradual lowering of temperature from room temperature to -193 ^{0}C in 14 hours at rate of 0.26 ^{0}C/ min.2. Soak: holding the temperature at -193 ^{0}C for 24 hours. 3. Ascend: Subsequently raising the temperature back to room temperature in 18 hours at a rate of 0.203 ^{0}C/ min.

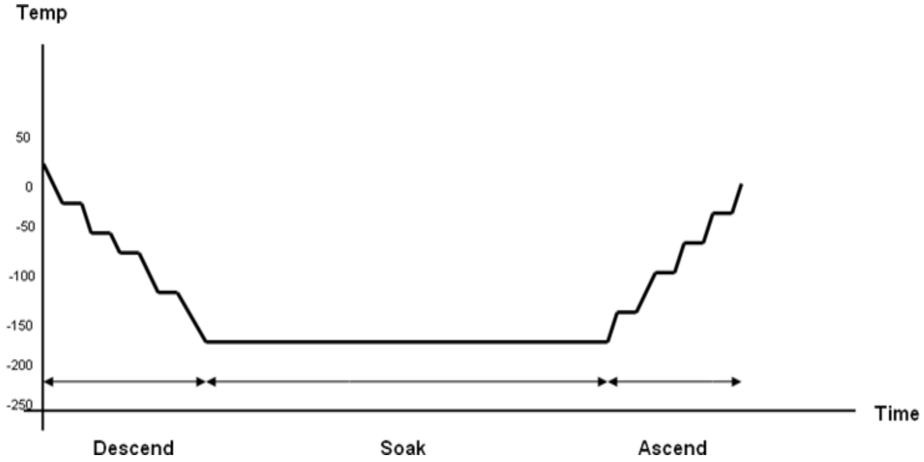

Fig.1 Schematic Representation of Cryogenic Treatment Cycle

3.2 Tempering: Tempering was done in Muffle furnace Cryo-treated samples for the following cases. 1. Tempering at 250 ^{0}C for 120 minute followed by air and Furnace cooling .2. Tempering at 300 ^{0}C for 120 minute followed by air and furnace cooling

3.3 XRD Test: XRD analysis was carried out under CuKa radiation of wavelength 1.5418 mm.

3.4 Micro-Hardness Test: 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 136^0 was used with a dwell time of 10 sec.

3.5 Micro-Structure Analysis: The micro-structures of both as received and treated inserts were studied under an Optical Microscope and Scanning Electron Microscope for analysing the η-phase distribution.

3.6 Machining & Tool Wear Measurement:

Based on the literature review and to realize the objective of the present work, the performance of the as-received, Cryo-treated and Cryo-treated and tempered uncoated WC-Co insert were studied in facing test of C45 steel bar.Face turning tests were carried out for two different cutting velocities 65.94 m/min and 103.62/min for C-45 steel under dry environment at a constant feed rate of 0.1 mm/rev and constant depth of cut of 1 mm for as received, Cryo-treated and Cryo treated and Tempered inserts. Based on the literature review and to realise the objectives of the present work, the performance of the as received uncoated WC-Co insert were studied in facing test on C-45 Steel bar. Face turning tests were carried out for two different cutting velocities 65.94 m/min and 103.62 m/min for C-45 Steel under dry environment at a constant feed rate of 0.1 mm/rev and constant depth of cut of 1 mm. Tool maker microscope used was Mitutoyo make with 1 micron accuracy. During tool life tests the inserts were with drawn 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.

4. Results & Discussions*5.*

4.1 Micro-Hardness Test: 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. As seen from table 2 the hardness of the inserts with post thermal treatments increased compared to the as received inserts. Upon Cryo-treatment, the hardness substantially increased from 1591 HV1 to 1695 HV1. Cryotreated samples show that the dispersion of carbides stabilized as the trial values are close to each other. With subsequent tempering hardness has increased. Cryotreated and tempered 300 ^{0}C samples show higher hardness. The highest hardness value can be observed for Cryotreated and tempered at 300 ^{0}C, furnace cooled. Improvement in hardness has take place because of segregation of carbide particles and densification of binder phase in the form of Cobalt. Also tempering process has stabilized the phases eliminating the residual gases resulting improved hardness. Furnace cooling induces better hardness compared air cooling when tempering is carried out at both 250 ^{0}C and 300 ^{0}C .Figures 2 (a) to (b) depict the results of XRD analysis carried out for the inserts that are subjected to different treatments. It can be seen that two phases prevail over the other CO-WC phases: the Eta phase Co_3W_3C and Kappa phase $Co_3W_{10}C_{3.4}$ 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, Cryotreated samples show improved stabilization of Kappa phase and there is around 6% increase in the hardness as supported by hardness values. (Table.1).Furnace cooled sample show better stabilized Kappa phase as supported by hardness values. (Table.1).

4.2 XRD Results

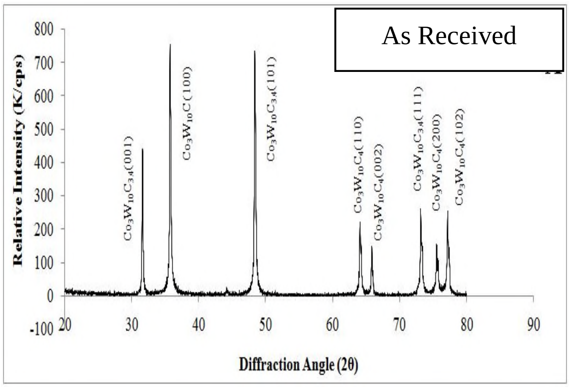

Fig. 2. (a) As received

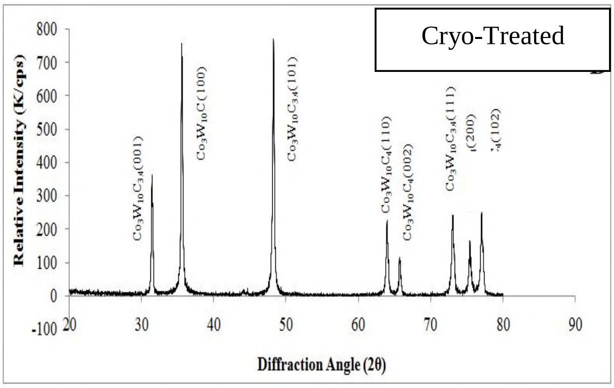

Fig. 2 (b) Cryotreated

XRD results obtained were studied and broadening of peaks was calculated for two prominent peaks. Average Crystal Size is calculated by Scherer Formula, The Scherer equation can be written as:

$$\tau = \frac{K\lambda}{\beta\cos\theta} \qquad (1)$$

Table 1. Hardness & Size of Particles

Sample	Average (HV1)	Change in Size of Crystallite (mm)
As received	1591.00	0.03205
Cryotreated	1695.67	0.06665
Cryotreated& tempered at 250 ^{0}C, air cooled	1651.67	0.02360
Cryotreated& tempered at 250 ^{0}C, furnace cooled	1671.76	0.09690
Cryotreated& tempered at 300 ^{0}C, air cooled	1783.46	0.09870
Cryotreated & tempered at 300 ^{0}C, furnace cooled	1859.43	0.09951

The calculated values are tabulated. Peak broadening is inversely proportional to size of particle. Increase in the size of particle is due to agglomeration (sticking of *particles* to one another) of two particles together, which shows that there is an increase in the bond strength due to cryogenic treatment at very low temperature**.** The size of particle in case of as received sample is 0.03025 µm which increases to 0.06665 µm after cryogenic temperature. When treated at low temperatures particles stick together increasing bond strength. The stabilization of carbide particles takes place and hardness is increased. Treated sample when tempered at 250 ^{0}C and air cooled, particle size decrease by 0.04305, air cooling does not induce required sticking force for particles and hence bonding strength does not increase, this will lead to reduced hardness as supported by hardness test. Cryotreated and tempered at 250 ^{0}C with furnace cooled samples show increases particle size better bonding strength and hardness compared to air cooling. Cryotreated sample when tempered at 300 ^{0}C and air cooled, particle size increase by 0.02105, air cooling induce required sticking force for particles and hence bonding strength does increase, and the increase in tempering temperature also causes increase in hardness as supported by hardness test. Cryotreated sample when tempered at 300 ^{0}C and furnace cooled, particle size increase by 0.097, furnace cooling induce required sticking force for particles and hence bonding strength increase, the increase in tempering temperature causes increase in hardness as supported by hardness test.

4.3 Microstructure Analysis: SEM Micrographs

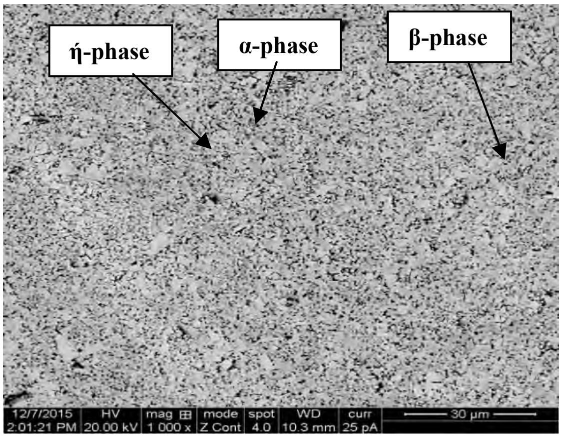

Fig. 3 As Received

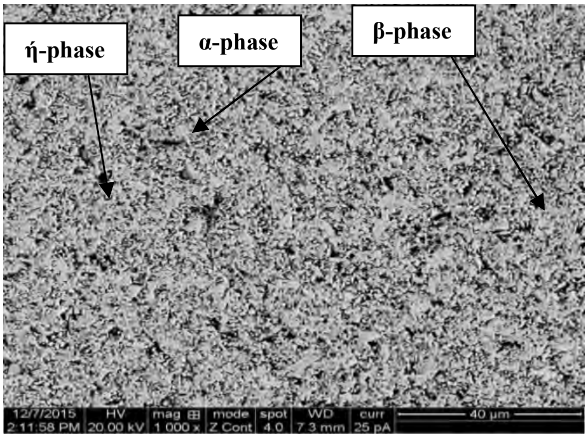

Fig. 4 CryoTreated

Fig. 3 and 4 show the microstructure of untreated insert and cryogenically treated inserts. In the microstructure shown following phases can be identified. The grey phase represent tungsten carbide (α-phase), white region specify cobalt binder (β- phase) and the comparatively dark field is (ή-phase). Compared to untreated samples, treated samples show better segregation of carbide particles. Treated samples show increased population of carbide phase which would have been the result of controlled cryogenic treatment. Uniform seggeregation of the particles is also the result of sufficient holding time during cryogenic treatment. This justifies the conversion of retained austenite to martensite and hence the hardness of material.

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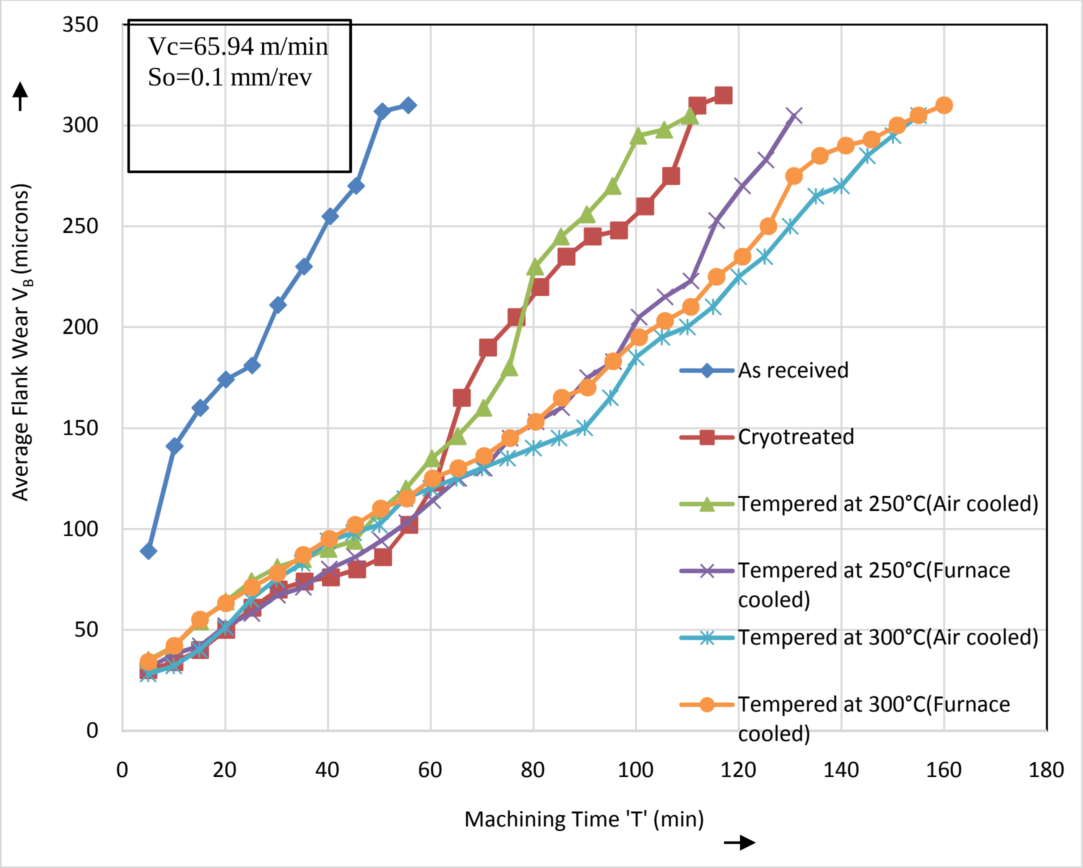

Fig. 5. Comparative Average flank wear Growth

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. Under all cutting velocities, Cryo-treated and tempered inserts provided the highest tool life followed by Cryo-treated tool inserts. Initially flank wear of both types of inserts is same but with consequent machining, cryogenically treated inserts showed less flank wear compared to untreated inserts. Also the tool life is reduced at high cutting spped. There was a gradual improvement in tool life observed in samples after treatment. The maximum tool life was shown by Cryo-treated and tempered and 300 ^{0}C followed by furnace cooling. Higher wear rate of untreated inserts during the machining can be attributed to coarse carbide structure.

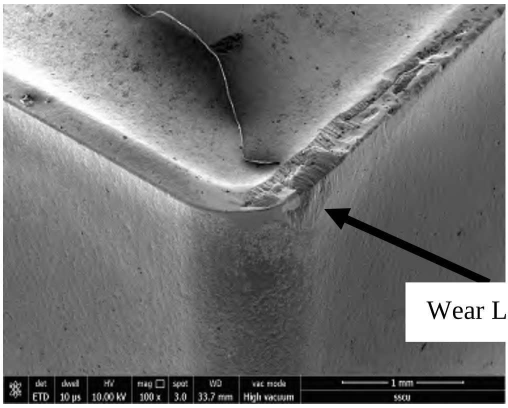

Fig.6. As Received Tool Insert

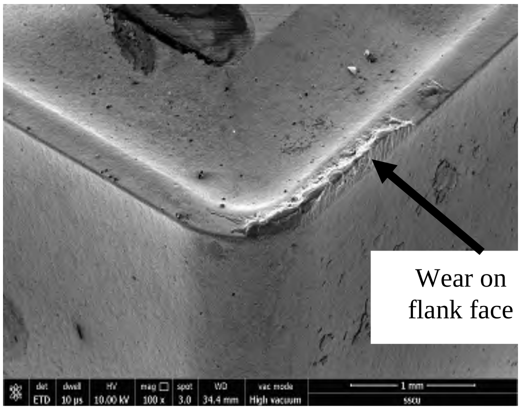

Fig.7 Cryogenically Treated Tool Insert

5. Conclusions:

1. Cryogenic Treatment of Tungsten Carbide tool inserts result in improved wear resistance.
2. Tempering as post treatment process has a significant influence on the phases present in tungsten carbide.
3. The observed wear patterns in treated samples show regular and well established trend.
4. Since Tungsten is hard material, the densification of binder Cobalt phase takes place improving tool life.
5. Treated samples show better and stabilized values of hardness.

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