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Comparative study of cryogenically treated tungsten carbide tool inserts with post treated of annealing & microwave irradiation

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Abstract:

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 led 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. But in machining of high strength temperature resistance alloys used in aerospace, marine and nuclear applications, they have failed miserably due to rapid wear. This has forced the machining Industry to bring in innovative changes in process design and application in terms of rigid machine tool and new cooling strategies. However, machining of these new classes of materials is still plagued by low productivity due to rapid wear. In the present work, uncoated Tungsten Carbide cutting tool inserts of geometry SNMG 120408-MR4 have been used. The inserts were cryogenically treated and were subjected to annealing in electric muffle furnace by pacing on refractory brick at temperatures 400^{o}C, 600^{o}C, and 800oC. 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 annealed inserts showed the highest tool life and wear resistance. Annealing has significant influence on the phases present in WC+Co inserts and subsequently influences their machining performance.

Keywords:

Machining, Cryogenic Treatment, Tungsten Carbide, Annealing

1. Introduction:

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 mechanical properties and in the crystal structure of materials. In last thirty years there has been increasing interests in the effects of cryogenic treatment on mechanical properties. Other related works show that both hardness and wear resistance of tool steels can be improved simultaneously through cryogenic treatment.

The present work proposes to study the performance of thermally treated W-CO cutting inserts in machining of difficult to machine alloys like Ti-6Al-4V and Inconel over a wide range of cutting velocity feed combinations.

Objective:

The objective of present work is to evaluate the performance of WC+Co uncoated cutting tool inserts in turning of C-45 steel under following conditions.

- As received
- Cryotreated
- Cryotreated and microwave irradiated
- Cryotreated and annealed

Performance evaluation is carried out by subjecting the inserts to machining (turning) conditions on constant speed Lathe at different feed rates, depth of cut and time intervals. Survey of literature shows that large part of the research work has been limited to cryogenic treatment on ferrous metals. Barron [1] performed abrasive wear tests on a wide variety of steels and concluded that metals which can exhibit retained austenite at room temperatures can have their wear resistance significantly increased by subjecting them to cryogenic treatment. Collins [2] has explained in detail the process of austenite to mortensite transformation and also explains how cryogenic treatment process can be used in combination with austeniting treatment to achieve either increase or decrease in hardness or an increase or decrease in wear in wear resistance for tool steels. Other related works show that both hardness and wear resistance of tool steels can be improved simultaneously through cryogenic treatment. The above detailed literature study has encouraged us to conduct detailed investigations on machining with cryogenically treated Carbide cutting tool inserts for the improvement in machinability This was supported by Molinari. A et al [3] and Mohan lal et al [4] who also justified the simultaneous improvement of hardness and wear resistance of tool steels upon Cryogenic treatment. Microstructure analysis on cryogenically treated tool steels indicates that treatment has increased the carbide population and also distributed the carbides evenly throughout the structure, resulting in improved wear resistance [5].

Works by T.V. Sreeramareddy et al [6] establishes that the flank wear of the cryogenically treated inserts is less compared to untreated inserts. The tool life of cryogenic treated inserts in case of C-45 steel was more compared to untreated inserts; also the surface finish of the cryogenically treated work piece was better when the work piece was machined compared to untreated inserts. That indicates that cryogenic treatment also improves machinability due to increase in thermal conductivity of tungsten carbide resulting in decrease in tool-tip temperature during turning operation.

Research efforts on the effects of cryogenic treatment on nonferrous metals are few. And it was also concluded that cryo-treatment is effective for the finished components. Due to developments in technologies the search for more competitive cutting tool material were sought, Which led to the development of diamonds, ceramics, indexable inserts and coated cutting tools. Research work on cryogenically treated [7] tool inserts exhibited better wear properties than untreated ones at low cutting speed and feeds. Research works on effects of cryogenic treatment on tungsten carbide has been done but is limited to uninterrupted cutting operation like turning operation. Studies by Seah et al.[8] has shown that cryogenic treatment improved the wear resistance and overall tool life of tungsten carbide tool inserts in turning. Recent works by A.Y.L.Yong et al [9] 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. Microstructure analysis [10] showed a distinct difference in the microstructure of Cryogenically treated and untreated inserts, especially the amount of distribution of ŋ-phase carbides which are thought to be the reasons for the induced transverse rupture strength, improved resistance to plastic deformation during cutting and lower toughness. However, machining of these new classes of materials is still plagued by low productivity due to rapid wear.

The above detailed literature study has encouraged us to conduct detailed investigations on machining with cryogenically treated Carbide cutting tool inserts for the improvement in mach inability

The present work aims at having beneficial improvements in properties of Carbide cutting tool inserts by following methodology.

2. Methodology:

The inserts are to be procured and sliced to required number of test pieces. Then theses inserts is to be subjected to Cryotreated, then annealed and microwave irradiated to reduce brittleness. Then theses inserts are used to machine C-45 steel and using Tool maker's Microscope wear is measured. Then hardness of treated and untreated inserts is measured. Based on the data collected Tool life and Wear resistance are to be analyzed.

2.1. The cryogenic treatment is as follows:

1. Descend: A gradual lowering of temperature from room temperature to -193^{0}C in 14 hours at the rate0 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 the rate of 0.203^{0}C/min.

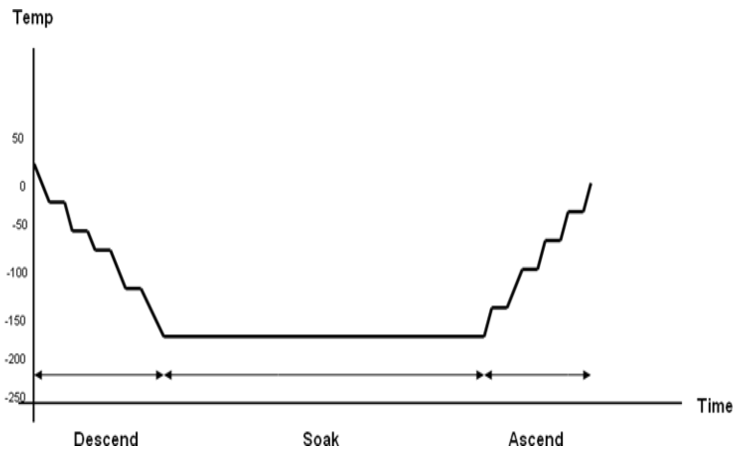

Figure. 1: Cryogenic treatment cycle (schematic)

2.2 Annealing:

The cryogenically treated inserts along with their samples were subjected to annealing in electric muffle furnace of specification given below. The inserts were placed on refractory brick, and then heated for 400^{o}C, 600^{o}C, 800^{o}C. The inserts were left to cool to room temperature inside the muffle furnace itself.

2.2.1. Electric Muffle Furnace Specification:

Dimensions: (450x450x600) mm

Muffle: (100x100x225) mm or 4x4x9 inch

Max working Temp: 1000^{o}C (<70 mins)

Temperature Control: (Direct ON/OFF) Automatic Controller with set point

Heating element: Kanthal-D

Thermocouple: Chromel-Allumel thermocouple K-type

Power rating: 2.2KW, V=230V

Temperature accuracy: + or – 5 to 8^{o}C (calibrated)

2.3. Micro-Hardness Test:

Hardness of the inserts were checked on a Micro Hardness Tester under a standard load of 1kg in accordance with ISO 1501-2002.

2.4. Micro-Structure of tool inserts:

The micro-structures of both as received and treated inserts were studied under a Optical Metallurgical Microscope. The detailed specimen preparation, polishing and etching procedure followed is given below.

2.4.1. Specimen Preparation, Polishing and Etching:

2.4.2. Sectioning:

The square insets are sectioned into 4 parts, thin pieces of 2mm thickness each, using Wire EDM machine.

2.4.3. Polishing:

After mounting, the specimens are ground flat and polished in holders appropriate for the automatic machine being used. The holders typically accept 4 to 8 samples. The initial grinding is done using a 220-grit resin bonded diamond lap. Scratches and work hardened regions must be removed with finer abrasives until the desired surface finish obtained.

Final grinding is done in a two-step process: First with a 600-grit diamond lap and next with a 6 µm diamond lap. All grinding are performed at 300 rpm, using copious amount of water for coarse grinding and an alcohol-based lubricant for fine grinding. Coarse polishing performed using a cloth with 6 µm diamond for 2 to 4 min. Polishing is continued with 3µm diamond media for 2 to 3 min.

Final polishing step involves 1µm diamond lap for 1 min. The coarse and fine polishing is performed at 150 rpm using an alcohol based lubricant. The surface should be cleaned between steps with an alcohol rinse, because the cobalt at the surface is chemically active during polishing and will be electrolytic ally attacked by tap water.

2.4.4. Etching:

To find out the microstructure of η-phase of WC-Co, Murakami's reagent: 10g of potassium hydroxide (KOH), 10g of potassium ferric cyanide ($k_3Fe\ (CN)_6$) and 100ml of distilled water.

2.5. Tool wear measurement:

Based on the literature review and to realise the objective of the present work, the performance of the cryotreated coated WC-Co insert were studied in face turning of C45 steel bar of dimension ø mm.

Face Turning tests were carried out for three different cutting velocities of (35-131), (55-228) and (88-365)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 1.5 mm for as received, cryo-treated and cryo-treated + annealed.

During tool life tests the inserts were withdrawn after each continuous cut and were studied under tool maker's microscope of least count 1µm for the wear pattern and average width of the flank wear.

3. Results and Discussions:

3.1. Results:

In keeping with objectives of the present investigation, experiments and metallurgical evaluation of the commercially available cutting tool inserts were carried out as mentioned above. Micro hardness of the tool inserts under various condition are listed in table.1. Figs 1&2 depict the micro structure of tool inserts under various conditions.

The performance of the said cutting tool inserts under actual machining conditions are recorded shown in the tables below. The graphs shown below Depict the growth of flank wear with respect to machining time.

3.2. Discussions:

3.2.1. Hardness:

As seen from table.1 the hardness of the inserts with post thermal treatments increased compared to the as received inserts. Upon cryo-treatment, the hardness substantially increased from 1389 HV1 to 1533 HV1. With subsequent annealing, the hardness slightly increased at 400°C and 800°C of annealing. However, at 600°C of annealing there was hardly any difference between cryo treated and annealed inserts. This needs to be investigated further.

Table.1 Parameters for micro-hardness

Work material	C45 Steel
Cutting tool inserts	Uncoated Tungsten Carbide
Cutting Velocities	35-131, 55-228 and 88-365 m/min
Feed	0.1 mm/rev
Depth of cut	1.5 mm
Machining Environment	Dry

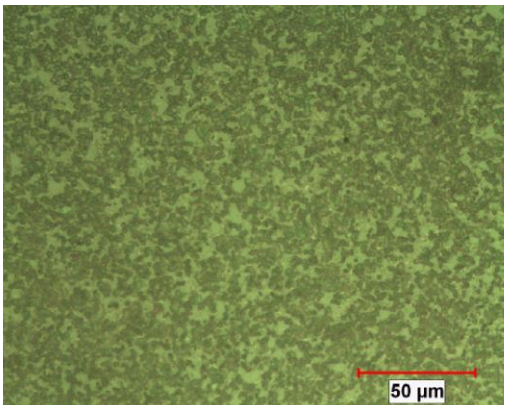

Figure. 2: As-received and cryotreated

3.2.2. Microstructure:

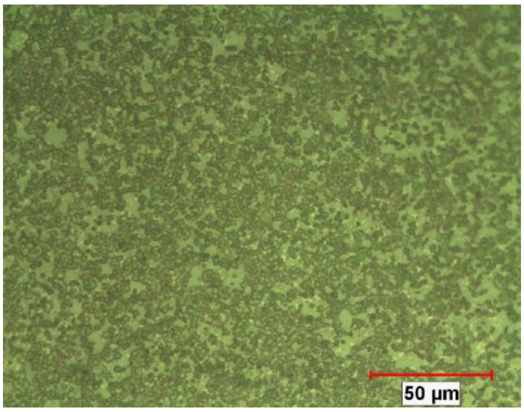

Figure. 3: Growth of average flank wear for cryo-treated tool inserts for different time intervals and for cutting velocity 35-131 m/min

In the microstructures depicted in figs 2 to 3, the dark regions represent the carbide phase and the white regions represent the binder phase. It can be seen in all the cases, the carbide phase distribution is fairly uniform with binder phase segregating slightly in few cases.

It is clearly observed from the experiment that in all the machining trials the growth of the flank wear more or less showed the established pattern. Under all cutting velocities, cryo-treated and annealed inserts showed the highest tool life followed by cryo-treated tool inserts. Also, as-received inserts showed the lowest tool life under all cutting velocities.

On the other hand it is also observed that the tool life of cutting tool inserts decreases on increase in the cutting velocity. The above list of tables and graphs clearly indicate the above mentioned conclusion.

Table. 2: Experimental conditions of C-45 steel

Time (min)	**V_B (microns)**
1.54	98
3.08	125
4.62	162
6.16	191
7.70	209
9.24	226
10.78	240
12.32	234
13.86	245
15.40	262
16.94	269
18.48	318

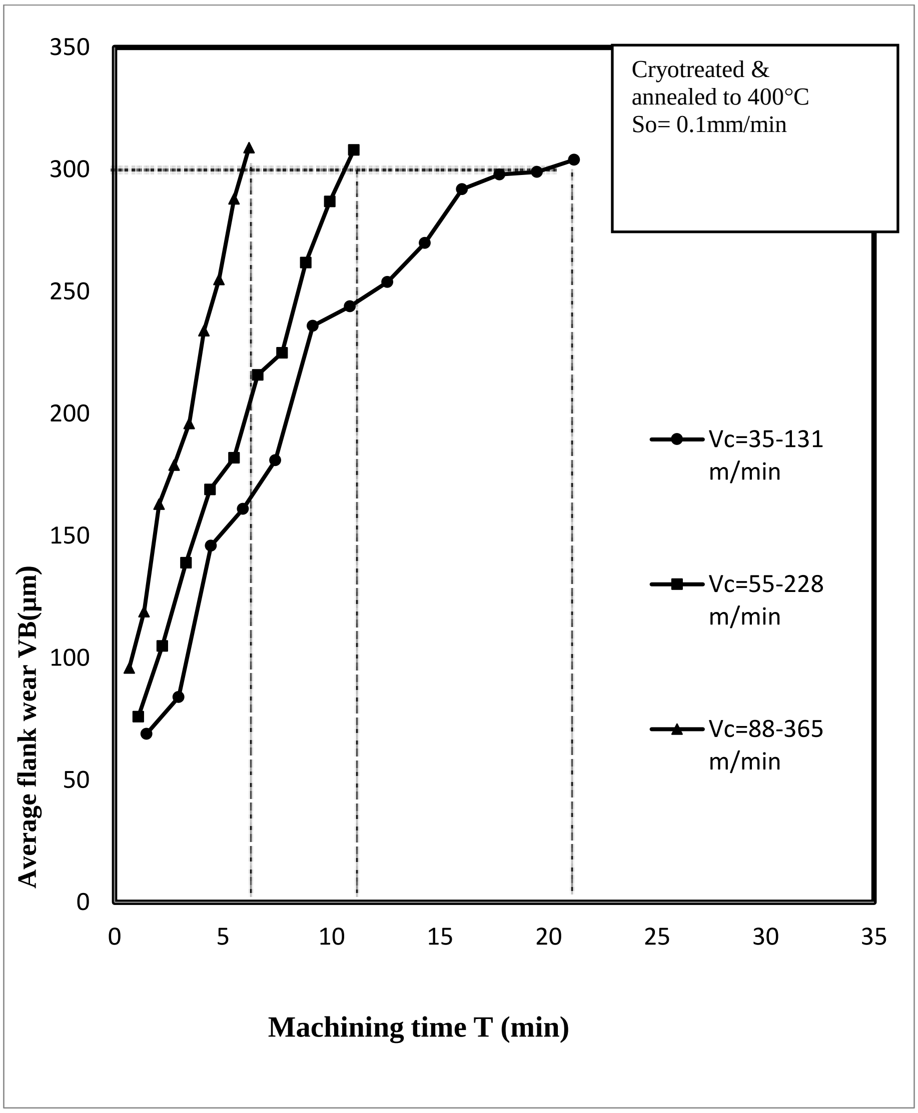

Figure.4: Graph showing variation of machine time according to average flank wear

Table. 3: Tool sample with hardness value

Tool sample	**Hardness Value**
As Received	1389 HV1
As Received and Cryogenically Treated	1533 HV1
Cryogenically Treated and Microwave Irradiated for 9 min	1571 HV1
Cryogenically Treated and Microwave Irradiated for 11 min	1531 HV1
Cryogenically Treated and Microwave Irradiated for 13 min	1580 HV1

4. Conclusion:

The following conclusions can be drawn based on the present investigations.

- Annealed WC+Co inserts performed better than as received inserts.
- Cryogenically treated inserts appears to be more beneficial than as received tool inserts.
- Tool wear resistance of cryogenically treated and annealed inserts have been proved to have higher resistance to tool wear than as-received and cryogenically treated inserts.

Present investigation clearly indicates that annealed has significant influence on the phases present in WC+Co inserts and subsequently influences their machining performance. Hence there is an ample scope for studying the effect of different times of annealing on carbide cutting tool inserts on their machining performance.

5. References:

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