

Investigation of the Effect of Cryogenic Treatment on Micro-Structure, Hardness and Tool-life of Carbide Insert

Manan Vasavada¹, Akshay Thakkar², Nihal Chauhan¹

Student, Department of Mechanical Engineering, L.J.I.E.T, Gujarat Technological University, Gujarat, India¹

Assistant Professor, Department of Mechanical Engineering, L.J.I.E.T, Gujarat Technological University, Gujarat, India²

ABSTRACT: Cryogenic treatment has been widely conceded as a means of improving tool life. This paper focuses on comparative investigation of conventionally used and cryogenic treated Tungsten carbide insert. Carbide insert initially kept at room temperature are subjected to deep cryogenic treatment at -196°C for 12 hours to 24 hours. Optical metallographic microscope is used to study the presence of η -carbides in the material. Improvement in η -carbide precipitation leads to reduction in crack propagation through the material and increases overall hardness of the material. The experimental investigation is performed on vertical milling machine to compare the metallurgical characteristics and performance of cryogenically treated and untreated carbide inserts. The study explicated significant enhancement in hardness and tool-life of cryogenic treated carbide insert.

KEYWORDS: Cryogenics Treatment, Carbide Insert, Stainless Steel, Tool-life, Microstructure

I. INTRODUCTION

Carbide inserts are small removable pieces of cemented carbide used for machining hard materials such as steels, high temperature alloys and nonferrous materials. The carbide inserts are available in a range of specifications, having different strengths, applications and limitations. The carbide insert is selected based on various machining parameters such as speed, feed, depth of cut, cooling system, work piece material, etc. The carbide insert selected should neither be too hard, as it would foster the comparatively soft work piece material to adhere to its surface causing crater wear; nor too soft, causing extensive flank wear which would reduce the tool-life and increase cost of machining; considering downtime cost, cost of tool-inserts, and cost due to delays.

Cryogenic treatment is a supplementary process to conventional heat treatment. It involves deep freezing of materials at very low temperature to enhance mechanical and physical properties. Cryogenic treatment or sub-zero treatment had been widely used for high precision parts. It can be classified into two: (1) Shallow Cryogenic treatment, utilizing temperature in tune of -72°C , and; (2) Deep Cryogenic treatment, with temperature around -196°C . Deep cryogenic treatment has shown greater impact on the properties of material than shallow cryogenic treatment.

As the material development takes place in manufacturing sector, advanced tool materials needs to be developed to machine them. We need tool material harder than that of workpiece to effectively machine them.

II. LITERATURE SURVEY

Enhancements made by cryogenic technology have been observed since long by many researchers. [1] Kraret *al* (2008) found that tungsten carbide tools can machine metals at speeds that cause the cutting edge to become red hot, without losing its hardness or sharpness. It exhibits about 2–3 times the productivity and 10 times the life of high-speed steel tools on machining non-ferrous materials. [2] T. V. Sreerama Reddy *et al* (2009) observed that the tool life of deep

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cryogenic treated coated cemented tungsten carbide inserts is larger by a factor of 1.27 compared to untreated inserts. [3] Nursel Altan Ozbek et al (2014) studied the effect of cryogenic treatment on various types of wear occurring on tool material, showing considerable improvements in flank wear, notch wear and crater wear, with notch wear being affected the most. He also analysed the effect of holding time, the time for which the carbide inserts are kept at cryogenic temperatures, finding the 24 hour period more enhancing than a 12 hour period. [4] A. Y. L. Yong et al (2007) studied the performance of cryogenically treated tools in milling operation, which concluded with better machining performance with cryogenic treated material. The study also showed that cryogenically treated tools performed better in wet machining compared to dry machining. [5] Sandeep Gandotra et al (2011) in his investigation of wear behaviour of coated and uncoated carbide inserts subjected to sub-zero temperature, found that cryogenic treatment improves tool-life upto 50 percent. Their experiment also suggested minimal difference in results with shallow and deep cryogenic treatment under light machining conditions. [6] Thakur et al (2008) in their SEM analysis of tungsten carbide cobalt micrographs concluded that the cobalt densification which occurred due to cryogenic treatment held the carbide particles more firmly resulting in increased wear-resistance in the inserts. [7] Gisip et al (2009) also confirmed the same and concluded that cobalt binder was retained better and exhibited a minimum high-temperature oxidation or corrosion deterioration. [8] Bryson (1999) attributed the wear-resistance, and hence the increase in tool life, of carbide tools to the improvement in the holding strength of the cobalt binder after cryogenic treatment. [9] Nirmal Khalsi et al (2009) observed the improvement in wear resistance after cryogenic treatment due to densification of Cobalt, which binds the carbide particles firmly. [10] Gulyaev A. P. (1937), in his research, observed that when the tool was treated by temperatures in range of -80°C to -100°C for periods of about 30 min to 1 hour, the retained austenite transformed into martensite which improved the tool life and made the structure more stable. The experiment proved that adding alloying elements lowers the temperature of the beginning of martensite transformation and final transformation temperature to sub-zero temperature range. [11] Popandopulo et al (1980) performed microstructure analysis on the tool during the cryogenic treatment and observed reduction of volume of the tool for temperature range of -90°C to 20°C . The reason behind this kind of behaviour is partial decomposition of martensite and precipitation of carbon atoms at dislocation lines and formation of ultramicroscopic carbides. Also the experiment concluded with improved cutting ability of the material and increased tool-life. [12] A. Molinari et al (2001), observed improvement in the properties of quenched and tempered high speed steel tools upon implementing Deep Cryogenic Treatment (-196°C) to the steel. It improved the hardness, homogeneity of material hardness and reduced the tool consumption and down time for setting up the equipment which helped in reducing the production cost by 50%. [13] D. Mohan Lal et al (2001) studied the effect of cryogenic treatment on the wear resistance of the tools and compared it with the tools subjected to conventional heat treatment by carrying out flank wear test and sliding wear test. The cryogenically treated untempered samples reflect 3%, 10% and 10.6% extra life compared to the cryogenically treated tempered samples of T1, M2 and D3, respectively. Cryogenic treatment of tempered samples at 133 K for a time period of 24 hours showed negative results but deep cryogenic treatment at 93K for 24 hours manifested effective results. The team concluded with improved stabilization of phases of steel and better wear resistance by utilizing sufficient degree of under-cooling for appropriate time. Cryogenic treatment tends to improve surface finish, wear resistance, hardness and grain structure of the material. Cryogenic processing can be performed on a wide variety of materials including metals, alloys, polymers, carbides, ceramics and composites, and even on herbs for medical applications.

III. CRYOGENIC TREATMENT

Cryogenic setup as shown in Figure 1 consists of three components which are cryogenic chamber, Nitrogen tank and temperature controller. The components to be cryogenically treated are kept in the air-tight chamber at room temperature. The liquid nitrogen from the tank is passed to the cryogenic chamber through pipes which gets converted into gaseous state before reaching the chamber. The nitrogen absorbs heat from the chamber gradually reducing the temperature to -196°C and gets back to the tank via compressing and cooling stations. The nitrogen returns to the tank in liquid state. The circulating fan is kept inside the chamber to homogenise the temperature and to increase the heat transfer rate. The components are kept for a period ranging from 12 to 24 hours depending upon the geometry and size. Then the temperature is steadily raised to room temperature. The temperature controller monitors the temperature of the chamber and regulates the flow of liquid nitrogen to maintain the temperature gradient constant throughout the process.

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The temperature gradient is kept at 0.5°C/min as higher temperature change rates can lead to cracking in the components.

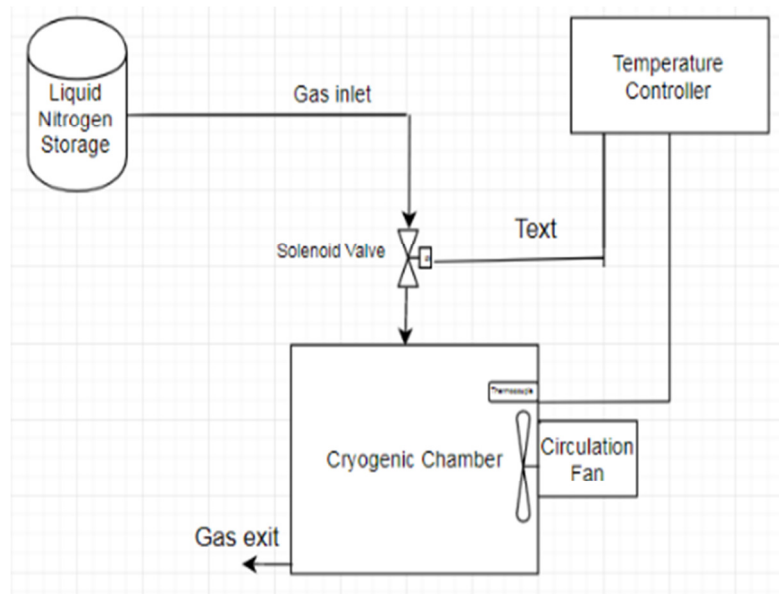


Figure 1: Schematics of the Cryogenic treatment setup

The cryogenic treatment increases the hardness of the material drastically, making it brittle. To acquire the desired physical properties the cryogenically treated component are annealed at 150°C. Annealing reduces hardness and enhances toughness, making it durable. Figure 2 shows graphical representation of time-temperature relation of the cryogenic treatment cycle.

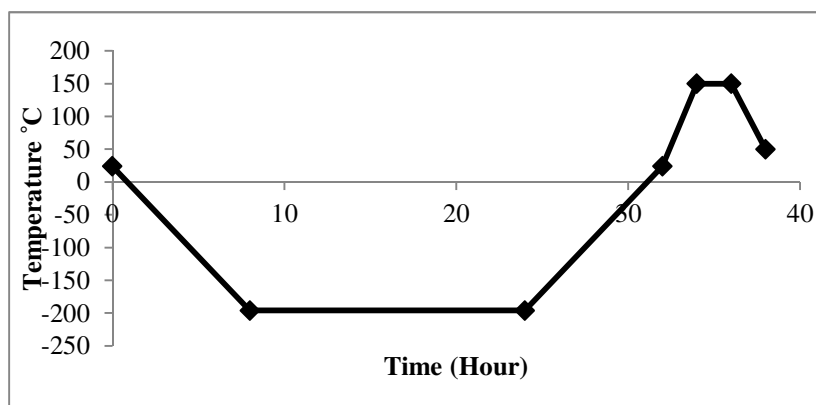


Figure 2: Time versus Temperature graph for cryogenic treatment cycle

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IV. EXPERIMENTAL PROCEDURE

The experiment is conducted as an effort to find out the effect of cryogenic treatment on the micro-structure, hardness and machining capability of the carbide inserts.

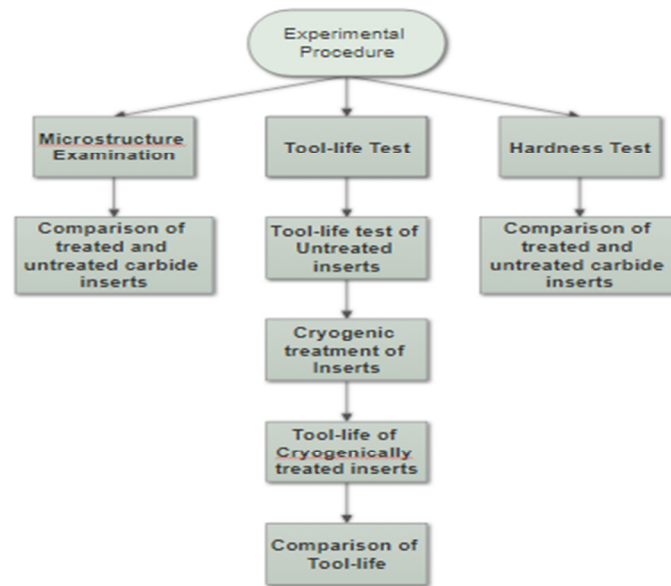


Figure 3: Schematics of the experiment

The experimental investigation is divided into three different sections as shown in Figure 3, one for each examination. Micro-structure examination is conducted on untreated and treated carbide inserts to understand the effect of cryogenic treatment on the material of the inserts.

Another set of untreated and treated carbide inserts is sent for hardness testing by ASTM E-407 method of testing. The Brinell hardness results will be tabulated in the results section.

The task for examining difference in machining capabilities is to manufacture the turbine blades from SS-310 forgings on a Vertical Milling Machine. A set of carbide inserts is subjected to particular machining conditions with predefined parameters such as machining cycle time, speed and feed, depth of cut and rpm. The tool-life of the inserts is recorded from the experiment. Then another set of carbide inserts is treated with cryogenic treatment before the trial. The cryogenically treated carbide inserts are subjected to identical machining conditions and tool-life is recorded for comparison. Details of the parameters kept identical for the experiment are listed in Table 1.

Table 1: Experimental data

Parameter	Data
Insert Description	JDMT070208R JM4060
No. of Inserts per Flute	3
No. of Corners per insert	2
Speed (RPM)	3500
Feed (mm/min)	2200
Depth of cut (mm)	0.3
Coolant method	Dry
Cycle time per tool (min)	100

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The results from Microstructure, hardness and tool-life examinations are compiled in Results and discussion section of the paper.

V. RESULTS AND DISCUSSION

1. Microstructure

The results shown by the microstructure examination performed on both the sets of inserts showed noticeable difference in the images. The cryogenically treated material as seen in Figure 6 had fine grain structure with reduced grain size compared to coarse and large grain structure observed in Figure 4 of untreated material. In Figure 7, the microstructure also showed significant increase in presence of η -carbides in case of cryogenically treated material compared to untreated material in Figure 5. The η -carbide precipitation was uniform with fine grain structure, which led to more compact packing of material. Due to large number of η -carbides present in the treated material, the crack propagation reduces and strength against fracture increases.

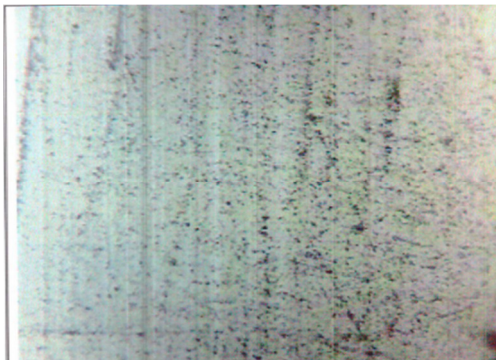


Figure 4: Untreated material at 100x magnification

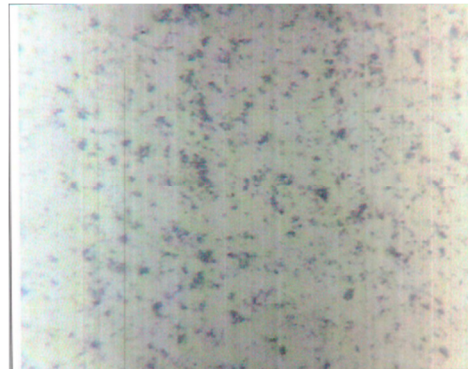


Figure 5: Untreated material at 500x magnification

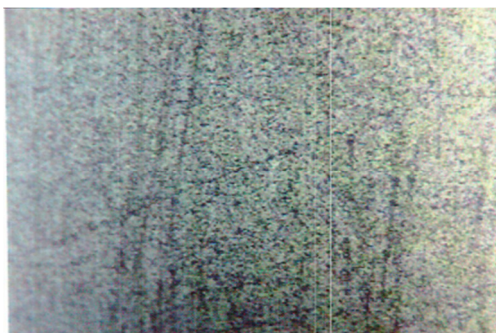


Figure 6: Treated material at 100x magnification

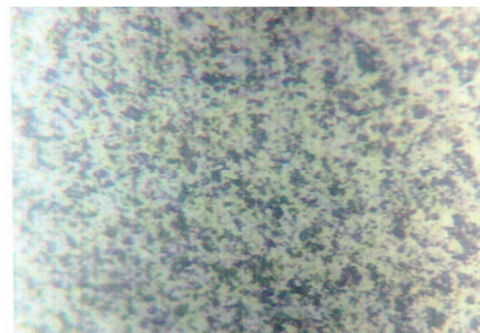


Figure 7: Treated material at 500x magnification

2. Hardness

The Brinell hardness test performed on untreated and cryogenically treated material by ASTM A 370 (14) method showed the results as tabulated in Table 2.

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Table 2: Hardness test data

Sample	Hardness (HRC)
Untreated carbide insert	41, 42, 42
Treated carbide insert	61, 62, 62

Percentage increment in hardness = $(61.66 - 41.66) / 41.66 = 48 \%$

3. Tool-life

The tool-life measured for treated and untreated carbide inserts is recorded in Table 3. The improvement in the tool-life of cryogenically treated carbide insert can be attributed to improved microstructure and hardness of the cryogenically treated material.

Table 3: Tool-life data of the experiment

Parameters	Untreated carbide insert	Treated carbide insert
Machining cycle time (Min)	100	100
Tool-life(No. of blades machined)	1	1.5
Tool-life (Min)	100	150

Percentage increment in Tool-life = $(150 - 100) / 100 = 50 \%$

VI. CONCLUSION

Cryogenic treatment led to a series of improvements in the material of carbide inserts. It changed the material to fine grain structure along with reduction in grain size. The precipitation of η -carbide increased and homogenized throughout the material. Improvement in η -carbide precipitation lead to reduction in crack propagation through the material and increased overall hardness of the material by 48%. The cryogenic treatment of Tungsten carbide led to improvement in microstructure, increment in hardness of the material and improved the tool-life of the inserts. The treatment led to a significant increment of 50% in the tool-life of the Tungsten Carbide inserts.

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