Effect of Deep Cryogenic Treatment on Hardness and Microstructure of Cemented Carbide Insert

Prashant M. Jondhale

Abstract—The cutting tool is an most important part used in machining industries for the production of finished products. In previous days at the start of twentinth century the life of cutting tools is increased by conventional heating process of decarburizing, annealing, aging, quenching and tempering.Todays industries are facing challenges of accomplishing high quality of final products with dimensional accuracy, surface finish and higher production rate to sustain in a very compatetive market. This leads to use of tools of newely developed material with higher mechanical properties, so it is therefore necessary to check their sustainability with continuous machining resulting higher process temperature. Nowadays cemented carbide which is a combination of tungsten carbide (WC) and cobalt (Co) is commonly used in every machining industry due to advanced properties. Many researchers have tried to improve the properties of cemented carbide insert by coating process via CVD and PVD coating. This paper deals with improvement in mechanical properties and related microstructral changes in tool by subjecting it to sub zero treatment known as cryogenic treatment. From the results it can be concluded that the hardness of cemented carbide insert is improved due to conversion of retained austenite into martensite and refinement of grain size which is responsible for improvement in wear resistance.

Index Terms— Cryogenic Treatment, Hardness, cemented Carbide, Microstructure, soaking period, Grain Size, Tool Life.

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1 INTRODUCTION

Machining is a process of metal cutting in which unnecessary material is removed from raw material to get desired size and shape by controlled material removing process. Machining process includes operations like turning and milling which have most of the percentage compared to other operations. With the development customer needs products with improved properties. This focuses industries to use of tools with greater properties which lead to improvement in existing tools. Today every machining industry used tools made of cemented carbide material which have greater mechanical properties even at high temperature. But with continuos machining after attainment of higher process temperature cemented carbide inserts wear out rapidly. Although the problem of wearing is some what reduced by instead of finding new material by application of coating over substrate with material having high hardness and better wear resistance properties.

In general two types of coating are preferred by the company's namely chemical vapour deposition (CVD) and Physical Vapour deposition (PVD). In chemical vapour deposition the substrate material is coated with three different materials having individual role. In general coating is made from Al_2O_3, TiN, TiCN, TiAlN which all have better machining properties. For the coating tools were ionized through high electrical currents are applied via vapour deposition. In CVD process the first layer of coating is made of TiCN (titanium carbo-nitide) which provides excellent resistance to wear and facsiliates better easy bonding with substrate material. The second layer of coating is made from Al_2O_3 (aluminium oxide) which gives chemical stability and high heat resistance. The third layer is made from TiN (titanium nitride) provides good surface properties. The coatings are made from few microns to 20 microns. The physical vapour deposition process uses two techniques namely thermal evaporation and sputtering. In thermal evaporation a solid material that is used to caot the substrate material is heated in a higvaccum chamber until is starts to boil and evaporates thereby producing high vapour pressure. In the sputtering process the target material which is used for coating is charged by electric current causing it to bombarded with ionized gas molecules in a vaccum environment causing the atoms to be sputtered off into the plasma. These vapourized atoms are then deposited on the substrate to be coated where they are condensed. The coating thickness of PVD process is less as compared to CVD process.

Sandhi carried out a comparative study on conventional heat treated S7 and M1 specimens by subjecting them to shallow cryogenic treatment at -84°C for 3 to 8 hours and deep cryogenic treatment at -196°C for 24 hours. The noticeable changes in the microstructure are observed by radical metallurgical microscope conataining grain size refinement of carbides providing more grain boundries obstructing dislocation and uniform distribution throughout the microstructure. They also concluded that hardness and toughness values of cryogenically treated specimens increased drastically when compared with conventional treated specimen.[1]

Herold applied cryogenic treatment to C2 tungsten carbide insert containing 6% cobalt at -306°F. Experimental observation and tool force data shows that tool wear is reduced as compared to untreated insert while turning tests with medium density fiberboard (MDF). The microstructural observatons shows that phase change occurred in cobalt binder and uniform distribution throughout the structure thereby strenghthening the insert.[2]

Thakur attempted to improve mechanical properties tungsten carbide insert with 93% WC and remaining is Co with minor element. They subjected inserts to deep cryogenic treatment at -196°C for 24 hours also other two inserts were heated upto 750°C in argon-oxygen rich environment to avoid oxidation then air cooling by forced convection and quenching in oil bath respectively. The microhardness of cryogenic treatment, air cooled and oil quenched insert is significantly improved when compared with non treated insert due to formation of complex carbides such as W2CCo6W6C and W2cCo3W3C. The SEM study of cryo-treated insert revealed that densification of cobalt firmly holds tungsten carbide particle thereby improving wear resistsance. The formation of η carbides at carbide-cobalt interface of CT insert and complex compound formed in case of air cooled and oil quenched insert improves surface hardness.[3]

Reddy performed deep cryogenic treatment on P-30 turning inserts at -176° and measured performance while machining of C45 workpiece in terms of flank wear, cutting force, surface finish of workpiece. The results shows that increased thermal conductivity of tungsten carbide improves machinability of insert due to decreased tool tip interface temperature during turning operation.[4]

Vedivel subjected CNMG 120408MT TT1300 coated carbide inserts to deep cryogenic treatment at -196°C for 10 to 60 hours followed by tempering at 400°C and slow cooling to bring back them to room temperature. The results show that for depth of cut 0.8mm at turning velocity of 200, 250, 300m/min sourface roughness of workpiece is improved as compared to non treated inserts.Further increment in depth of cut shows less improvement comparing to improvement for 0.8mm. The observational data of power consumption shows low power required for cryogenic treated when compared to non treated inserts at the same time flank wear reduced substantially. The presence of η carbides in the microstructure after deep cryogenic treatment is responsible for improved hardness and wear resistance.[5]

2 CRYOGENIC CYCLE

In general cryogenic process ranging from -80°C to -140°C is known as shallow cryogenic treatment (SCT) and cryogenic process ranging from -140°C to -273°C is known as deep cryogenic treatment (DCT). In the present study the CCMT 120412 MT turning inserts were subjected to deep cryogenic treatment at -269.5°C for 10hr., 14hr. and 18hr. of soaking period. The inserts were cooled from room temperature to cryogenic temperature at a controlled rate of 1°C/min as faster cooling rate leads to nonstationary defect (microcracking) in crystal structure due to thermal shocking.The different soaking period is important for stabilization of carbides in the crystal structure to convert retained austenite remained during sintering into martensite. After soaking period the inserts were brought back to room temperature at controlled rate of 1°C. The controlled heating rate during warm up also allows time for settlement/stabilization of carbide insideinside the microstructure.

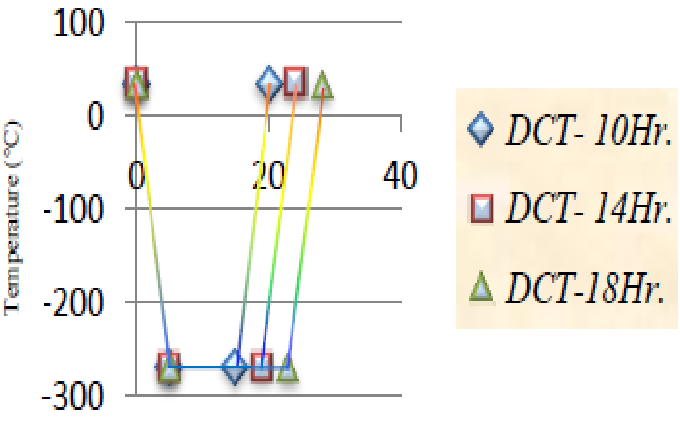

Fig. 1 Cryogenic Cycle

The above figure presents detailes about deep cryogenic cycle of cemented carbide inserts. It consist of three different parameters 1) Ramp Down, 2) Soaking Period and 3) Ramp Up.

1) Ramp Down: In cryogenic process the temperature of specimens is decresed from room temperature to cryogenic temperature this process is known as ramp down. Ramp down is a most critical parameter to control as sudden cooling/dipping results in the formation of cracks within the microstructure. The controlled rate of cooling gives time for easy changes in microstructure. Many researchers have stated that controlled rate of cooling between the ranges of 1°C to 2°C gives best results.

2) Soaking Period: The soaking period of cryogenic treatment is longer as compare to case hardening which employed to increase the surface hardness of the outer surface. The soaking period depends upon the type of material and part size. Longer soaking period is essential necessary to when uniform properties are required within whole structure.

3) Ramp Up: In ramp up process the specimen from cryogenic temperature is heated upto room temperature at a controlled rate. Past research work reveals that all the microstructural changes are made during soaking period but some of the changes were also possible during heating up process. The controlled rate of heating adds up time for changes to be occurring.

4) Cryogenic Temperature: The most critical parameter of cryogenic cycle is selection of cryogenic temperature. As the shallow cryogenic treatment improves the toughness and hardness but conversion rate of retained austenite to martensite is less whereas in case in deep cryogenic treatment inproves toughness and hardness more than that of shallow cryogenic treatment but it converts all the retained austenite into martensite.

- *Prashant M. Jondhale currently pursuing masters degree program in mechanical (Design) engineering in Amrutvahini College of Engineering, Sangamner, India, Mo. 7709121441. E-mail: pjautoindia@gmail.com*

3 METHODOLOGY

3.1 Material Sample

The tool/ insert selected in this study isCCMT 1204 MT insert used for turning of cast iron material. The insert is 80° rhombic in shape with 7° clearance angle having positive rake angle. The insert has 12.70mm inscribed circle diameter, 4.76mm thickness and 1.20mm corner radius with internal hole for fixing.

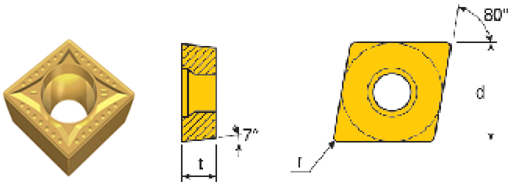

Fig. 2CCMT 120412 MT Cemented Carbide Insert

The insert is CVD coated with TiCN (titanium carbonitride) and Al_2O_3 (aluminium oxide).

3.2 Chemical Composition

The chemical compostion of insert is done by positive material identification ASTM 1476:2004:Re20124 method to know the elements present in the material. The details of chemical composition are tabulated in following table.

Table 1 Chemical Composition of CCMT 120412 Insert

Element	Percentage (%)
Tungsten (W)	34.99
Iron (Fe)	0.45
Titanium (Ti)	63.36
Cobalt (Co)	1.19

4 Results

4.1 Hardness

The hardness values (Vickers Hardness) of un-treated (UT) and cryogenic treated inserts for different soaking period are presented in the following table. It shows that, upon cryotreatment the hardness value of un-treated insert is slightly more than that of cryotreated insert with 10hr soaking period while hardness value is substantially increased from 2221.33HV to 2255.67HV for 14hr and 2280.67HV for 18hr soaking period. From the result table it can be concluded that there is slight/ small increase in hardness value for higher soaking period. This needs to be investigated further.

Table 2Hardness value of non-treated and deep cryotreated inserts

Type of Sample	Hardness at Different Location (HV)			Average Hardness (HV)
Untreated	2230	2168	2216	2221.33
DCT-10Hr	2197	2188	2235	2206.67
DCT-14Hr	2212	2274	2281	2255.67
DCT-18Hr	2252	2281	2309	2280.67

4.2 Microstructure Study

The first step in microstructure study is that preparation of specimen. The insert is firstly sectioned in two parts by wire EDM process to avoid altering of structure by heating during cutting. After sectioning the insert is mounted in epoxy material for easy handling during grinding and polishing. The insert is grinded to fascilitate easy polishing which is done by series of fine polish papers. Finally the insert is dipped in appropriate solution for easy microstructural detection. The microstructural observation is made under optical microscope. The microstructure images of untreated and deep cryogenic treated inserts are shown in figure below.

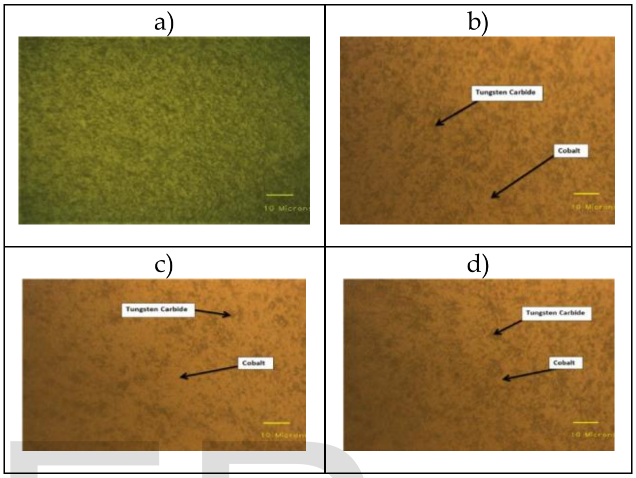

Fig. 3Microstructure images of a)untreated, b)DCT-Hr, c)DCT-14Hr and d) DCT-18Hr

The dark region shows the carbide phase while white region shows the binder phase. From the microstructural images it can be evident that, the binder phase of cryogenically treated inserts is uniformly distributed with binder phase than non-treated inserts. This uniform distribution of binder phase leads to improvement in the toughness which plays an important role from the perspective of wear reduction.

4.3Grain Size

The particle size of all the inserts is measured to check whether there is any effect of cryogenic treatment on grain size. The table below shows the effect on grain size of insert for different cycle time.

Table 3 Grain size of inserts

Type of Sample	Particle Size
Untreated	2.5
DCT-10Hr	1.4
DCT-14Hr	1.8
DCT-18Hr	2.1

5 CONCLUSIONS

Based on the experimental study and result value;

1) Hardness of cryogenic treated inserts for different cycle time is increased as compared to untreated inserts.
2) It is evident from that the cobalt is uniformly distributed throughout the structure.
3) The grain size of cryogenic treated inserts is decreased as compared to untreated inserts which allows more grain

boundries which help to avoid dislocations during machining at high temperature.

REFERENCES

[1] D.A. Sandhi, R. Davis, A. Masih, R.D. Hemrom, A. Samual and N.V. Chand J, "A Comparative Study of the effect of Thermal Treatments on the Mechanical Behavior of Tool Steels," *International Journal of Current Engineering and Technology*,vol. 4, no. 3, pp. 1643-1648, 2014.

[2] A.S. Herold "Cryogenic Treatment og Tungsten Carbide Reduces Tool Wear when machining Medium Density Fiberhood,"*Forest Product Journal*, vol. 54, no. 2, pp. 53-56, 2004.

[3] D. Thakur, B. Ramamoorthy and L. Vijayaraghavan, "Influence of Different Post Treatmentys on Tungsten Carbide- Cobalt Inserts," *J. Material Letters*,vol. 6,no. 28, pp. 4403-4406, 2008.

[4] T.V. Serama Reddy, T. Sornakumar Reddy, M. Venkatrama Reddy, R. Venkatram and A. Senthilkumar, "Turning Studies of Deep Cryogenic Treated p-40 Tungsten Carbide cutting Tool Inserts," *Technica Communication Machining Science and Technology*, vol. 13, no. 2, pp. 269-281, 2009.

[5] K. Vadivel and R. Rudramoorthy, "Performance Analysis of Cryogenically Treated Coated Carbide Inserts," *International Journal of Advance Manufacturing Technology*, vol. 42, pp. 222-232, 2009.