

## **Optimisation Of Wear Resistant High Speed Endmill For Machining 316L Stainless Steel**

<sup>1</sup>R. Karthikeyan, <sup>2</sup>Dr.S.Sathiyamurthy,

<sup>1</sup>P.G. Student, M.E.(CAD), Sri Ramanujar Engineering College, Chennai-127, (Tamilnadu)

<sup>2</sup>Professor, Sri Ramanujar Engineering College, Chennai-127, (Tamilnadu)

---

**ABSTRACT-** In this project work, the influence of cryogenic treatment on HSS endmill tool could be studied, followed by performance evaluation in milling of mild steels using untreated and cryo treated carbide endmills. Microstructural characterisation and Phase particles could be studied with the help of Optical Microscopy and Scanning electron microscopy (SEM). Chemical composition of the untreated and cryo- treated inserts can be determined. Micro hardness of the same specimens would be evaluated using Vickers micro hardness. The milling tests were conducted at three different spindle speeds while feed rate and depth of cut were kept constant. The influences of cryogenic treatment were investigated on the average flank wear and chip characteristics. Both the worn parts of the cutting tools as well as the chips were also examined using Scanning Electron Microscope.

---

**KEYWORDS** - 316 L Stainless Steel, Cryogenic, HSS Endmill, SEM.

---

### **I. INTRODUCTION**

More than hundred years have passed since the development of the first cutting-tool material, carbon steel, suitable for use in metal cutting. Since then cutting tool materials have been undergoing continuous evaluation. Today a great variety of cutting tool materials is available which can satisfy the ever changing demands in terms of the life of the tool, the rate of metal removal or productivity, surface quality, cost effectiveness and the capability to provide satisfactory performance in diverse applications. With the advent of newer materials with strategic engineering applications and poor machinability it is becoming increasingly essential to find newer cutting tool material or modification of existing cutting tool material to suit to a specific requirement. Over the years various cooling methods have been adopted for extending the tool life. Some of the technique involves conventional flat cooling, jet cooling, mixed cooling, high pressure jet cooling etc. Recently cryogenic cooling in machining was also found significant interest in research. Alternating to enhance tool life is application of suitable coating materials on the surface of the cutting tools (PVD and CVD) was widely used technique for tool coating. Some of the famously used tool coating used TiC, TiCN, TiN, Al<sub>2</sub>O<sub>3</sub>, TiAlN, ZrN etc. This coating in general posses high wear resistance, hot hardness, chemical in hardness, and antifriction properties that help the cutting tool to be operated under hostile cutting condition. Cryogenic treatment of cutting tools is the newest addition to the existing techniques for improving the cutting tool performance.

### **1.1. BACKGROUND**

Metal cutting process forms the basis of the engineering industry and is involved either directly or indirectly in the manufacture of nearly every product of our modern civilization. The cutting tool is one of the important elements in realizing the full potential out of any metal cutting operation. Over the years the demands of economic competition have motivated a lot of research in the field of metal cutting leading to the evolution of new tool materials of remarkable performance and vast potential for an impressive increase in productivity. Changes in work piece materials, manufacturing processes and even government regulations catalyze parallel advances in metal cutting tooling technology.

As manufacturers continually seek and apply new manufacturing materials that are lighter and stronger and therefore more fuel efficient it follows that cutting tools must be so developed that can machine new materials at the highest possible productivity. The most important elements in the design of cutting tools is the material construction and there judicious selection. The properties that a tool material must process are as follows:

- Capacity to retain form stability at elevated temperatures during high cutting speeds.
- Cost and ease of fabrication
- High resistance to brittle fracture
- Resistance to diffusion
- Resistance to thermal and mechanical shock

Developmental activities in the area of cutting tool materials are guided by the knowledge of the extreme conditions of stress and temperature produced at the tool-work piece interface. Tool wear occurs by one or more complex mechanisms which includes abrasive wear, chipping at the cutting edge, thermal cracking etc. Since most of these processes are greatly accelerated by increased temperatures, the more obvious requirements for tool materials are improvements in physical, mechanical and chemical properties at elevated temperature.

## **1.2. TECHNOLOGICAL DEVELOPMENT**

Tool materials have improved rapidly during the last sixty years and in many instances, the development of new tool materials has necessitated a change in the design trend of machine tools to make full use of the potentialities of tool materials for high productivity. Progress from carbon tool steels, high speed steels and cast alloys to carbides and ceramics has facilitated the application of higher speeds at each stage of development. With the advent of carbides and ceramics radical changes have taken place in the design of tool holders and cutters and the concept of the throw away tipped tool where the insert is held mechanically and is discarded after use represents a major advance in the metal removing technology of modern times.

## **1.3. SURFACE TREATMENTS**

Advances in manufacturing technologies (increased cutting speeds, dry machining, etc.) triggered the fast commercial growth of various surface treatments for cutting tools; on the other hand these surface coating technologies enabled these advances in manufacturing technologies. No single treatment will solve every problem and their use should be restricted to those operations where extra expense of the treatment can be justified by a substantial performance gain.

The processes of surface treatments more formally surface engineering tailor the surfaces of engineering materials to:

- Control friction and wear
- Improve corrosion resistance
- Change physical property
- Vary appearance
- Reduce cost

Ultimately the functions on service lines of the materials can be improved.

Common surface treatments can be divided into two major categories:

- a) Treatments that cover surfaces
- b) Treatments that alter surfaces

Treatments covering surfaces:

- Organic coatings such as paints, cements, laminates, fused powders, lubricants, or floor toppings on the surfaces of materials
- Inorganic coating such as electroplating, autocatalytic platings (electroless platings), conversion coatings, thermal sprayings, hot dippings, furnace fusing, or coat thin films on the surfaces of the materials (PVD and CVD)
- Treatments altering surfaces:
- High energy treatments such as ion implantation, laser glazing/fusion, and electron beam treatment.
- Diffusion treatments include boronizing, and other high temperature reaction processes, e.g., TiC, VC.
- Hardenings such as flame, induction, laser or electron beam
- Heavy diffusion treatments include carburizing, nitriding, and carbonitriding
- Special treatments such as cryogenic, magnetic and sonic treatment

## **1.4 CRYOGENIC TREATMENT**

The use of thermal treatments to improve mechanical properties of metal components is an ancient art expanded down the ages until today. Many of the developed processes apply treatments in a range of temperature higher than room temperature. The first attempts to perform subzero treatments were investigated at the beginning of the 20th century, but the actual interest on cryogenic treatment (or cryotreatment, CT) was developed during the last years of the century. The basic CT consists in a gradual cooling of the component until the defined temperature, holding it for a given time (freezing time) and then progressively leading it back to the room temperature. The aim is to obtain an improvement of mechanical properties, typically hardness and wear resistance, but in recent tests fatigue limit too, and to achieve an optimal ratio between conflicting properties, like hardness and toughness. The research about CT has been validated by the first results on machinery tools, which have shown remarkably enhancement in hardness and durability. From the Nineties, the interest in CT effects has also been applied to many different components: i.e. motor racing parts, in particular gears and bearings, oil drills, gun barrels, knives, surgical and dental instruments and even brass musical instruments, piano and guitar strings (Dean Markley BlueSteel), baseball bats and golf clubs too. Nowadays, many

companies offer CT services, especially in the USA and in Canada, and in some cases if no improvement in component life has been obtained they promise a refund. Even though the mechanism behind improvement has not been totally clarified, different hypotheses coherently with microstructural observations have been suggested in literature.

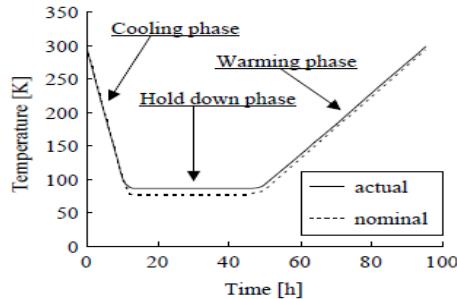


Figure. 1.5.1 DCT temperature profile

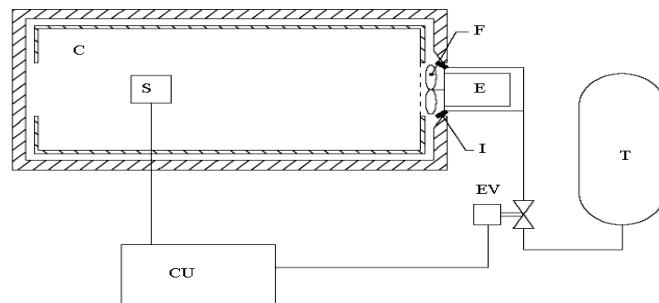


Figure.1.6.1 Layout of a direct nebulization cryogenic system

## II. EXPERIMENTAL WORK

### 2.1. CUTTING TOOLS

#### 2.1.1. High speed steel

High speed steels owe their name to the fact that they were originally developed for high speed metal cutting. The properties of high resistance to wear and heat high initial hardness of about 60 to 65 RC at service temperature of 600 to 650 °C and the economical price of HSS have made them a logical choice of many cutting industries. This finds applications as turning tools, twist end mills, counter bores, taps and dies, reamers, broaches, milling cutters, hobs, saws, etc. The perfect combination of alloying elements and the domain of heat treatment processes confers excellent hardness and wear resistance properties allied to good toughness. The HSS end mill tool samples considered in this work are M2 steels procured from Addison (ISO – 9002 company) with dimensions 12.70 x 152.40 mm.

### 2.2 CRYOGENICS

Cryogenics is defined as the branches of physics and engineering that study very low temperatures, how to produce them, and how materials behave at those temperatures. Rather than the familiar temperature scales of Fahrenheit and Celsius, cryogenicists use the Kelvin and Rankine scales. The word cryogenics literally means "the production of icy cold"; however the term is used today as a synonym for the low-temperature state. It is not well-defined at what point on the temperature scale refrigeration ends and cryogenics begins. The workers at the National Institute of Standards and Technology at Boulder, Colorado have chosen to consider the field of cryogenics as that involving temperatures below -180 °C (93.15 K). This is a logical dividing line, since the normal boiling points of the so-called permanent gases (such as helium, hydrogen, neon, nitrogen, oxygen, and normal air) lie below -180 °C while the Freon refrigerants, hydrogen sulphide, and other common refrigerants have boiling points above -180 °C. Cryogenic temperatures are achieved either by the rapid evaporation of volatile liquids or by the expansion of gases confined initially at pressures of 150 to 200 atmospheres. The expansion may be simple, that is, through a valve to a region of lower pressure, or it may occur in the cylinder of a reciprocating engine, with the gas driving the piston of the engine. The second method is more efficient but is also more difficult to apply. Cryogenic treatment is a one-time permanent treatment

process and it affects the entire cross-section of the material usually done at the end of conventional heat treatment process but before tempering. Also it is not a substitute process but rather a supplement to conventional heat treatment process. It is believed to improve wear resistance as well the surface hardness and thermal stability of various materials. This treatment is done to make sure there is no retained austenite during quenching. When steel is at the hardening temperature, there is a solid solution of Carbon and Iron, known as Austenite. The amount of martensite formed at quenching is a function of the lowest temperature encountered. At any given temperature of quenching there is a certain amount of martensite and the balance is untransformed austenite. This untransformed austenite is very brittle and can cause loss of strength or hardness, dimensional instability, or cracking. Quenches are usually done to room temperature. Most medium carbon steels and low alloy steels undergo transformation to 100 % martensite at room temperature. However, high carbon and high alloy steels have retained Austenite at room temperature. To eliminate retained Austenite, the temperature has to be lowered. Liquefied gases, such as liquid nitrogen and liquid helium, are used in many cryogenic applications. Liquid nitrogen is the most commonly used element in cryogenics and is legally purchasable around the world. Liquid helium is also commonly used and allows for the lowest attainable temperatures to be reached. These gases are held in either special containers known as Dewar flasks, which are generally about six feet tall (1.8 m) and three feet (91.5 cm) in diameter, or giant tanks in larger commercial operations. Cryogenic transfer pumps are the pumps used on LNG piers to transfer Liquefied Natural Gas from LNG Carriers to LNG storage tanks.

### **2.2.1 The Making of Liquid Nitrogen**

A common method for production of liquid nitrogen is the liquefaction of air. Liquefaction is the phase change of a substance from the gaseous phase to the liquid phase. In the liquid nitrogen compressors or generators, air is compressed, expanded and cooled via the Joule-Thompson's effect. Since nitrogen boils at a different temperature than oxygen, the nitrogen can be distilled out of the liquid air, recompressed and reliquefied. Once liquid nitrogen is removed from the distillation chamber it is stored in a pressurized tank or a well insulated dewar flask. Liquid nitrogen is converted to a gas before it enters the chamber so that at no time does liquid nitrogen come in to contact with the parts assuring that the dangers of cracking from too rapid cooling are eliminated.

### **2.2.2 Cryogenic Treatment Procedure**

The liquid nitrogen as generated from the nitrogen plant is stored in storage vessels. With help of transfer lines, it is directed to a closed vacuum evacuated chamber called cryogenic freezer through a nozzle. The supply of liquid nitrogen into the cryo-freezer is operated with the help of solenoid valves. Inside the chamber gradual cooling occurs at a rate of 2° C /min from the room temperature to a temperature of -196° C. Once the sub-zero temperature is reached, specimens are transferred to the nitrogen chamber or soaking chamber where they are stored for 24 hours with continuous supply of liquid nitrogen. The entire process is schematically shown in Figure. 2.2.2.1.



Figure. 2.2.2.1 Photograph of the cryogenic treatment set up



Figure. 4.2.2.2 Untreated & Cryo-Treated HSS Endmill

### III. RESULTS AND DISCUSSION

#### 3.1 FLANK WEAR TEST

The end mills M2 grade HSS tools as well as cemented carbide tool were subjected to milling operation in HMT NL26 Mill according to the machining specifications given in Table 3.1.

**Table 3.1 Machining Specifications for milling HSS and Cemented carbide end mills**

SPECIFICATIONS	HSS
Cutting Velocity (m/min.)	50
Depth of Cut (cm)	0.6
Feed (mm/rev)	0.05
Cutting Condition	Dry
Work piece materials	316L SS

Results of Flank wear test for both cryogenically treated and untreated HSS samples are shown in Table 2 and Table 3 respectively.

**Table 3.2 Results of flank wear test of untreated HSS end mill**

S. No	Time (min)	Flank wear (mm)
1	10	0.265
2	20	0.290
3	30	0.310
4	40	0.335
5	50	0.395
6	60	0.425

**Table 3.3 Results of flank wear test of cryo treated HSS end mill**

S. No	Time (min)	Flank wear (mm)
1	10	0.150
2	20	0.180
3	30	0.195
4	40	0.235
5	50	0.290
6	60	0.360

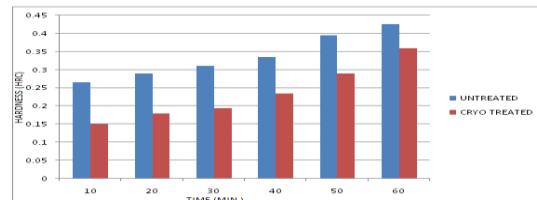


Figure 3.1.1 Hardness Comparison For Untreated And Cryo-Treated  
From the graph it was observed that cryogenically treated HSS tools showed slightly higher value of tool life.



Figure 5.1.2. Machined Work Piece

The superior performance of cryogenically treated HSS can be attributed to the transformation of almost all retained austenite into martensite, a harder structure and precipitation of fine and hard carbides.

### **3.2 HARDNESS TEST**

Table 3.6 shows the hardness of both cryogenically treated and untreated HSS samples. They are practically the same thus indicating that the cryogenic treatments had slight influence on this property of this tools.

**Table 3.4 Results of Hardness for HSS end mill**

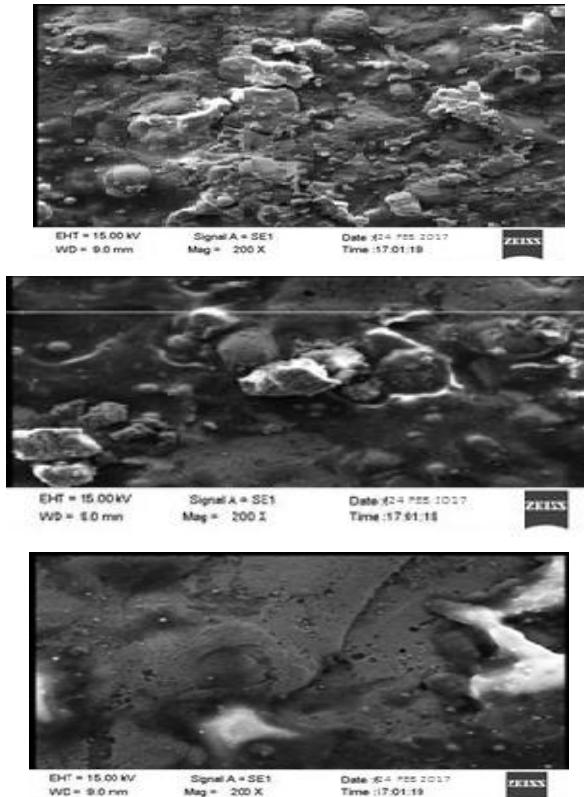
UNTREATED	CRYO TREATED
66HV5/20	72HV5/20
67HV10/20	73HV10/20
68HV15/20	75HV15/20
70HV20/20	76HV20/20

Even the micro hardness results also did not show conspicuous difference between the treated and untreated tools. The precipitation of fine carbides during the cryogenic treatment cycle may affect the wear resistance and the tool toughness but only a small, if any in tool hardness. It was observed that initially the hardness falls sharply at the cryogenic cycle and when the tool is heated to the room temperature the hardness is totally recovered.

### **3.3 METALLOGRAPHIC EXAMINATION**

#### **3.3.1 SEM analysis**

SEM was carried for both cryogenically treated and untreated HSS samples to study the microstructural changes. Results of the SEM analysis are shown in Figureure. 9 and Figureure. 10 for cryogenically treated and untreated HSS & Carbide samples respectively. The results showed the presence of the fine precipitated carbide particles in case of cryogenically treated samples which verify that the refinement of carbides takes place after the cryogenic treatment.



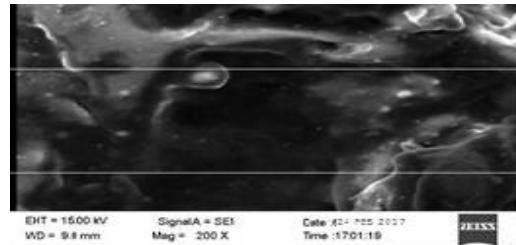


Figure 3.1.3. SEM Images of HSS Treated and Untreated End mill

#### IV. CONCLUSIONS

1. The tool life is increased by 19% for HSS end mill end mill for machining 316L stainless steel after the cryogenic treatment.
2. In this flank wear test the wear of cryogenically treated tools is less as compared to that of untreated tools.
3. From SEM analysis, it is evident that refinement of carbides is more in case of cryogenically treated HSS tools in comparison to that of untreated tools.
4. There is not much difference in hardness between cryogenically treated and untreated High Speed Steel end mills.

#### REFERENCES

- [1] Dong, Lin , Xiao, "Deep cryogenic treatment of high-speed steel and its mechanism". Heat Treatment of Metals. Volume .No. 3, (1998): pp. 55–59
- [2] Popandopulo, Zhukova, "Transformations in High Speed steels during cold treatment Volume No. 10 (2000) pp. 9-11
- [3] Paulin, Frozen gears, Gear Technol. (1993), pp. 26–28.Huang, Zhu, Liao, Beyerlein, M.A. Bourke and T.E. Mitchell, Microstructure of cryogenic treated M2 tool steel, Material Sci. Eng.( 2003): pp. 241–244.
- [4] Yun, Xiaoping , Hongshen, "Deep cryogenic treatment of high-speed steel and its mechanism". Heat Treat. Met. (2008): pp. 55–59.
- [5] Molinari, Pellizzari, Gialanella, Straffelini, Stiasny, "Effect of deep cryogenic treatment on the mechanical properties of tool steels", J. Mater. Process. Technol. Volume No. 118 (2011): pp. 350–355.
- [6] Seah, Rahman, Yong, "Performance evaluation of cryogenically treated tungsten carbide cutting tool inserts". Journal of Engineering Manufacture .Volume No. 1, (2003): pp. 29–43.
- [7] Ku H. and Paulin, P., March 1993. Frozen gears. In: Gear Technology.Dolinsek K. Smolnikov, E.A., Tkachenko, V.I., 1980. How cold treatment in liquid nitrogen affects cutting tool life. Machine Tooling 51 (6), 22–24.
- [8] FritzKlocke, Speich, G.R., 1985. Ferrous martensitic structures. ASM Handbook, vol. 9, pp. 668–672.
- [9] Viktor J., Liu, H.-h., Wang, J., Shen, B.-l., Yang, H.-s., Gao, S.-j., Huang, S.-j. 2005. Effects of deep cryogenic treatment on property of 3Cr13Mo1V1.5 high chromium cast iron. Materials and Design 28 (3), 1059–1064.
- [10] Chockalingam A., Madesh N. and Narun E. 2006. Effect of cryogenic treatment on property of 14Cr2Mn2V high chromium cast iron subjected to sub critical treatment. Journal of Iron and Steel Research 13 (6), 43–48.
- [11] Narasimha B. and Diekman, F. J. "Cryogenics – The Racer's Edge", Heat Treating Progress, pp. 43-50, November 2001.
- [12] Prasad P. and Trzaskoma, The Vests of silicon carbide whiskers on the initiation and propagation of pits on silicon carbide/aluminum metal matrix composites, in: Tenth International Congress on Metallic Corrosion, Madras, India, November 1987, vol. V, Trans. Tech. Publications, 1989, pp. 231–239.
- [13] Khairi Yusu, D.M. Aylor, P.J. Moran, J. Electrochem. Soc. 132 (6) (1985) 1277.Sonawane Gaurav L., J.F. McIntyre, A.H. Le, S.L. Colledge, R.K. Conrad, Corrosion behavior of SiC reinforced aluminum alloys, United States Naval Surface Warfare Centre, Report No. NSWC-TR-87-326, 1987.
- [14] Kadam F., J.F. McIntyre, P.K. Conrad, S.L. Colledge, Technical note: the eVect of heat treatment on the pitting behaviour of SiCw/AA2124, Corrosion 46 (11) (1990) 902.
- [15] Nagendran M., Vinay B. and Rajesh S. Deep cryogenic treatment of high-speed steel and its mechanism, IJER, Vol.2, Issue 3, pp.333-339.
- [16] Veselina Dimitrova, M.D. Skibo, StiVness and Strength of SiC-Al Composites, Sandia National Laboratories, Livermore, CA, 1981.
- [17] Vikas Verma N., Raju siva and Ganpathy Rao, Optimisation of tool body performance of HSS steel, IJSERS, Vol. 3, pp-251-257.