# EFFECT OF CRYOGENIC TREATMENT OF CEMENTED CARBIDE INSERTS ON PROPERTIES & PERFORMANCE EVALUATION IN MACHINING OF STAINLESS STEEL

Thesis Submitted in Partial Fulfillment
of the Requirements for the Award of

**Master of Technology**
**In**
**Production Engineering**

By

**Biranchi Narayan Sahoo**
**Roll No: 209ME2204**

**Department of Mechanical Engineering**
**National Institute of Technology**
**Rourkela**
**2011**

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Under the Guidance of

**Prof. S.Gangopadhyay**

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Successful completion of work will never be one man's task. It requires hard work in right direction. There are many who have helped to make my experience as a student a rewarding one.

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**Biranchi Narayan Sahoo**

**Roll No.209 ME 2204**

**Dept. of Mechanical Engg**

***National Institute Of Technology, Rourkela***

***CERTIFICATE***

This is to certify that the thesis entitled, **“Effect of Cryogenic Treatment of Cemented Carbide Inserts on Properties & Performance Evaluation in Machining of Stainless Steel”** submitted by **Mr. Biranchi Narayan Sahoo** in partial fulfillment of requirements for the award of Degree of Master of Technology in **Mechanical Engineering** with specialization in **“Production Engineering”** at National Institute of Technology, Rourkela is an authentic work carried out by him under my guidance and supervision. To the best of my knowledge the matter embodied in the thesis has not been submitted to any other University or Institute for the award of any Degree or Diploma.

Date: 03-06-2011

Dr. **S. Gangopadhyay**
Assistant Professor,
Department of Mechanical Engineering,
National Institute of Technology
Rourkela- 769008

**ABSTRACT**

In this research work, the influence of cryogenic treatment on different characteristics of ISO P30 grade cemented carbide insert was studied, followed by performance evaluation in dry turning of AISI 316 grade austenitic stainless steels using untreated and cryo treated carbide inserts. Microstructural characterisation and crystallographic orientation were studied with the help of scanning electron microscopy (SEM) and X-ray diffraction (XRD) respectively. Chemical composition of the untreated and cryo treated inserts were determined using energy dispersive spectroscopy (EDS) through X-ray. Microhardness of the same specimens were evaluated using Vickers microhardness. The results indicated that cryo treatment resulted in formation of hard and wear resistant $\eta$ phase carbides. At the same time, the concentration of binder phase i.e. cobalt on the top surface region increased. The turning tests were conducted at three different cutting speeds (100, 150, and 200 m/min.) while feed rate and depth of cut were kept constant at 0.2 mm/rev and 1 mm, respectively. 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 optical microscopy and SEM. The results showed that cryogenic treatment significantly improved the average flank wear. The cryo treated demonstrated superior resistance to tool wear compared to its untreated counterpart in the entire range of cutting speeds. The chip thickness along with chip reduction coeffiecient was found to decrease for cryo treated insert compared to those for untreated insert during dry turning of AISI 316 grade austenitic stainless steel.

Keywords: Cryogenic treatment, cemented carbide, microstructure, dry turning, tool wear, chip characteristics.

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# CHAPTER 1

# Introduction

# 1. INTRODUCTION

More than hundred years have passed since the development of the first cutting-tool material, carbon steel, suitable for use in metal cutting (Smith, 1989). Since then cutting tool materials have been undergoing continuous evaluation. Today a great variety of cutting tool materials are 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. Some of the basic as well as widely used cutting tool materials have been discussed below.

## 1.1 Different Cutting Tool Materials

### 1.1.1 High speed steel

High speed steel (HSS) is a high carbon ferrous alloy consisting of W, Mo, Cr, V, and Co. HSS is generally available in cast, wrought and sintered (obtained by using powder metallurgy technique) form. HSS is inexpensive compared to other tool materials. It is easily shaped, and has excellent fracture toughness, and fatigue resistance. HSS is suitable for use only at limited cutting velocities of 30-50 m/min because of its limited wear resistance and chemical stability. HSS is generally used for geometrically complex rotary cutting tools such as drills, reamers, taps, and end-mills, as well as for broaches. HSS are broadly classified as T-type steels which have tungsten as the dominant alloying element, and M-type steels in which the primary alloying element is molybdenum. M-types are more widely used for rotary tooling, especially drills, milling cutters, and taps.

### 1.1.2 Cemented carbide

Cemented carbide is a modern cutting tool material manufactured by mixing, compacting and sintering primarily tungsten carbide (WC) and cobalt (Co) powders. Co acts as a binder for the hard WC grains. The carbide tools have strong metallic characteristics having good electrical and thermal conductivity. They are chemically more stable, have high stiffness and exhibit lower friction, and operate at higher cutting velocities than HSS tools. But carbide tools are more brittle and more expensive than HSS. They are generally recommended for machining steel. K grade carbides are straight tungsten carbide grades with no alloying carbides. They are used for machining grey cast iron, nonferrous metals, and nonmetallic materials. M grade carbides are alloyed WC grades generally with less amount of TiC than the corresponding P series, and have wider application in machining austenitic stainless steel, manganese steel as well as steel castings. Each grade within a group is assigned a number to represent its position from maximum hardness to maximum toughness (higher the number, tougher the tool). P grades are rated from P01 to P50, M grades from M10 to M40, and K grades from K01 to K40. The performance of carbide cutting tool is dependent on the percentage of Co and grain size of carbide(s).

### 1.1.3 Ceramics

Ceramics are inorganic, nonmetallic materials that are subjected to high temperature during synthesis or use. They retain excellent hardness and stiffness at temperature greater than 1000°C, and do not react chemically with most work materials at these temperatures. There are two main categories of commercially available ceramic tools:

- Alumina-based ceramics comprising of pure oxide, mixed oxides, and silicon carbide (SiC) whisker reinforced alumina ceramics.
- Silicon nitride-based ceramics.

### 1.1.4 Cermets

Cermets are ceramic materials in a metal binder. They consist of TiC, TiN, or TiCN hard particles held together by a softer binder alloy of Co and/or Ni, Mo. Cermets are less susceptible to diffusion wear than WC, and have more favorable frictional characteristics. Cermet cutting tools are suitable for the machining of steels, cast irons, cast steels and nonferrous free-machining alloys. They are capable of operating at higher cutting velocities than cemented carbides thus allowing better surface finish. However, they have a lower resistance to fracture, lower thermal conductivity and a higher thermal expansion coefficient than WC, and are more feed sensitive.

In addition to these, diamond and cubic boron nitride are two of the newer additions to the variety of cutting tools materials. However, due to very high cost of production, their application is only justified where conventional cutting tools fail to yield satisfactory results.

## 1.2 Modification Techniques for Improving Performance of Cutting Tools

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, Al2O3, TiAlN, ZrN etc. This coating in general posses high wear resistance, hot hardness, chemical inhardness, 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. Some of the cryogenic cooling approaches are discussed as follows.

### 1.2.1 Cryogenic cooling approaches

Cryogenic cooling approaches in metal cutting may be classified into four groups according to applications of the researchers: cryogenic pre-cooling the work piece by repulsing or an enclosed bath and cryogenic chip cooling, indirect cryogenic cooling or cryogenic tool back cooling or conductive remote cooling, cryogenic jet cooling by injection of cryogen to the cutting zone by general flooding or to the cutting tool edges or faces, tool–chip and tool–work interfaces by micro-nozzles (Yildiz et al. 2008)

### 1.2.2 Cryogenic treatment

Cryogenics are defined as working at very low temperatures below -150°C (123K).Various gases such as nitrogen, helium, oxygen, hydrogen, and neon can be utilized. Being cryogenics, the normal boiling point of such lies below -180°C(93K).They find wider applications in industries such as manufacturing, automotive, aerospace, electronics, food processing, and health for cooling purpose. Liquid nitrogen is the most commonly used element in cryogenics. It is produced industrially by fractional distillation of liquid air and is often referred to by the abbreviation, LN2. Nitrogen melts at -210.01°C and boils at -198.79°C, it is the most abundant gas, composes about four-fifths (78.03%) by volume of the atmosphere. It is a colorless, odorless, tasteless and non-toxic gas. These characteristics of liquid nitrogen have made it as a preferred coolant

There are several different cryogenic processes, which have been used tested by researchers. The first cryogenic process applied temperatures in the range of -78°C to -85 °C to the material and held at the temperature for several hours (Hallum, D.L., 1996). This treatment does improve wear resistance as a result of converting some retained austenite to martensite and creating a more uniform and refined structure. The more recent application, known as deep cryogenic processing, subjects a material to a controlled lowering of the temperature to -196°C and held for approximately twenty four hours. After holding the material for twenty four hours, the material is then slowly raised to +196°C before slowly returning to room temperature. The benefits obtained by this deep cryogenic process are many. Austenite is significantly decreased through a transformation which increases the martensite in the structure. In addition, carbides are increased as a result of the formation of micro-fine carbide fillers. These changes lead to an increase in durability and enhancing cutting tool life.

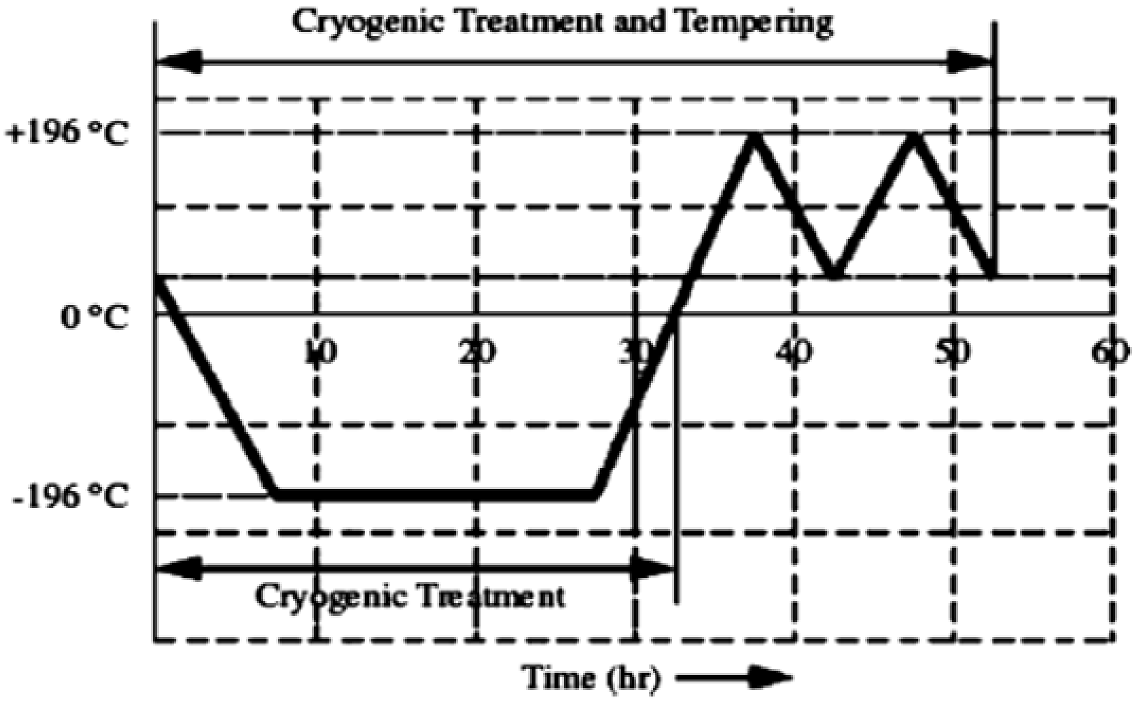



Figure 1.1 Step of cryogenic treatment (Gill et al., 2006)

### 1.3 Need for Machinability Study of Stainless Steel

The term machinability refers to the ease with which a metal can be machined to an acceptable surface finish. Materials with good machinability require little power to cut, can be cut quickly, easily obtain a good finish, and do not wear the tooling much, such materials are said to be free machining. The factors that typically improve a material's performance often degrade its machinability. Therefore, to manufacture components economically, engineers are challenged to find ways to improve machinability without harming performance.

Machinability can be difficult to predict because machining has so many variables. Two sets of factors are the condition of work materials and the physical properties of work materials.

The condition of the work material includes eight factors: microstructure, grain size, heat treatment, chemical composition, fabrication, hardness, yield strength, and tensile strength.

Physical properties are those of the individual material groups, such as the modulus of elasticity, thermal conductivity, thermal expansion, and work hardening.

There are many factors affecting machinability, but no widely accepted way to quantify it. Common metrics for comparison include tool life, surface finish, cutting temperature, and tool forces and power consumption.

Due to their difference in properties when compared with carbon steels, slightly different techniques are required when machining stainless steels. The carbon content of steel greatly affects its machinability. High-carbon steels are difficult to machine because they are strong and because they may contain carbides that roughen the cutting tool. On the other end of the field, low-carbon steels are difficult because they are too soft. Low-carbon steels are "gummy" and attach to the cutting tool, resulting in a built up edge that shortens tool life (Korkut and Ciftci , 2004). Therefore, steel has the best machinability with medium amounts of carbon, about 0.20%. Chromium, molybdenum and other alloying metals are often added to steel to improve its strength. However, most of these metals also decrease machinability.

Inclusions in steel, especially oxides, may roughen the cutting tool. Machinable steel should be free of these oxides.

Machinability of Stainless steels is less compared to regular carbon steel because they are tougher, gummier and tend to work hardens very rapidly. Slightly hardening the stainless steel may decrease its stickiness and make it easier to cut.

One of the major advantages of the stainless steels, and the austenitic grades in particular, is their ability to be fabricated by all the standard fabrication techniques. The common austenitic grades can be folded, bent, cold and hot forged, deep drawn, spun and roll formed. Because of the materials' high strength and very high work hardening rate all of these operations require more force than for carbon steels, so a heavier machine may be needed. Austenitic stainless steels also have very high ductilities, so are in fact capable of being very heavily cold formed, despite their high strengths and high work hardening rates, into items such as deep drawn laundry troughs. Few other metals are capable of achieving this degree of deformation without splitting.

### 1.3.1 Different types of stainless steel

Stainless Steels are usually classified into four categories depending on their primary constituent of the matrix:

#### *1.3.1.1 Martensitic stainless steels*

It is a high carbon containing steel, having a higher carbon level (nearly 1%) and 19% chromium. Martensitic stainless steel contains chromium (19%), molybdenum (0.25–1%), nickel (less than 2%), and carbon (about 0.1–1%) giving it more hardness but making the material a bit more brittle. Presence of nickel and molybdenum increases its strength. It can be easily hardened by subjecting it to heat, and is highly resistant to abrasion, but it displays less resistance to corrosion compared to other alloys of stainless steel. It has poor weldability and is magnetic. It displays magnetic properties and is used in the manufacture of surgical instruments, valves, knife blades, etc. Increasing hardness typically reduces tool life and machinability. Increasing the carbon content increases the proportion of abrasive chromium carbides in the matrix and reduces tool life and machinability.

#### *1.3.1.2 Ferritic stainless steels*

These are plain chromium stainless steels with varying chromium content between 11% and 18%, but with low carbon content. Ferritic alloys are generally more machinable than other alloys. Their machinability generally decreases with increasing chromium content. They have a moderate to good corrosion resistance, are not hardenable by heat treatment and always used in the unhealed conditions. They are magnetic. The formability is not as good as the austenitic. These are commonly used in computer floppy disk hubs, automotive trim, automotive exhausts, material handling equipment and in hot water tanks.

#### *1.3.1.3 Austenitic stainless steels*

Most commonly used austenitic stainless steel contains 19% chromium and 9% nickel. They have an excellent corrosion resistance, weldability, formability fabricability, ductility, cleanability and cleanliness characteristics. Along with good high and excellent low temperature properties, these are non magnetic (if annealed) and are hardenable by cold work only.

#### *1.3.1.4 Duplex stainless steels*

These are stainless steels containing relatively high chromium (between 18 to 29%) and moderate amounts of nickel (between 4.5 to 8%). The nickel content is insufficient to generate a fully austenitic structure and the resulting combination of ferritic and austenitic structures is called duplex. Most duplex steels contain molybdenum in a range of 2.5 - 4%. These have a high resistance to stress corrosion, cracking and chloride ion attacks. They have a higher tensile and yield strength than austenitic of ferritic steels as well as good weldability and formability. They are commonly used in marine applications, desalination plants, heat exchangers and petrochemical plants.

### 1.3.2 Difference between AISI 304 and 316 grade austenitic stainless steel

Type 304 is the most common austenitic grades, containing normally, 20% chromium and 10 % nickel, combined with a maximum of 0.08 % carbon. While type 316 contains 16% to 18% chromium and 11% to 14% nickel it is the presence of molybdenum that distinguishes 316 grade from 304 grade. 316 grade contains 2% - 3% molybdenum and carbon content is 0.03 %. Mo is added to 316 grade improve the corrosion resistance to chlorides. In chlorine environment, 316 stainless steel offers a high resistance to crevice corrosion and pitting than 304 stainless steel.

Type 304 is used for chemical possessing equipment, for food, for dairy, for heat exchangers, and for the milder chemicals. While Type 316 is used in chemical processing, in the pulp and paper industry, for food and beverage processing and dispensing. Type 316 stainless steel is often used in heavy gauge welding applications because the risk of pitting, cracking and corrosion is reduced, while type 304 stainless steel is often used in the creation of cookware and in the construction of dairy equipment, such as milking machines.

### 1.3.3 Different engineering applications of austenitic stainless steel

The major engineering applications of austenitic stainless steel include

- Food preparation equipment particularly in chloride environment
- Laboratory benches and equipment

- Coastal architecture panelling, railing and trim
- Boat fitting
- Chemical containers including for transport
- Heat exchanger
- Woven or welded screens for mining, quarrying and water filtration

# CHAPTER 2

# Literature Review

# 2. LITERATURE REVIEW

## 2.1 Effect of Cryogenic Treatment on Characteristic of Cemented Carbide

Cryogenic treatment, the discipline upon which the present study is based, can be considered a recent development. A few researchers have studied the impact of cryogenic treatment on tungsten carbide inserts. (Seah et al. 2003, Yong et al. 2006, Reddy et al. 2007, Gill et al. 2009)

### 2.1.1 Physical characteristics

Gallagher et al. (2005) analyzed the microstructural alterations of α (tungsten carbide), β (cobalt binder), γ (carbide of cubic lattice) and η (multiple carbides of tungsten and at least one metal of the binder) phases within the tungsten carbide tools caused by the cryogenic treatment, and links these changes to the corresponding enhanced tool life. Thakur et al. (2008) with the help of XRD study showed the formation of complex phases like $W_3Co_3C$ and $W_6Co_6C$ after cryo treatment. This phases are known as η phase. These complex phases results in the increase in hardness due to exposure of skeleton carbide matrix due to later post treatments. Reddy et al. (2009) observed that The surface roughness of the workpiece was lower by approximately 20% when the workpiece was machined with deep cryogenic treated tungsten carbide tool inserts in comparison with untreated inserts for cutting speeds in the range between 200 and 350 m/min. Reddy et al. (2009) concluded that the surface finish of the workpiece is better, when the workpiece was machined, with cryogenic treated inserts in comparison with untreated inserts at all cutting speeds.

### 2.1.2 Mechanical characteristics

Kao (1984), in his research on the effects of cryogenic treatment of sintered tungsten carbide, also noted a slight increase in hardness of the cryogenically treated tool. Chen (2002), in his research on the cryogenic treatment of tungsten carbide, noted that there were significant improvements in the hardness of cemented carbides after they were subjected to cryogenic treatment. He also found that the hardness of the cryogenically treated tools increased with increasing cobalt content as well. It should also be noted that the decrease in hardness of the untreated tool as the cobalt content increases is much greater in degree compared to the increase achieved with cryogenic treatment. Thakur et al. (2008) studied that there is a slight increase in the micro hardness due to the controlled cryogenic treatment compared to untreated WC–Co sample. But other two post treatments showed a considerable improvement in the hardness. The formation of the complex compounds such as $Co_6W_6C$ or $Co_3W_3C$ might have increased the hardness in the case of the samples due to forced air cooling and oil quenching. Reddy et al. (2008) investigated that the surface finish of the C45 workpiece is better on machining with low temperature treated inserts in comparison with untreated inserts at all cutting speeds. Thus there is also a decrease in main cutting force of 2.0% and improvement in surface roughness of the work piece of 8.42%.According to Jiang Yong and Chen Ding (2011)Hardness and compression strength of the YG8 samples treated by cryogenic environment are higher than that of the untreated ones, while bending strength and toughness show no significant changes. The improvement of mechanical properties is highly dependent on the soaking time

### 2.2 Effect of Cryo Treatment on Machining Performance of Cemented Carbides

#### 2.2.1 Effect of cryo treatment on tool life

Various researchers demonstrated that cryogenic treatment of cemented carbide results in change in performance of their performance in machining. Kao (1987) reported increase in abrasion wear resistance of sintered tungsten carbides after cryogenic treatment. 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 binder after cryogenic treatment. He believed that cryogenic treatment also acts to relieve the stresses introduced during the sintering process under which carbide tools are produced. However, Bryson also warned that under certain conditions, cryogenic treatment would have little or no effect on carbide tools, such as when reprocessed carbides are used. Seah et al. (2003) implemented the cryogenic treatment on cobalt bonded tungsten carbide (Co-WC) and found that the treated tools were superior to those of the untreated as-received inserts at high cutting speeds. From this study, they concluded that cryogenic treatment of tungsten carbide inserts increased the number of η-phase particles, a theory which they supported with photographs taken using a scanning electron microscope. They assigned this as a reason for reducing transverse rupture strength hence greater resistance to chipping, improved resistance to plastic deformation during cutting, and lower toughness. After experimental evaluation of comparative performance of cryogenically treated TiCN-coated carbide inserts and Kennametal GradeKC990 inserts by gas infusion process (dry process). Stewart (2004) applied cryogenic treatment to C2 tungsten carbide (6%Co) and compared with untreated carbide to determine if tool wear could be reduced during turning tests with medium density fiberboard. Both the tool force data and observation of the cutting edges indicate that tool wear was reduced. He postulated that the cryogenic treatment appeared to have an effect upon the cobalt binder by changing phase or crystal structure so that more cobalt binder was retained during cutting. Yong et al. (2006) showed that cryogenic treatment no doubt improves the resistance to chipping of tool sand to a less significant extent, improves flank wear resistance. They stated that tools under mild cutting conditions stand to gain from cryogenic treatment, but heavy duty cutting operations with long periods of heating of the cutting tool will not benefit from it. Reddy et al. (2007) observed the improvement in life of normal and deep cryogenically treated carbide inserts by an amount of 9.58% and 21.8% respectively. They studied the improvement in tool life of cryogenically treated P-30 tungsten carbide inserts and concluded that precipitation and distributions of the η phase after cryogenic treatment have improved the flank wear resistance. Also they observed a slight increase in grain size which increases the toughness. In another study, Yong et al. (2007) cryogenically treated tungsten carbide milling inserts and found28.9–38.6%increase in tool life. They confirmed that, in contrary to steels, there is no martensite phase in tungsten carbide, as such; any improvement in tool life or wear resistance would be due to other mechanisms. Gill et al. (2009) did comparative investigation of the wear behavior of cryogenically treated tungsten carbide inserts in dry and wet orthogonal turning conditions to excavate the affect of coolants on the performance of cryogenically treated tungsten carbide inserts. The authors claimed that the use of coolant coupled with cryogenic treatment of tungsten carbide inserts further improved the tool life. They also concluded that considerable increase in life of cryogenically treated tools can be attained for interrupted machining mode as compared with continuous machining mode. Reddy et al. (2009) observed that the tool life of deep cryogenic treated coated cemented tungsten carbide cutting tool inserts of ISO P-40 grade is larger by a factor of 1.27 (27% increase) when compared to untreated inserts for cutting speeds in the range between 200 and 350m/min. Gill et al. (2011) concluded The deep cryogenic treatment has destructive effect on the performance of TiAlN coated tungsten carbide inserts especially at lower cutting speeds. However, at higher cutting speeds, marginal gain in tool life can be obtained. Also, deep cryogenic treatment weakens coating–substrate interfacial adhesion bonding. Overall, deep cryogenic treatment is not recommended for TiAlN coated tungsten carbide inserts as the benefit gained is not significant.

### 2.2.2 Effect of cryo treatment on cutting force

Stewart (2004) investigated that cryogenic treatment on C2 grade tungsten carbide inserts recorded lower tool force while turning MDF thus enhancing the life of inserts. Reddy et al. (2007) studied that the main cutting forces for the low temperature treated inserts are lesser when compared to untreated inserts. Reddy et al. (2009) observed that the main cutting forces for the deep cryogenic treated inserts were lesser by 11% when compared to untreated inserts for cutting speeds in the range between 200 and 350 m/min.

## 2.3 Machinability Study of Stainless Steel

### 2.3.1 Effect of machining parameters on cutting force

Ciftci. (2005) investigated that AISI 316 resulted in higher forces at all cutting speeds employed than AISI 304. The 2.0% Mo present in AISI 316 was considered to be the cause of the higher forces. Zhuang et al. (2010) studied two steel, free cutting austenitic stainless steel and austenite stainless steel 1Crl8Ni9Ti at various cutting speeds, they find that the cutting forces generally decreased with the increase of cutting speed in the range 10 - 80 m/min. They reached 418 N and 336 N at 10 m/min cutting speed for steel A and B, respectively. And at 80 m/min cutting speed, principal forces were 343 N and 275 N for steel A and B, respectively.

### 2.3.2 Effect of machining parameters on tool life

Agarwal et al. (1995) depicted that deep craters formed on the rake face of the coated tools during machining of three cast austenitic stainless steels having different composition. It was mainly due to the rapid diffusion wear of the tools. TiN coatings have failed to providing any barrier to such diffusion wear. As Ti, N, and C are highly soluble in austenitic stainless steel. Thus tendency for the rapid tool-chip adhesion and rake crater wear on the coated carbide have been obtained during the machining of the austenitic stainless steel. During machining diffusion of carbon from the tool to the chip under surface have been observed. According to Lin (2002), the effect of tool life while drilling stainless steel at high speed machining using a TiN coated tool with curved cutting edges were used. The cutting parameters being used for test to be carried out was cutting speed of 65, 75, and 85 m/min, feed rate of 0.05, 0.1, 0.15 and 0.2 mm/rev.the tool rejection criteria for the machining trials was maximum flank wear land of >0.8mm. It has been observed that tool life increased as the feed rate decreased. Tekiner et al. (2003) studied the values of flank wear resulting from five different cutting speeds 120, 135, 150, 165 and 180 m/min and three different feed rates 0.2, 0.25 and 0.3 mm/rev. flank wear is decreasing while feed rate is rising from 0.2 to 0.25 mm/rev; and then it is starting to increase when it is rising 0.3 mm/rev . Built up edge values forming on insert used in different cutting parameter were measured by microscope, by doing this, it was seen that cutting speed increased and built up edge value decreased. Korkut et al. (2003) investigated that tool flank wear decreased with increasing the cutting speed up to 180 m/min. The poor performance of the tool could well be explained by the thermal softening of the tool due to the higher influence of the heat on the cutting tool and less efficient heat dissipation at the lower cutting speeds. Zhuang et al. (2010) showed Tool life for turning free cutting Pb-free austenitic stainless steel is superior to that of an austenite stainless steel lCr18Ni9Ti.

### 2.3.3 Effect of machining parameters on surface finish

Tekiner et al. (2004) showed the lowest average value of surface roughness was obtained at 150 m/min cutting speed. Surface roughness values obtained from at 165 and 180 m/min cutting speeds were little higher than the one obtained from at 150 m/min and, if the surface roughness quality is important, feed rate should not be higher than 0.25 mm/rev. According to Korkut et al. (2003), surface roughness values were found to decrease with the increasing cutting speed. This was attributed to the presence of built-up-edge at the lower cutting speeds. Inhomogeneous distribution of chip thickness at the lower cutting speeds might also indicate the variation in the cutting forces and this may be another reason for poor surface finish due to the force fluctuations. According to Ciftci (2005) cutting speed was found to have a significant effect on the machined surface roughness values. With increasing cutting speed, surface roughness values decreased until a minimum value was reached, beyond which they increased. Higher surface roughness values at lower cutting speeds were attributed to the high BUE formation tendency. Chipping of the cutting edges, evidenced by the SEM examinations, was also found to be responsible for the high surface roughness values. Selvaraj et al. (2010), studied that dry turning test on cast duplex stainless steels using TiC and TiCN coated cemented carbide cutting tool at five different cutting speed 80, 100, 120,140 and 160 m/min and three different feed rates 0.04, 0.08 and 0.12 mm/rev with constant depth of cut 0.5mm was done and investigated the influence of cutting speed and feed rate on the machined surface roughness. It has been observed that with increasing cutting speed up to 100 m/min the surface roughness values decreases due to the decreasing built up edge formation up to 100 m/min. but with further increase in cutting speed up to 180 m/min surface roughness value increases due to the increasing cutting tool nose wear at higher speed. Moreover, the feed rates used in the study were 0.04, 0.08 and 0.12 mm/rev showed a significant effect on surface roughness. It has been observed that surface roughness obtained at the feed rate of 0.04 mm/rev gave a minimum value. This was due to the widening in the area of contact and changes in the force per unit length, resulting in great distortion of sticky chip. Later, Orrego et al. (2010) depicted that feed rate exhibited a better effect on surface roughness than cutting speed. Surface finish of AISI 304 stainless steel after tested by turning machining was mainly affected by the feed rate. The test was conducted for understanding the effect of the variation of feed rate and cutting speed in surface integrity while turning AISI 304 austenitic stainless steel using cemented carbide tool. Three different values of feed i.e. 0.15, 0.3 and 0.6 mm/rev and three values of cutting speed i.e.  40, 80 and 120 m/min with constant depth of cut 1mm were in the study. It was observed that feed rate was the most influencing parameter affecting surface roughness values. The result depicted that surface roughness had a negligible variation with the cutting speed. With high feed rate of 0.6 mm/rev, it showed a highest value of surface roughness and with lowest feed rate showed a lowest surface roughness. From this it can be explain that with increasing feed rate, surface roughness value also increases. The flattest surface finishing obtained through roughness measurements was found for the cutting condition of 0.15 mm/rev and 120 m/min.

### 2.3.4 Effect of machining parameters on chip characteristic

Tekiner et al. (2004) investigated that chip curl radii decreased and chip thickness increased in low cutting speeds and in high feed rates. Chip flowed slowly owing to the increase of chip thickness and by this way heat was thrown slowly. Slow chip flow and high temperature converted the chip colour into yellow. At the same time, power consumption at the machine decreased owing to low chip thickness during chip removal. Korkut et al. (2004) studied that chip curl radius and chip thickness were found to be related to the cutting speed at which the machining tests were performed. Low cutting speed led to small chip curl radius and big chip thickness while with increasing cutting speed, chip curl radius increased and chip thickness decreased gradually. Akasawa et al. (2003) showed the surface characteristics of chips were strongly dependent on the work materials. The damage to the under surface of the chip produced by turning 304 was minimal, while there were many pits, laps and remnants of BUE on the chip surface of resulfurized steels. After machining 304Bi, 304Ca and 316Ca, no fragments of BUE were found on the chip surface. The chip thickness of 304 and 316 grade stainless steel was decreased at all cutting speeds with the addition of free-machining elements. Paro et al. (2001) analyzed chips from cutting speed of 60, 65, 70 m/min. Chips were strongly deformed to small short conical-helical chips or arc type chips

**2.4 Objective**

From the literature review, it is has been found that cryogenic treatment has tremendous potential for enhancing the wear resistance of cutting tool materials. Though substantial work has been reported on the effect of cryo treatment of different tool steels on their properties and performances in cutting and forming applications, similar study is also required for cemented carbide which is more commonly used cutting tool material.

Though some studies has shown the prospect of cryo treatment in enhancing the tool life of cemented carbide, the exact mechanism is yet to be fully understood. Therefore, the physical and mechanical properties of cemented carbide need to be thoroughly studied which can be subsequently correlated with the machining performance. Though it is considerably challenging to machine AISI 316 grade austenitic stainless steel, not much work has been reported so far on the detailed machinability study of the work material. Therefore in the current study, the effect of cryo treatment of cemented carbide inserts has also been investigated in the dry turning of AISI 316 grade austenitic stainless steel. Such study has yet to be reported so far. Keeping these in mind, the objective of the current research work has been formulated as follows:

- Cryogenic treatment of cemented carbide insert under controlled environment.
- Effect of cryo treatment on microstructure of the cryogenically treated tungsten carbide inserts with the help of SEM

- Effect of cryo treatment on crystallographic orientation of cemented carbide with the help of XRD
- Effect of cryo treatment on Vicker microhardness of cemented carbide insert
- Effect of cryo treatment of cemented carbide inserts on performance evaluation in dry of turning of AISI 316 grade austenitic stainless steel in terms of tool wear and chip characteristics (chip thickness, colour, and type) after machining with different values of cutting speed.

# CHAPTER 3

# Experimental Methods

# 3. EXPERIMENTAL METHODS AND CONDITIONS

## 3.1 Cryogenic Treatment

### 3.1.1 Experimental setup

The cryogenic Treatment was done by Kryo 550-16 chamber

The *Kryo 550-16* incorporates all of the critical features expected from high specification biological chamber. The -180 ºC to + 40 ºC temperature range allows flexibility for a wide range of applications and protocols. The -180 ºC end temperature ensures the sample integrity while transferring to long term storage.

The integrated *Focused Control Technology* provides secure and accurate profile control. This ensures that even when connected to a host PC, the freezer control remains unaffected by any failures that may occur on a external computer or network. The controller includes protection against short term power failures.

PC connectivity is provided by an RS232 connection providing profile editing, real-time run graphs and PC storage of run data via the *DeltaT* application. Calibration and Qualification tools can also be provided when connected to *DeltaT-iQ*.

Alternatively the optional in-built server provides a quick and trouble-free method of accessing the host device from any PC on a network. The heart of the unit is the device-specific application and web site, resident in the server which allows customized access to the host device. The web enabled 550 also benefits from simple connection to an ethernet network, no software to install and SMTP mail server for e-mail notifications.

The *Kryo 550-16* is designed to heat and cool samples accurately along user-defined temperature-time profiles.


Figure 3.1 Kryo 550-16 chamber

Figure 3.2 Experimental set up for cryogenic treatment

### 3.1.2 Cryogenic treatment procedure

In this study, the tungsten carbide inserts were cryogenically treated under dry condition where the inserts being treated were not exposed to the liquid nitrogen to eliminate the risk and damage of thermal shock. The procedure used for the treatment in this study is outlined in the following steps and is shown in Fig.3.3. Inserts were placed in a container and the temperature was brought to -196°C in intervals by computerized control at the rate of $0.5^{0}$C/min. The temperature was held constant for 20h before the process was reversed. The inserts were slowly brought to room temperature allowing the material to stabilize. Then the inserts were subjected to tempering cycles to relieve the stresses induced by cryogenic treatment. This was accomplished by increasing the temperature to$+196^{0}$C and then a slowly reducing the temperature back to room temperature.

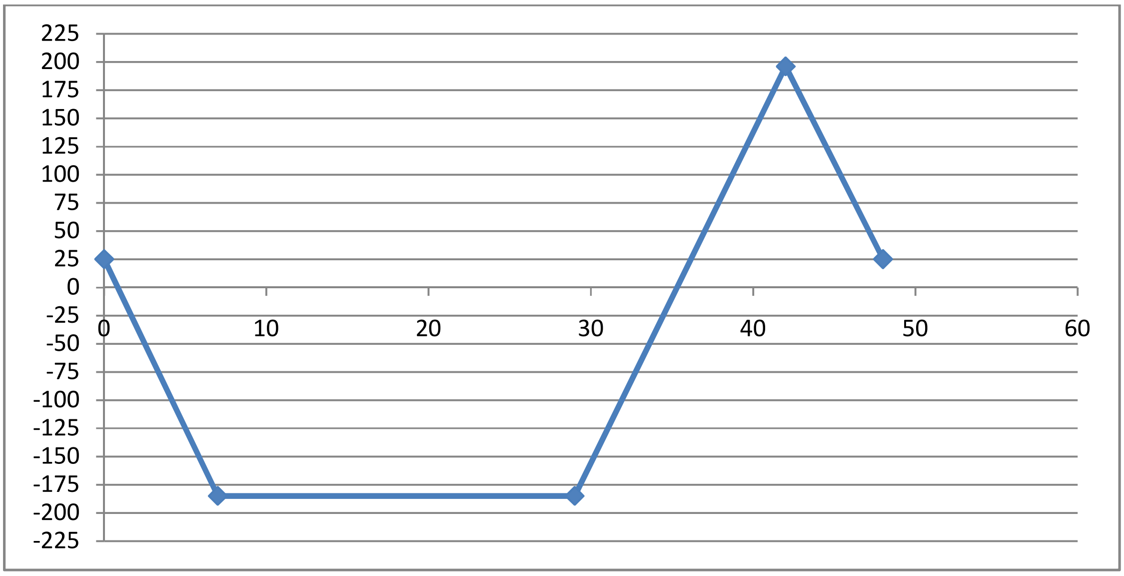



Figure 3.3 Step of Cryogenic Treatment


Figure 3.4 Furnace

### 3.2. Physical Characterization

#### 3.2.1 Scanning electron microscopy (SEM)

Surface morphology and microstructure of the treated and untreated were studied using a high resolution jeol jsm 6480lv scanning electron microscope (SEM) operated at an acceleration voltage of 15 kV. The composition of the inserts was determined by EDS (INCA, Oxford Instruments, UK) microanalysis coupled with the SEM. The EDS detector was equipped with an ultra thin window, and hence it was capable of detecting elements heavier than beryllium reliably. EDS analysis was performed at an acceleration voltage of 20 kV.

#### 3.2.2 X-ray diffraction (XRD)

Crystal structure was characterized using X-ray diffraction (XRD) technique. Diffraction measurements were performed with a high resolution Philips, PANalytical PW 3040/60 X'Pert PRO instrument using Cu K$\alpha$ radiation of wavelength 0.15418 nm. A 2$\theta$ scan range from 30° to 80° was selected. The voltage and current settings were 30 kV and 20 mA respectively. The samples were continuously scanned with a step size of 0.05° (2$\theta$) and a count time of 2 s per step. The data were later analyzed with X'pert High score software (Philips Analytical B.V., Netherlands)

### 3.3 Mechanical Characterization

#### 3.3.1 Vickers microhardness test

Vickers micro hardness test is one of the most commonly used techniques for the measurement of microhardness of treated and untreated samples. It uses a highly polished, pointed, square-based pyramidal diamond indenter with face angle of 136°. The Vickers hardness number (HV) is the ratio of the load applied to the indenter to the surface area of indentation:

$$HV = \frac{2P\sin(\alpha/2)}{D^2} \quad \text{...3.1}$$

Here, $P$ is the applied load in kgf, $\alpha$ is the angle between opposite faces of the diamond indenter, 136° and $D$ is the mean diagonal of the indentation in mm. Vickers microhardness is typically expressed in kgf/mm$^2$ without mentioning the unit. At least five indentations under 0.5 N load (dwell time = 15 s) were considered for each treated and untreated specimen.

### 3.4 Performance Evaluation of Treated and Untreated Cutting Tools in Machining

#### 3.4.1 Turning operation

Comparative performance evaluation of untreated carbide tool and the treated carbide tool was performed during turning of stainless steel (AISI 316 steel). Table 3.3details the machining condition during turning of 316 steel with untreated and treated cemented carbide tools.

The chemical composition of the work material is provided in Table 3.1. The SEM images of the microstructure of 316 steel are depicted in Figure 3.5. The nominal mechanical properties of the same material are given in Table 3.2.

Since the cutting mechanics involved in turning operation is relatively simpler, a difficult-to-machine material like stainless steel (316 steel) was considered for the turning test. All the tests were carried out on a heavy duty lathe (Make: Hindustan Machine Tools (HMT) Ltd., Bangalore, India; Model: NH26) fitted with variable spindle drive (Make: ABB). The experimental setup for turning tests is shown in Figure 3.6

During the first part of the experiment, cutting velocity was varied from 100 m/min to 200 m/min with a constant feed of 0.2 mm/rev and depth of cut of 1 mm in order to investigate the influence of cutting speed on tool wear for both untreated and treated tools. The duration of machining for each trial was only 60 s during

Table 3.1 Chemical Composition of AISI 316 grade austenitic stainless steel.

| Elements | C | Mn | Si | P | S | Cr | Mo | Ni | N |
|---|---|---|---|---|---|---|---|---|---|
| Wt % | 0,03 | 2.0 | 0.75 | 0.045 | 0.03 | 18.0 | 3.0 | 14.0 | 0.10 |

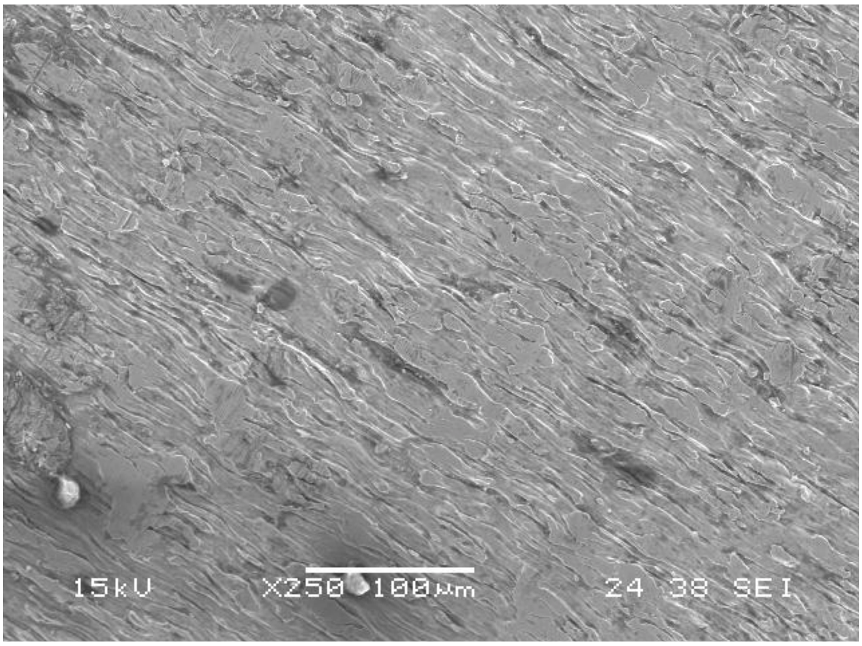



Figure 3.5 SEM Images of Microstructure of AISI 316 grade austenitic stainless steel.

Table 3.2 Properties of AISI 316 grade austenitic stainless steel.

| | |
|---|---|
| Density | 8000 |
| Poisson's Ratio | 0.27–0.30 |
| Elastic Modulus (GPa) | 193 |
| Tensile Strength (Mpa) | 515 |
| Yield Strength (Mpa) | 205 |
| Vickers Hardness | 260 |
| Thermal Conductivity (W/(m·K)) | 16.3 |

Table 3.3 Experimental Conditions for Turning

| | |
|---|---|
| Workpiece material | AISI 316 steel |
| Inserts used | Uncoated cemented carbide insert (ISO p30 grade, WC-6%Co) |
| Insert designation | SCMT 12 04 08 |
| Tool geometry | −6°, −6°, 6°, 6°, 15°, 75°, 0.8 (mm) |
| Cutting velocity (m/min) | 100,150,200 |
| Feed (mm/rev) | 0.2 |
| Depth of cut (mm) | 1 |
| Environment | Dry |

After 60 s of machining, the condition of the cutting tools was studied using optical microscopy (SZ 1145TR PT Zoom Stereo microscope, Olympus), SEM (JEOL JSM-6490) and EDS. This was followed by removal of built-up material from the rake surface of the tools using a solution containing 20% conc. $H_2SO_4$. The carbide inserts were then again examined using optical microscopy, SEM and EDS. Therefore, the strength and weakness of untreated and treated tools were ascertained from cutting force data and degree of formation of built-up edge particularly at low cutting velocity.


Figure 3.6 Photographs of Experimental Setup for Turning of AISI 316 grade austenitic stainless steel.

After different intervals of machining, the conditions of the tools were monitored after using optical microscopy and average flank wear (VB) was measured. Once VB reached 0.3 mm, the tool life was considered to be over. This was followed by analysis of the tools using SEM and EDS.

Figure 3.7 Zoom stereo optical microscope

### 3.5 Description of Cutting Tool

Tool Designation

SCMT 12 04 08

S - Insert Shape = $90^0$

C – Clearance Angle = $7^0$

M – Medium Tolerance = ±0.005 inch

T – Insert Features (Counter sinking hole with chip groove on top surface for easy flow of chip over rake surface)

12 –length of each cutting edge is 12 mm

04 –nominal thickness of the insert is 4 mm

08 – nose radius = 0.8 mm

Table 3.4 Tool Designation

| S.N | Cutting Tool | ISO Grade and Specification | Composition |
|---|---|---|---|
| 1 | Uncoated cemented carbide insert | P30<br>SCMT120408 | WC-Co+<br>TiC+TaC |

### 3.6 Designation Tool Holder

ISO SSBCR 2020K12 (Kennametal, India)

# CHAPTER 4

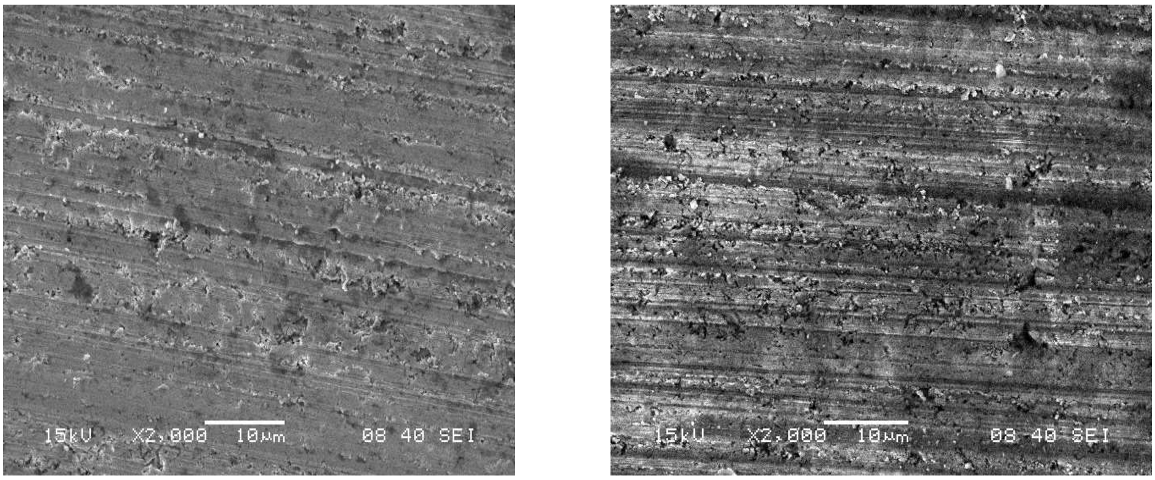
# Result and Discussion

# 4. RESULTS AND DISCUSSION

## 4.1. Effect of Cryogenic Treatment on Characteristics of Cemented Carbide Inserts

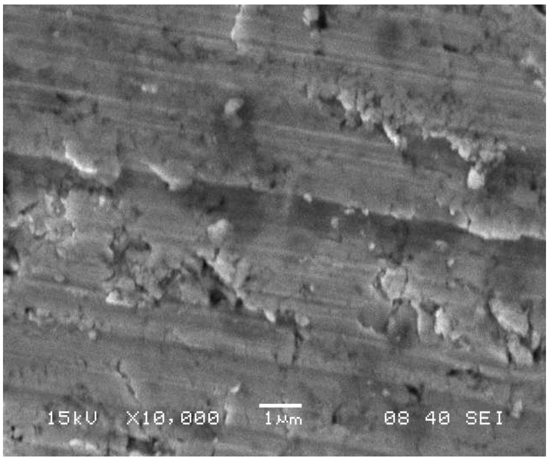
### 4.1.1 SEM study

After cryogenic treatment, first inserts were observed under scanning electron microscope. Figure 4.1 and 4.2 shows the microstructure of untreated and cryo treated inserts at low and high magnification respectively. These SEM images of untreated and cryo treated inserts are clearly distinct and the cryo treated morphology clearly reveals the presence of several black spots which are known as eta (η) phase carbides. These phases consist of carbides of W and Co with chemical formula $Co_6W_6C$ and $Co_3W_3C$. These η phase carbides which are relatively harder provide greater wear resistance compared to the untreated carbide inserts. The formation of η phase in cryo treated cemented carbide inserts were also observed by previous researchers (Seah et al., 2003, Gallagher et al. 2005, Reddy et al. 2007, Thakur et al. 2008).




a b

Figure 4.1 Lower magnification (2000X) SEM images of rake face of (a) untreated, (b) cryo treated cemented carbide inserts

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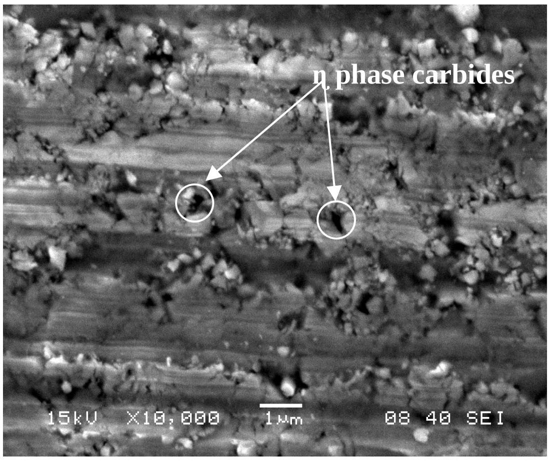
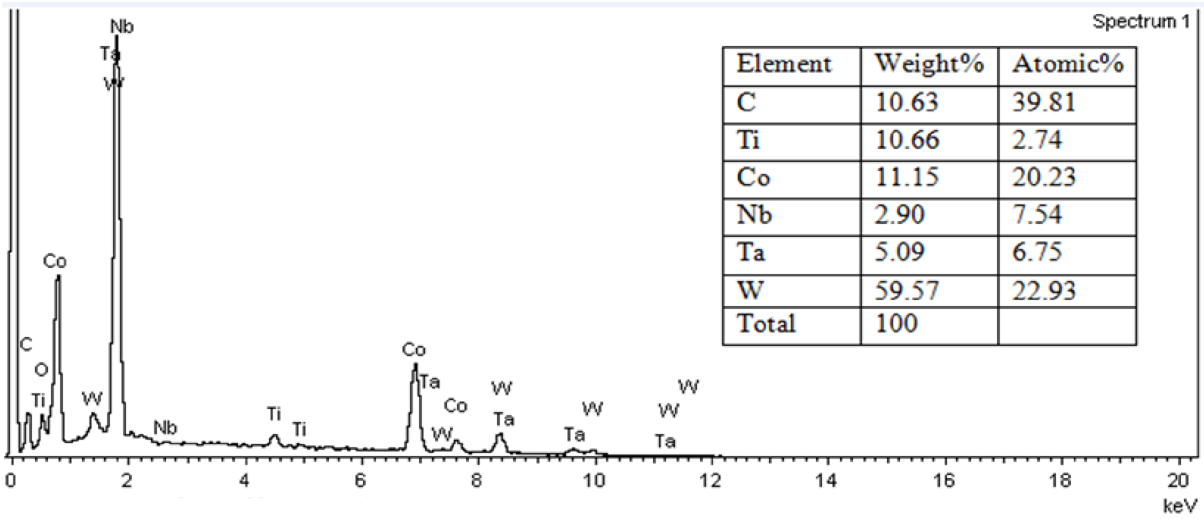



b

Figure 4.2 Higher magnification (10000X) SEM images of rake face (10000 X) of (a) untreated, (b) cryo treated cemented carbide inserts

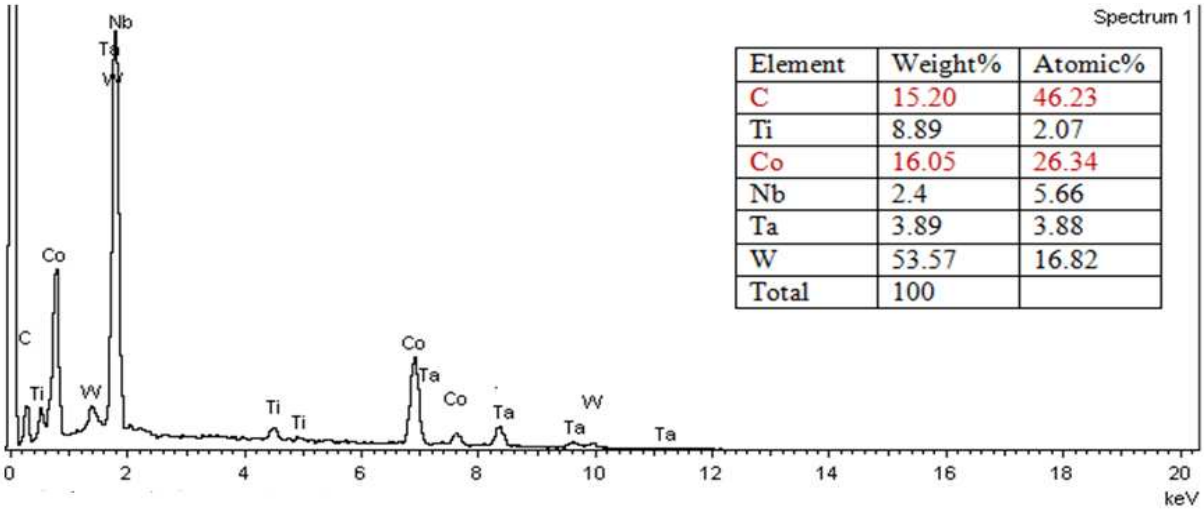
### 4.1.2 EDS Analysis

The composition of the top surface of both the untreated and cryo treated were examined using energy dispersive spectroscopy (EDS) through X-ray. Figure 4.3 which depict EDS spectra along with chemical composition demonstrated that some change in composition took place on the surface of the inserts after cryo treatment. Notable changes include increase in concentration of Co and C on the top surface of cryo treated inserts. This shows that redistribution and densification of Co took place on the top surface of cry treated inserts. Increase in C percentage may be attributed to the formation of η phase carbides which were also revealed from SEM images (Fig. 4.1 and 4.2). The increase in binder phase might be helpful in enhancing the bonding strength of WC particles.




| Element | Weight% | Atomic% |
|---|---|---|
| C | 10.63 | 39.81 |
| Ti | 10.66 | 2.74 |
| Co | 11.15 | 20.23 |
| Nb | 2.90 | 7.54 |
| Ta | 5.09 | 6.75 |
| W | 59.57 | 22.93 |
| Total | 100 | |

a



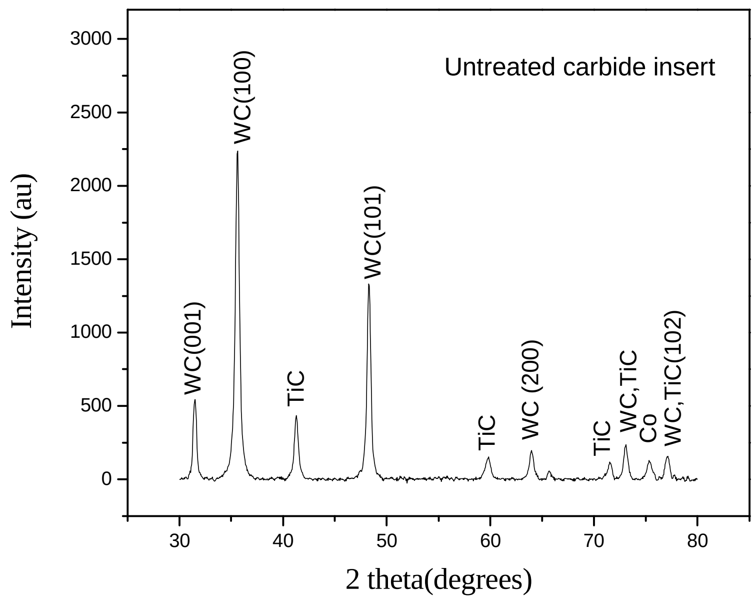

| Element | Weight% | Atomic% |
|---|---|---|
| C | 15.20 | 46.23 |
| Ti | 8.89 | 2.07 |
| Co | 16.05 | 26.34 |
| Nb | 2.4 | 5.66 |
| Ta | 3.89 | 3.88 |
| W | 53.57 | 16.82 |
| Total | 100 | |

b

Figure 4.3 Representative EDS spectra for (a) untreated and (b) cryo treated cemented carbide inserts

### 4.1.3 XRD Analysis

The crystallographic phases and its orientation of untreated and cryo treated carbide inserts were studied using X-ray diffraction technique. Figure 4.4 shows XRD spectra for untreated and cryo treated carbide inserts. Both the profile indicates the presence of WC, TiC, Co. However, the XRD profile of the cryo treated inserts qualitatively indicated more amount of Co on the top

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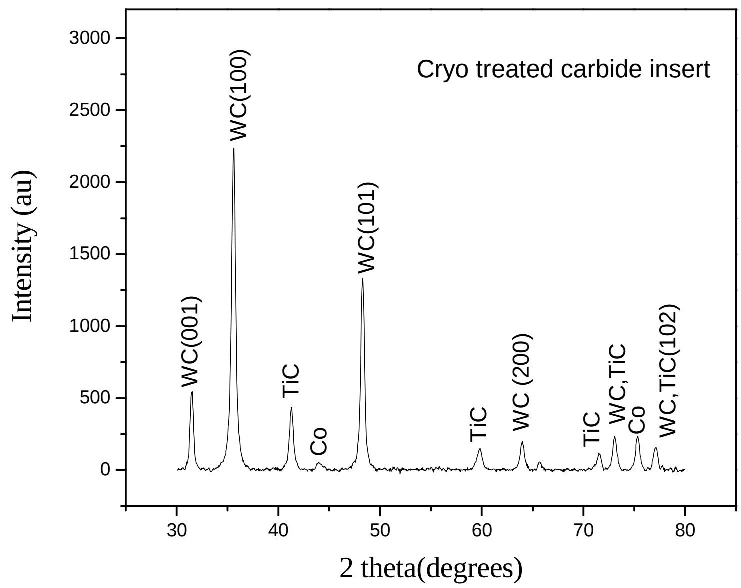



b

Figure 4.4 XRD Spectra for (a) untreated and (b) cryo treated ISO P30 cemented carbide insert surface. This again indicates the phase reorientation or densification of Co binder phase, an observation which was also supported by EDS analysis.

### 4.1.4 Vickers microhardness

Microhardness is one of the important mechanical characteristics and results from different microstructural and phase change of a material. Therefore, the influence of cryo treatment was studied on the Vickers microhardness of ISO P30 cemented carbide inserts. The experiment was carried out according to the procedure described in Section 3.3, and the results are shown in figure 4.5. It indicates that average Vickers microhardness of untreated insert was 1369 kgf/mm$^2$ whereas that of cryo treated one was 1409 kgf/mm$^2$. Therefore, there was a 3% increase in the microhardness of the inserts after cryogenic treatment. The small or insignificant increase in microhardness despite the presence of η phase carbides might be attributed to the simultaneous densification of surface cobalt due to cryo treatment.

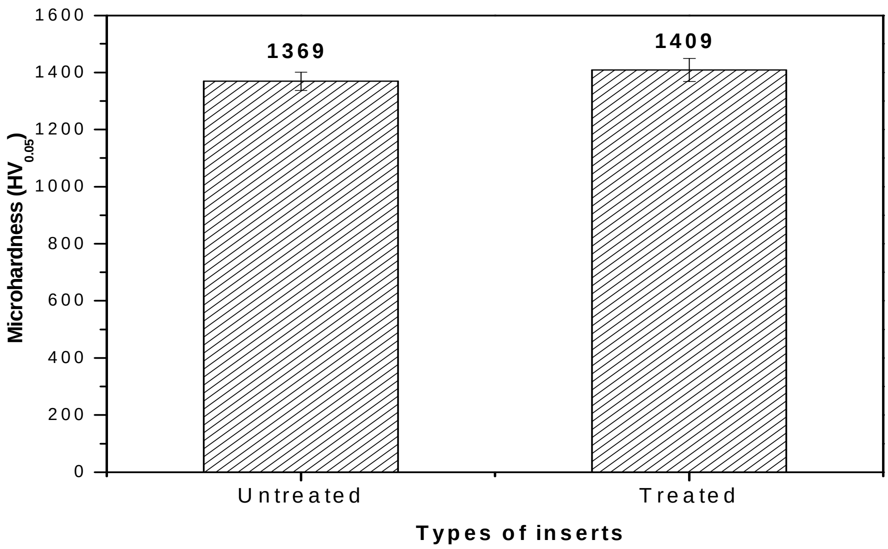



Figure 4.5 Variation of micro hardness for various post treatment

## 4.2. Effect of Cryogenic Treatment on Performance Evaluation in Machining of Cemented Carbide Inserts

### 4.2.1. Study of tool life

After comparative evaluation of the characteristics of untreated and cryo treated inserts, attempt was made to investigate the influence of cryo treatment on machining performance of ISO P30 cemented carbide inserts in dry turning of AISI 316 grade stainless steel. During the performance evaluation in machining, tool life test was conducted for different values of cutting speed i,e 100, 150, 200 m/min. with a constant feed of 0.2 mm/rev and depth of cut 1mm. Figure 4.6 demonstrates the optical micrographs It is evident from that the tool life of untreated inserts was 360 sec where as cryo treated carbide inserts lasted up to 600 s.

Similar trend was also obtained for a cutting speed of 150 m/min. Here the untreated inserts fail after 240 s where as cryo treated inserts continued up to 360 s shown in figure 4.7. More over evident of edge chipping was observed on untreated inserts.

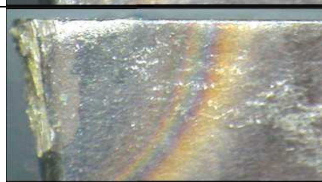
| Workpiece: 316 steel, Vc: 100 m/min, f: 0.2 mm/rev, t: 1 mm, Environment: Dry | | | |
|---|---|---|---|
| Sl.No. | Machining Duration(Sec) | Untreated | Treated |
| 1 | 120 |  |  |
| 2 | 240 |  |  |
| 3 | 300 |  |  |
| 4 | 360 |  |  |
| 5 | 420 | |  |
| 6 | 480 | |  |
| 7 | 540 | |  |
| 8 | 600 | |  |

Figure 4.6 Optical micrographs (with magnification 35 x) of the flank surface of untreated and treated turning inserts after different durations of machining.

| Workpiece: 316 steel, Vc: 150 m/min, f: 0.2 mm/rev, t: 1 mm, Environment: Dry | | | |
|---|---|---|---|
| SL.NO. | MACHINING DURATION (Sec) | UNTREATED | TREATED |
| 1 | 60 |  |  |
| 2 | 120 |  |  |
| 3 | 180 |  |  |
| 4 | 240 |  |  |
| 5 | 300 | |  |
| 6 | 360 | |  |

Figure 4.7 Optical micrographs (with magnification 35 x) of the flank surface of untreated and treated turning inserts after different durations of machining.

When the cutting speed was increased up to 200m/min tool life decreased for both untreated and cryo treated inserts, however the tool life of cryo treated inserts was found to be more compare to untreated inserts as shown in figure 4.8

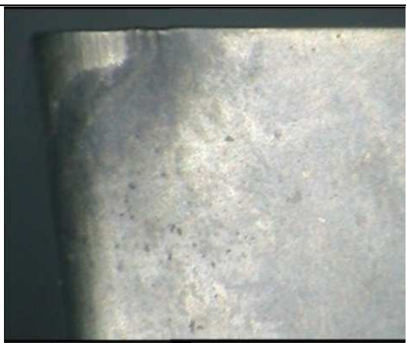
| Work piece: 316 steel, Vc: 200 m/min, f: 0.2 mm/rev, t: 1 mm, Environment: Dry | | | |
|---|---|---|---|
| SL.NO. | MACHINING DURATION | UNTREATED | TREATED |
| 1 | 60 |  |  |
| 2 | 120 |  |  |
| 3 | 180 | |  |

Figure 4.8 Optical micrographs (with magnification 35 x) of the flank surface of untreated and treated turning inserts after different durations of machining.

| Workpiece: 316 steel, Vc: 100 m/min, f: 0.2 mm/rev, t: 1 mm, Environment: Dry | | | |
|---|---|---|---|
| Sl.No. | Machining Duration (Sec) | Untreated | Treated |
| 1 | 120 |  |  |
| 2 | 240 |  |  |
| 3 | 300 |  |  |
| 4 | 360 |  |  |
| 5 | 420 | |  |
| 6 | 480 | |  |
| 7 | 540 | |  |
| 8 | 600 | |  |

Figure 4.9 Optical micrographs (with magnification 35 x) of the rake surface of untreated and treated turning inserts after different durations of machining.

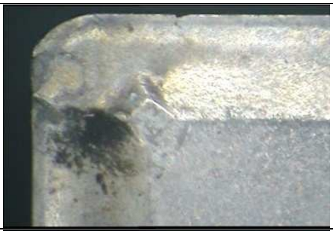
| Workpiece: 316 steel, Vc: 150 m/min, f: 0.2 mm/rev, t: 1 mm, Environment: Dry | | | |
|---|---|---|---|
| SL.NO. | MACHINING DURATION (Sec) | UNTREATED | TREATED |
| 1 | 60 |  |  |
| 2 | 120 |  |  |
| 3 | 180 |  |  |
| 4 | 240 |  |  |
| 5 | 300 | |  |
| 6 | 360 | |  |

Figure 4.10 Optical micrographs (with magnification 35 x) of the rake surface of untreated and treated turning inserts after different durations of machining.

Figure 4.9, 4.10, 4.11 shows the optical microscopic image of the rake surface of untreated and cryo treated inserts after machining with different cutting speed. Some crater wear took place on the untreated inserts. Evident of some amount of crater wear noted on untreated inserts, however no such evident of damages rake surface of cryo treated inserts would be found

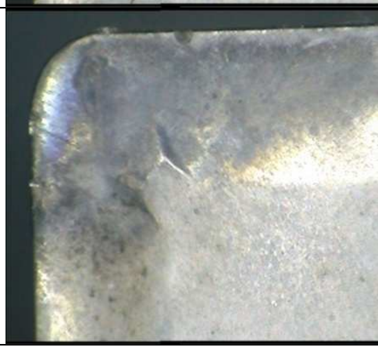
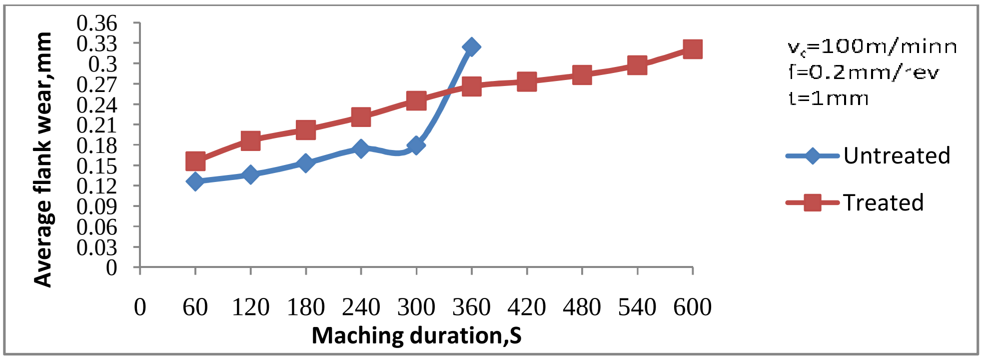
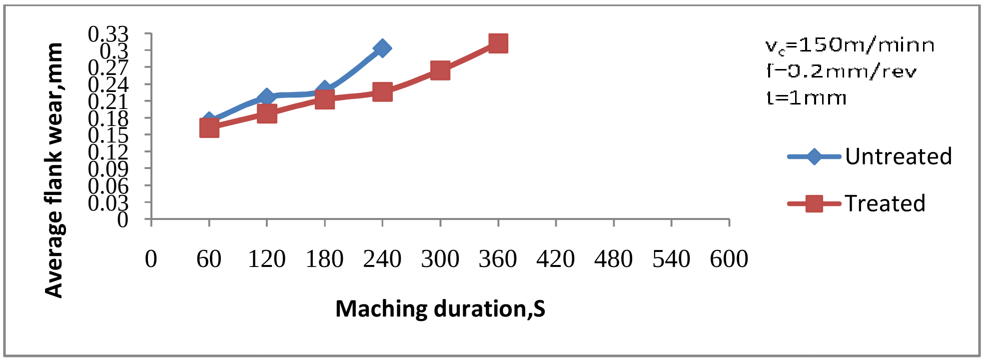
| Work piece: 316 steel, Vc: 200 m/min, f: 0.2 mm/rev, t: 1 mm, Environment: Dry | | | |
|---|---|---|---|
| SL.NO. | MACHINING DURATION | UNTREATED | TREATED |
| 1 | 60 |  |  |
| 2 | 120 |  |  |
| 3 | 180 | |  |

Figure 4.11 Optical micrographs (with magnification 35 x) of the rake surface of untreated and cryo treated turning inserts after different durations of machining.

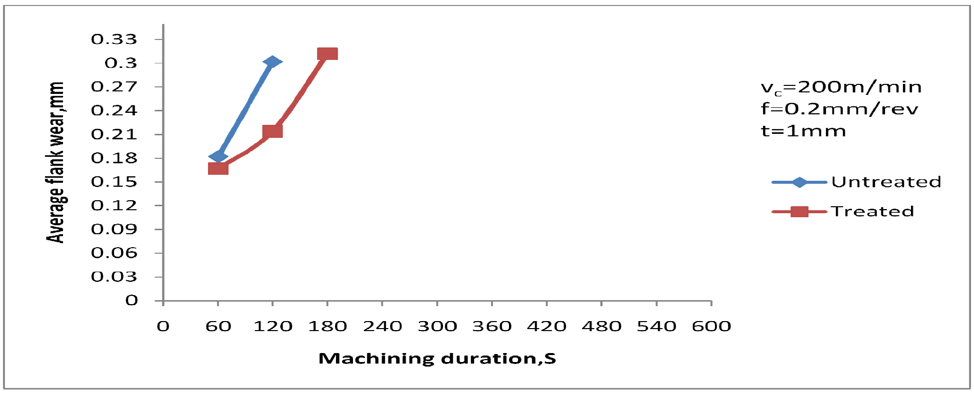
The previous result have been shown graphically in Figure 4.15.it is evident that cryo treated carbides inserts result in superior tool life compare to its untreated counterpart for the entire range of cutting speed.




a



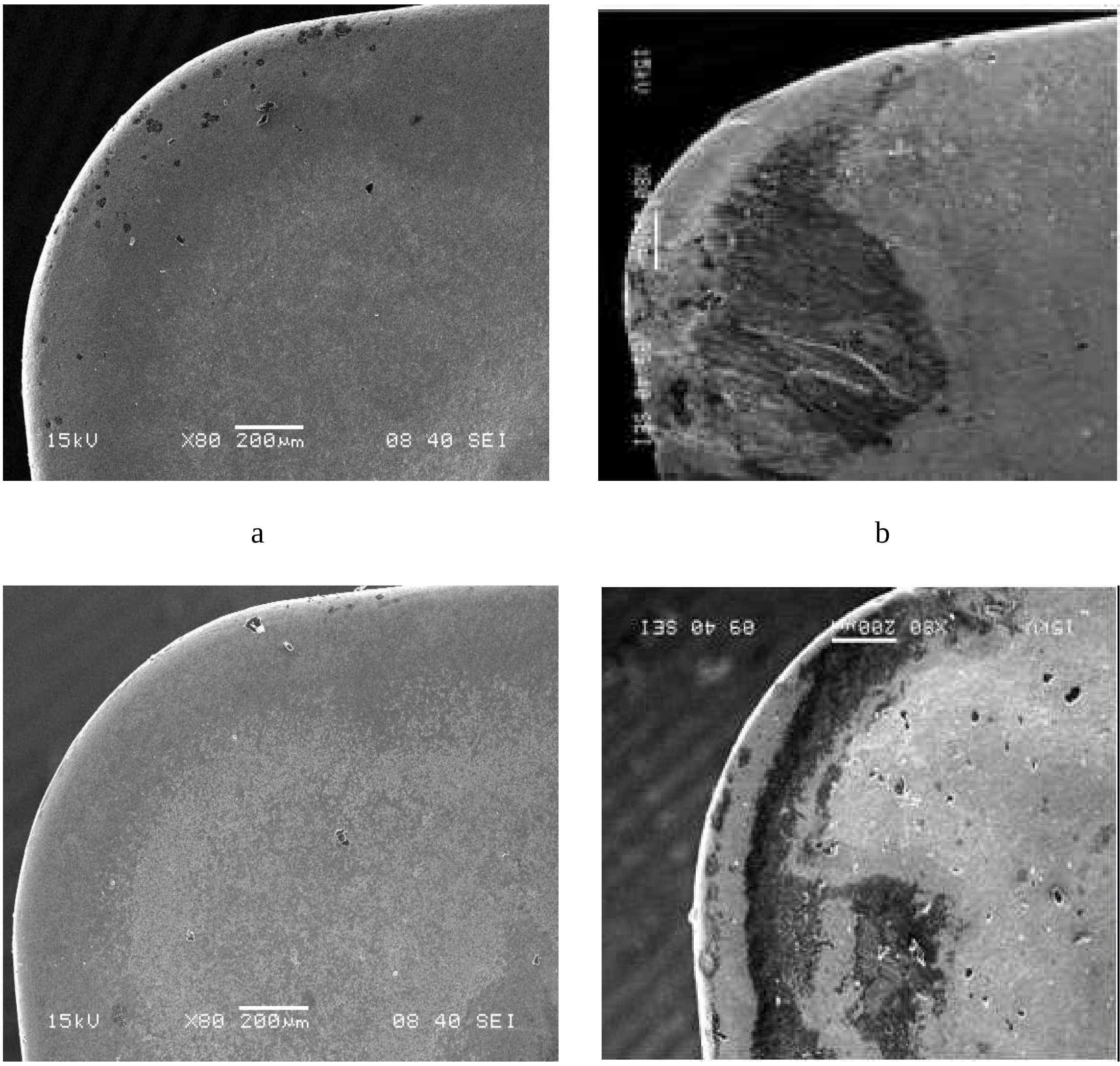

b




C

Figure 4.12 Effect of cutting speed:(a) $V_c$=100m/min (b) $V_c$=150m/min and (c) $V_c$=200m/min and machining duration on average flank wear

This may be attributed to higher wear resistance due to formation of $\eta$ phase carbide which are very hard and densification of surface cobalt which enhances bonding strength of tungsten carbide

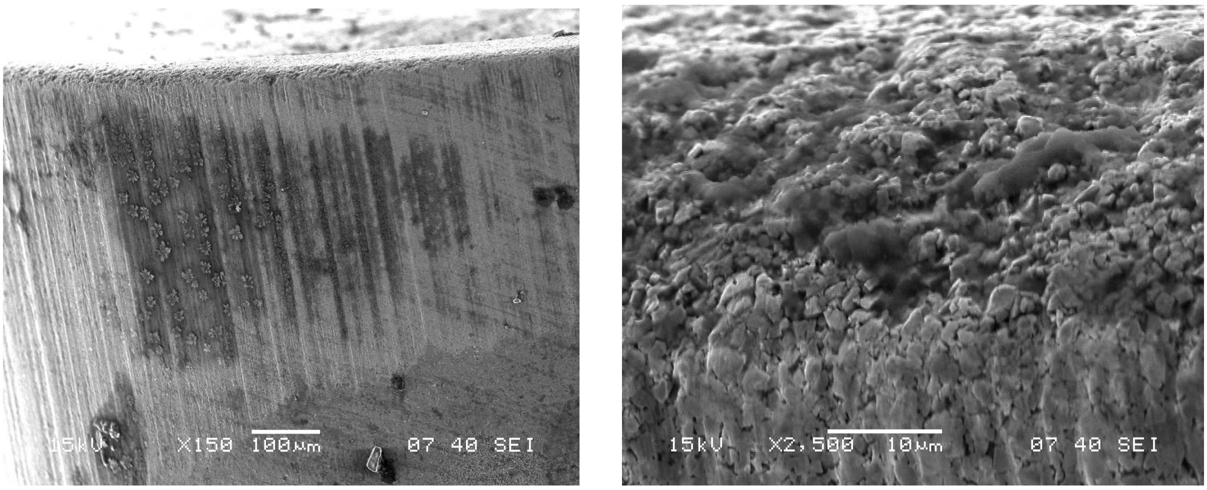



a b

c d

Figure 4.13 SEM Images of rake face of cemented carbide inserts (a) untreated (before machining), (b) untreated (after machining), (c) cryo treated (before machining), (d) cryo treated (after machining).

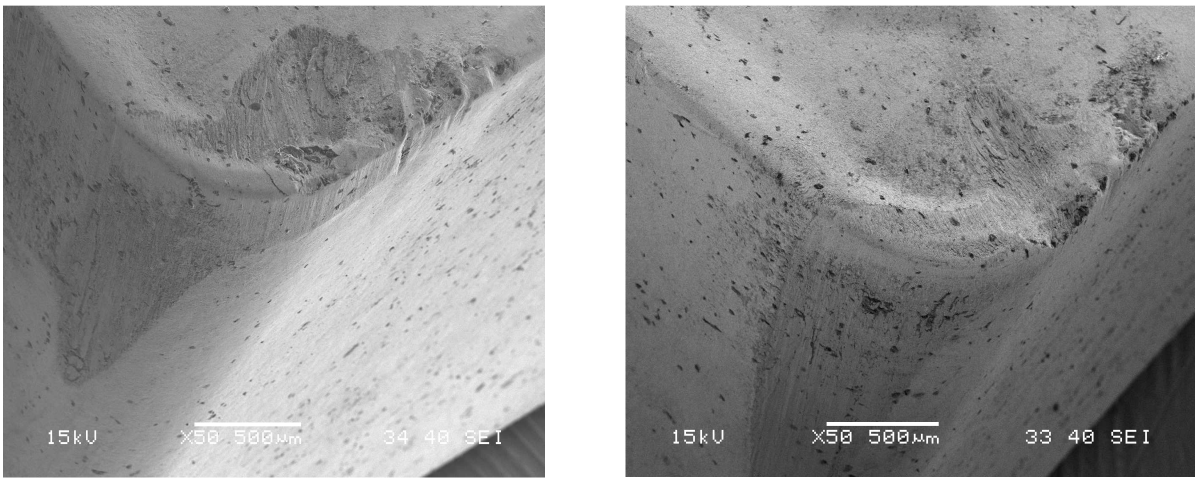
Figure 4.14 shows the SEM images of the tool after machining .Very smooth and regular flank wear band was observed for cryo treated and no evident of edge chipping was observed




a b

Figure 4.14 SEM image of flank face of cryo treated inserts after $V_c$=100m/min, T=600sec

This figure shows of SEM images principal cutting edge of cryo treated inserts after machining with 100m/min.




a b

Figure 4.15 SEM image of flank face of (a) untreated, (b) cryo treated inserts after $V_c$=200m/min

Table 4.1 Average flank wear for untreated insert

| Sl No | Machining Duration(sec) | | Cutting Velocity, $V_c$ (m/min) | | |
|---|---|---|---|---|---|
| | | | 100 | 150 | 200 |
| 1 | 60 | Average Flank Wear, VB(mm) | 0.126 | 0.174 | 0.182 |
| 2 | 120 | | 0.136 | 0.216 | 0.302 |
| 3 | 180 | | 0.153 | 0.229 | |
| 4 | 240 | | 0.174 | 0.303 | |
| 5 | 300 | | 0.179 | | |
| 6 | 360 | | 0.324 | | |

Table 4.2 Average flank wear for treated inserts

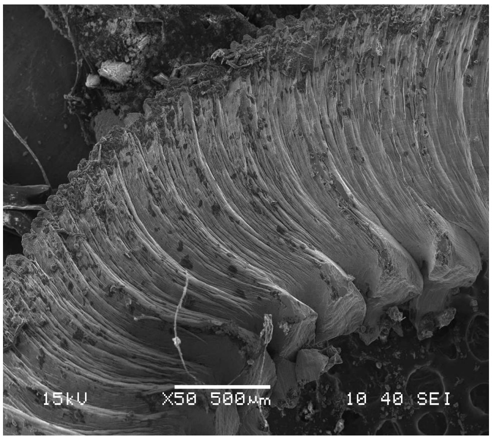
| Sl No | Machining Duration(s) | | Cutting Velocity, $V_c$ (m/min) | | |
|---|---|---|---|---|---|
| | | | 100 | 150 | 200 |
| 1 | 60 | Average Flank Wear, VB(mm) | 0.156 | 0.162 | 0.167 |
| 2 | 120 | | 0.186 | 0.187 | 0.214 |
| 3 | 180 | | 0.202 | 0.212 | 0.312 |
| 4 | 240 | | 0.221 | 0.226 | |
| 5 | 300 | | 0.245 | 0.264 | |
| 6 | 360 | | 0.266 | 0.312 | |
| 7 | 420 | | 0.273 | | |
| 8 | 480 | | 0.283 | | |
| 9 | 540 | | 0.297 | | |
| 10 | 600 | | 0.321 | | |

### 4.2.2 Chipmorphology

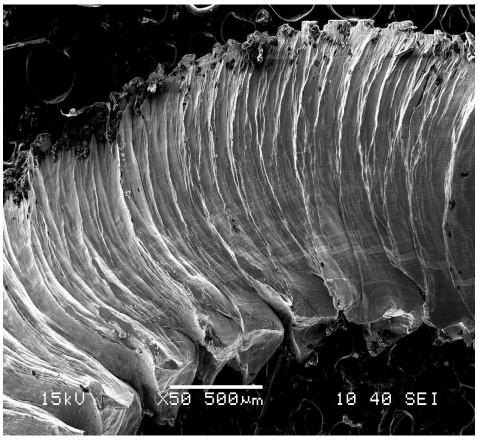
Figure 4.16 shows the micro morphology of the chip of untreated and cryo treated inserts for different cutting speed .It is evident chip radius in less after machining with cryo treated inserts compare that of untreated inserts.

| Sl.No. | Cutting Speed($V_c$) | Untreated | Cryo treated |
|---|---|---|---|
| 1 | 100 |  |  |
| 2 | 150 |  |  |
| 3 | 200 |  |  |

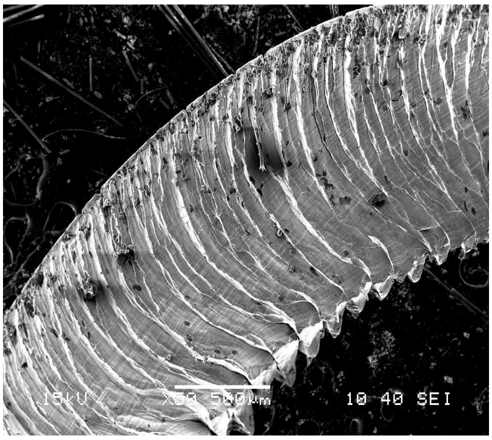
Figure 4.16 Optical microscope of chip at different cutting speed




a




b




c

Figure 4.17 SEM image of chip (a)$V_c$=100m/min, (b) $V_c$=150m/min, (c) $V_c$=200m/min

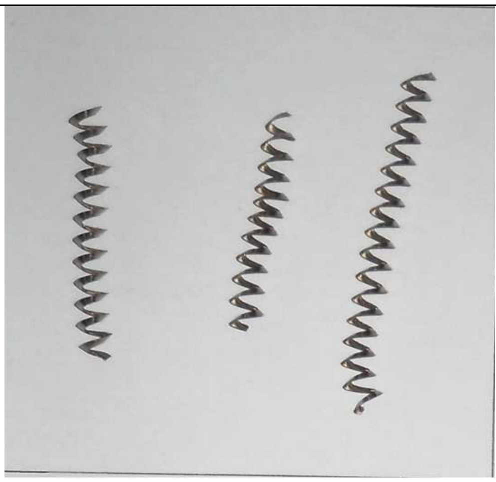
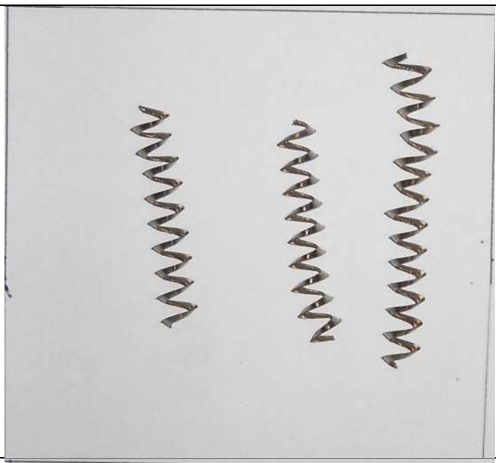
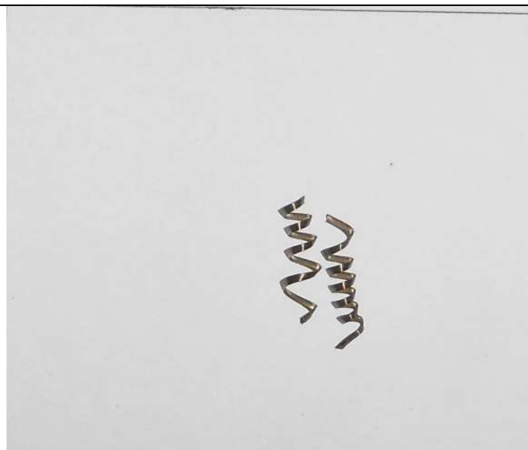
| $V_C$ (m.min) | Untreated | Cryo treated |
|---|---|---|
| 100 |  |  |
| 150 |  |  |
| 200 |  |  |

Figure 4.18 optical images of chip at different cutting speed

Table 4.3 Chip Characteristic at different cutting speed for untreated insert

| Sl.No. | Machining duration (s) | Types of chip | Colour of chip | Chip thickness (mm) | Chip reduction coefficient (ζ) |
|---|---|---|---|---|---|
| Vc=100 m/min, f=0.2mm/rev,t=1mm | | | | | |
| 1 | 60 | Continous | Yellow | 0.48 | 2.49 |
| 2 | 120 | Continous | Yellow | 0.4833 | 2.50 |
| 3 | 180 | Continous | Yellow | 0.4933 | 2.55 |
| Vc=150 m/min,f=0.2mm/rev,t=1mm | | | | | |
| 1 | 60 | Discontinous | Yellow | 0.4166 | 2.16 |
| 2 | 120 | Discontinous | Yellow | 0.433 | 2.24 |
| 3 | 180 | Discontinous | Yellow | 0.446 | 2.31 |
| Vc=200 m/min,f=0.2mm/rev,t=1mm | | | | | |
| 1 | 60 | Continous | Yellow | 0.40 | 2.07 |
| 2 | 120 | Continous | Yellow | 0.403 | 2.09 |
| 3 | 180 | Continous | Yellow | 0.426 | 2.21 |

Table 4.4 Chip characteristic at different cutting speed for treated insert

| Sl.No. | Machining duration (s) | Types of chip | Colour of chip | Chip thickness (mm) | Chip reduction coefficient (ζ) |
|---|---|---|---|---|---|
| Vc=100 m/min,f=0.2mm/rev,t=1mm | | | | | |
| 1 | 60 | Continous | Yellow | 0.42 | 2.176 |
| 2 | 120 | Continous | Yellow | 0.43 | 2.22 |
| 3 | 180 | Continous | Yellow | 0.433 | 2.24 |
| Vc=150 m/min,f=0.2mm/rev,t=1mm | | | | | |
| 1 | 60 | Discontinous | Yellow | 0.38 | 1.96 |
| 2 | 120 | Discontinous | Yellow | 0.33 | 1.70 |
| 3 | 180 | Discontinous | Yellow | 0.35 | 1.81 |
| Vc=200 m/min,f=0.2mm/rev,t=1mm | | | | | |
| 1 | 60 | Continous | Yellow | 0.32 | 1.65 |
| 2 | 120 | Continous | Yellow | 0.33 | 1.70 |
| 3 | 180 | Continous | Yellow | 0.34 | 1.76 |

It is evident from the figure 4.19 that average chip thickness decreased with cutting speed for both untreated and cryo treated inserts .However the average chip thickness is constituently less for treated carbide inserts compare to untreated carbide inserts after machining with different cutting speed. Higher wear resistance of rake surface of cryo treated inserts, secondary deformation of the chip is less which result in less damage on rake surface was observed and chip tool interface friction is also less. It is ensure higher degree of secondary deformation of chip and consequently less chip thickness

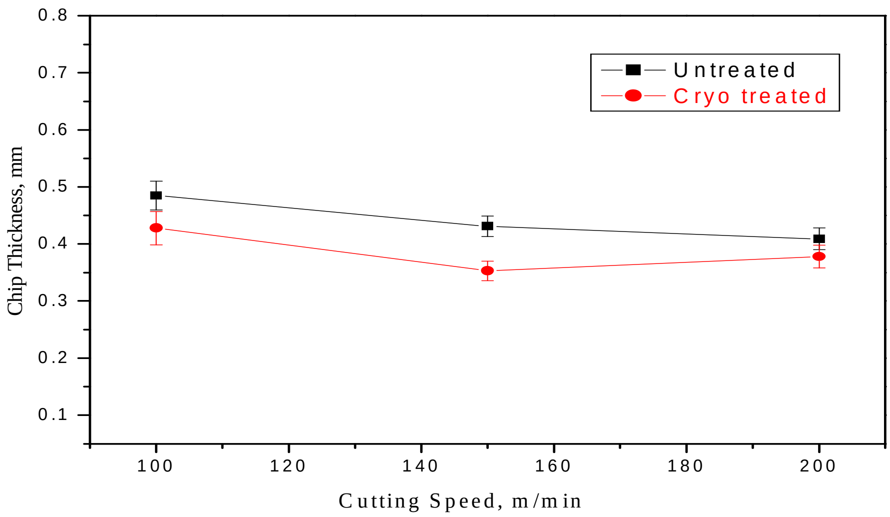



Figure 4.19 Variation of chip thickness with cutting speed for untreated and treated inserts

# CHAPTER 5

# Conclusion

# 5. CONCLUSION

1. Cryogenic treatment of P-30 cemented carbide inserts results in change in microstructure, formation of η phase carbides and redistribution or densification of Co which automatically increase wear resistance.

2. The microhardness of cryo treated inserts was more on that of untreated inserts. How ever the increase is not significant.

3. Cryogenic treatment of P-30 cemented carbide inserts resulted in increasing of tool life for different cutting speed during machining of AISI 316 grade austenitic stainless steel.

4. Smooth and more regular wear pattern were observed for cryogenically treated inserts

5. Cryogenic treatment also improved resistance to chipping.

6. The chip curl radius as well as chip thickness was found to be less for chip after machining with cryo treated inserts.

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