# FABRICATION AND PERFORMANCE MEASUREMENT OF UNCOATED CARBIDE INSERT

**By**

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A thesis submitted to the Department of Industrial & Production Engineering, Bangladesh University of Engineering & Technology, Dhaka, in partial fulfillment of the requirements for the degree of Master of Engineering in Industrial & Production Engineering (IPE).



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The thesis titled "Fabrication and performance measurement of uncoated carbide insert" submitted by Khan Habibur Rahman, Student No- 100108013P, Session - October 2001 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Engineering in Industrial & Production Engineering (IPE) on 22 May 2007

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Khan Habibur Rahman

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# ABSTRACT

Tungsten carbide/cobalt ("WC/Co") is widely used for cutting tools, metal-forming tools, mining tools, and wear resistance surfaces for various applications. For these applications the important mechanical properties are hardness, toughness, compressive strength, transverse rupture strength, and wear resistance.

The properties of tungsten carbide/cobalt (WC/Co) are controlled by composition and microstructure. The hardness increases with decreasing Co (Cobalt) content and smaller particle size of WC. Again addition of titanium carbide and tantalum carbide with WC/Co improve significantly hot hardness; reduce transverse rupture strength and the tendency of chips to weld of the cutting tool edge.

In this project work, carbide insert was fabricated by varying composition and reducing the grain size of tungsten carbide (WC) in BOF (Bangladesh Ordnance Factories). Here this insert is termed as the 'New Insert' and the standard/traditional insert of BOF is termed as 'Existing Insert'. The composition of fabricated carbide was selected by reviewing several papers and handbooks. The grain size of WC is measured by using the sieve. Other parameters of present WC fabrication process remain unchanged.

To compare the performance, brazed insert turning tool was manufactured by the newly fabricated insert and machining on steel was performed. Process parameters such as tool wear, surface finish and temperature was recorded for both the newly fabricated insert and existing insert with same cutting condition. It is found that surface finish improved whereas tool wear and temperature generation reduces for the newly fabricated insert tool.

## CONTENTS

# Chapter-1



# Introduction

## 1.1 INTRODUCTION

Cemented tungsten carbides are a class of very hard wear resistant materials produced by powder metallurgy processing. Karl Schroter made significant contributions toward the development of modern cemented carbide in Germany in the early 1920's. Carbides are commercially one of the oldest and most successful powder metallurgy products. The wide application of cemented carbides for cutting tools and wear resisting parts because of their combination of mechanical, physical, and chemical properties. The ingredients of most commercial carbides are tungsten carbide, titanium carbide, tantalum carbide and cobalt binder.

In a production system machine tool, cutter, attachments, and tooling has vital role. Among these things fast-moving item is cutter or cutting tool. If the performance of cutting tool is not good, then it causes the increase in production time and decreases in quality and finally affects the production cost.

There are wide variety of tool materials has been developed to fulfill the demands of modern production practice on different machine tools. The best tool material for a certain job is the one that will produce the best job at the lowest cost.

The growing demand for higher productivity, product quality and overall economy in manufacturing by machining, particularly to meet the challenges thrown by liberalization and global cost competitiveness, insists high metal removal rate and high stability and long life of cutting tool.

But high production machining with high cutting velocity, feed and depth of cut is inherently associated with generation of large amount of heat and high cutting temperature. So the desirable properties for any tool material will be the ability to resist softening at high temperature (Hot hardness), a low co-efficient of friction, good wear resistance qualities, and sufficient toughness to resist fracture. Use of cemented carbide tools in machining is a solution to avoid these problems. The main characteristics of cemented carbide tools are high hardness, high heat resistance, high wear resistance and high hot hardness (because it will maintain a cutting edge at temperature about 1000°C). Carbide tools permit cutting speed 2~3 times that of cast alloy tools. [1,2]

Depending upon the amount of cobalt (binder material) content, titanium carbide and the grain size of tungsten carbide, variety of cobalt bonded cemented carbides has been developed for different machining purpose.

Cemented carbide tools containing tungsten carbide and cobalt (binder material) are suitable for drawing dies, forming-die inserts, punches and cutting tools for machining cast iron and most other materials except steel. Cemented carbide containing only tungsten carbide and cobalt are known as "straight grades". Straight grades carbides cannot satisfactorily machine steel because the chips stick or weld to the tool surface and soon ruins the tool. To eliminate this difficulty, titanium or tantalum carbides are added with WC. This type of carbides is termed as "complex grade". [3,4,5]

Use of cemented carbide tools in production factory will reduce production cost, improve product quality & quantity, reduce cutting fluid cost and save power. Now for the development of carbide-cutting tool inserts, it is very essential to study the effect of cobalt content, titanium carbide and the grain size of tungsten carbide in cemented carbide tools

The most important advance in carbide cutting tool technology is the development of coated tools. Typical coatings are Titanium Carbide (TiC), Titanium Nitride (TiN), Titanium Carbonitride (TiCN), and Alumina ($Al_2O_3$). Among these TiN is widely used for its lower coefficient of friction against steels compared to WC/Co

In BOF (Bangladesh Ordnance Factories) both straight grade and complex grade carbide is used to produce die (forming and drawing) and cutting tool inserts respectively by powder metallurgy process. The quality of carbide die (92% WC & 8% Co) of BOF is good. But there is scope of improvement of the quality of cutting tool inserts of BOF.

The aim of the present research is to fabricate uncoated carbide cutting insert by varying some process parameter such as particle size, composition, sintering temperature and soaking time during the fabrication process of carbide tools. Then some specimen carbide tools will be fabricated by varying the experimental parameter. To find out the performance of these fabricated cutting tools, machining on steel will be performed. And tools wear and surface finish will be measured. This work also designed to find out the performance both of existing insert and that of experimentally produced insert.

## 1.2 OBJECTIVES OF THE STUDY

The main objectives of this project work are: .

i. Fabrication of carbide insert by changing process parameters e.g. particle size of powder (WC), Soaking time, Sintering temperature, and Powder Composition (WC, TiC, Co).

ii. Preparation of carbide turning tool by the fabricated insert.

iii. Measurement of tool wears and surface finish.

iv. Comparison of performance of the experimentally fabricated tool with the existing tool.

v. Selection of optimum parameter for best carbide tool.

## 1.3 METHODOLOGY

The step-by-step methodology for this project work is outlined below:

i. Study the present fabrication process of carbide insert.

ii. Selection of (powder) composition for carbide tips by studying the literature.

iii. Selection of duration / values of other process parameters (Soaking time, and Sintering temperature)

iv. Performance evaluation (under same cutting condition) of the existing and experimentally fabricated inserts / tips that includes the following:

(a) Measurement of tool wears under different cutting length and time

(b) Surface roughness under different cutting time and length

v. Comparison of the performance of newly fabricated cutting tool with the previous cutting tool

## 1.4 FABRICATION OF CEMENTED CARBIDES

In 1923 Karl Schroter discovered a new technique. In this technique carburized tungsten is mixed with metallic cobalt. This mixture is pressed into a die and heated to a temperature below the melting point of cobalt, under a protective atmosphere of hydrogen or in vacuum. In this process of sintering the tungsten carbide dissolves in the cobalt and by recrystallization the carbide grains grow. On cooling the carbide is precipitated from the cobalt. These carbide grains are cemented (joined) together by cobalt. Hence the name cemented carbide. [2]

Carbides are made by blending micron-sized tungsten carbide and cobalt powders, then compacting the mixture in a mold and sintering the molded part at a temperature high enough to cause the cobalt to flow in the pores under capillary action. During this process the cobalt fills the voids between the tungsten grains and thoroughly coats each grain under action of surface tension. When the cobalt solidifies, it cements the grains together and forms a dense composite. Cemented carbides get their hardness from the tungsten grains and their toughness from the tight bonds produced by the cementing action of the cobalt metal. By varying the amount of cobalt and tungsten carbide grain size the hardness, wear resistance and toughness (shock resistance) of the carbide can be changed to suit the particular tungsten carbide needs.

# Chapter-2

# BACKGROUND STUDY AND LITERATURE REVIEW

## 2.1 INTRODUCTION

In 1923 Karl Schroter discovered a new technique. In this technique carburized tungsten is mixed with metallic cobalt. This mixture is pressed into a die and heated to a temperature below the melting point of cobalt, under a protective atmosphere of hydrogen or in vacuum. In this process of sintering, the tungsten carbide dissolves in the cobalt and by recrystallization the carbide grains grow.

## 2.2 CHARACTERISTICS OF CEMENTED CARBIDE TOOLS

In 1979, Kumar Dr. B, [1] showed the main characteristics of cemented carbide tools are

i. High hardness.
ii. High heat resistance.
iii. High wear resistance
iv. High hot hardness unto a temperature of 900°C.
v. Low specific heat.
vi. High thermal conductivity.
vii. Low thermal expansion (compared to steels).
viii. They can operate at high cutting speeds ranging from 45 to 360 meter per minute.
ix. Grinding is very difficult and can be done only with silicon carbide or diamond wheels.

In 1987 Amstead, B.H [2] found that carbide tools permit cutting speed 2~3 times that of cast alloy tools. The main characteristics of cemented carbide tools are high hardness, high heat resistance, high wear resistance and high hot hardness (because it will maintain a cutting edge at temperature about 1000°C). Carbide tools must be very rigidly supported to prevent cracking as they are very brittle and has low resistance to shock. Cemented carbide (contains WC and cobalt) cannot satisfactorily machine steel because the chips stick or weld to the tool surface and soon ruins the tool. To eliminate this difficulty, titanium or tantalum carbides are added with WC.

## 2.3 CLASSIFICATION OF CEMENTED CARBIDES

The first cemented carbide was produced by tungsten carbide with a cobalt binder. Over the years, this original material has been modified in many ways to produce a variety of cemented carbides that can be used in a wide range of applications.

In 1989 ASM committee [3] classified cemented carbides mainly into two categories (depending on the ingredients used).

Cemented carbide containing only tungsten carbide and cobalt (binder material) are known as "straight grades". Straight grade carbide are suitable for drawing dies, forming-die inserts, punches and cutting tools for machining cast iron and most other materials except steel.

Cemented carbide containing tungsten carbide, titanium carbide, tantalum carbide, and/or niobium carbide and cobalt, and/or nickel (binder material) are known as " Complex grades". Complex grades are used chiefly to make cutting tools and cutting tool insert for machining steel. Tools made of complex grades exhibit less wear than that of straight grades. Also the complex grades have better resistance to deformation at the temperatures developed along the cutting edge.

To think about the improvement of cemented carbide, it is essential to know the properties of different grades carbide and the effect of alloying elements, grain size of powder, sintering temperature, etc.

## 2.4 PROPERTIES OF REFRACTORY METAL CARBIDES AND BINDER MATERIALS USED IN MANUFACTURING OF CEMENTED CARBIDE [3,9]

According to ASM committee [3] the properties of a tungsten carbide depend on the properties of refractory material used in that carbide. The Properties of refractory metal carbides tungsten carbide (WC), titanium carbide (TiC), Vanadium carbide (VC), Hafnium carbide (Hf), Zirconium carbide (ZrC), Niobium carbide (NbC), Tantalum carbide (TaC) and properties of binder material Nickel and Cobalt are shown in Table 2.1. Knowledge of these basic properties of the refractory carbides is useful in understanding, generally, why cemented carbides resist wear at elevated temperature and have high modulus of elasticity and high densities.

**Table: 2.1** Properties of refractory metal carbides and binder materials used in manufacturing of cemented carbide.

| Material | Hardness HV (50 kg) | Crystal structure | Melting temperature (°C) | Theoretical density, $g/cm^3$ | Modulus of elasticity, GPa | Thermal expansion, μm/m°K |
|---|---|---|---|---|---|---|
| WC | 2200 | Hexagonal | 2800 | 15.63 | 696 | 5.2 |
| TiC | 3000 | Cubic | 3100 | 4.94 | 451 | 7.7 |
| VC | 2900 | Cubic | 2700 | 5.71 | 422 | 7.2 |
| HfC | 2600 | Cubic | 3900 | 12.76 | 352 | 6.6 |
| ZrC | 2700 | Cubic | 3400 | 6.56 | 348 | 6.7 |
| NbC | 2000 | Cubic | 3600 | 7.8 | 338 | 6.7 |
| TaC | 1800 | Cubic | 3800 | 14.50 | 285 | 6.3 |
| $Cr_3C_2$ | 1400 | Orthorhombic | 1800 | 6.66 | 373 | 10.3 |
| Co | <100 | Cubic/ hexagonal | 1495 | 8.9 | 207 | 16.0 |
| Ni | <100 | Cubic | 1455 | 8.9 | 207 | 15.0 |

## 2.5 VARIATIONS OF PROPERTIES WITH COBALT CONTENT FOR STRAIGHT GRADES OF CEMENTED CARBIDES

**According to ASM committee** [3] the properties of tungsten carbide/cobalt (WC/Co) are controlled by composition and microstructure. The hardness, compressive strength, modulus of elasticity and abrasion resistance increases with decreasing of cobalt content and particle size (Fig. 2.1 ~ Fig. 2.5)

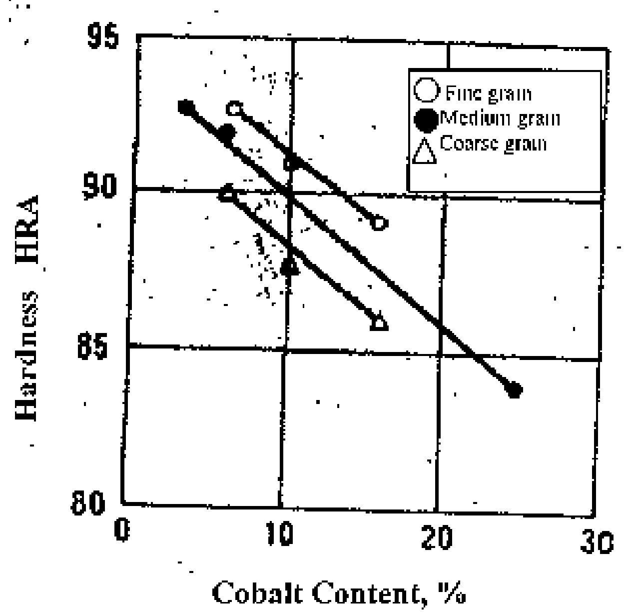



**Figure 2.1** Variations of hardness with cobalt content for straight grades of cemented carbides.

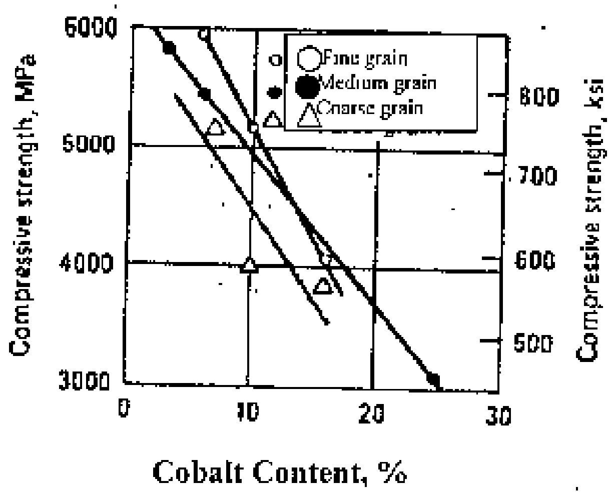



**Figure 2.2** Variations of Compressive Strength with cobalt content for straight grades of cemented carbides.

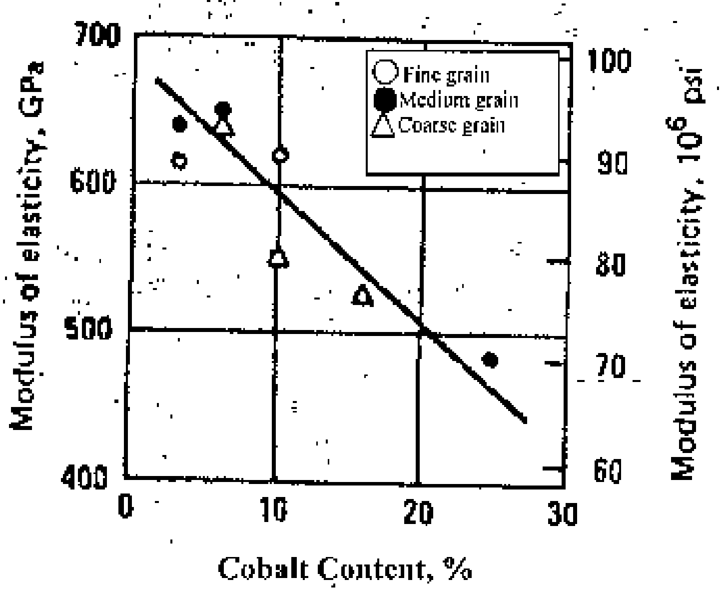



**Figure 2.3** Variations of Modulus of Elasticity with cobalt content for straight grades of cemented carbides.

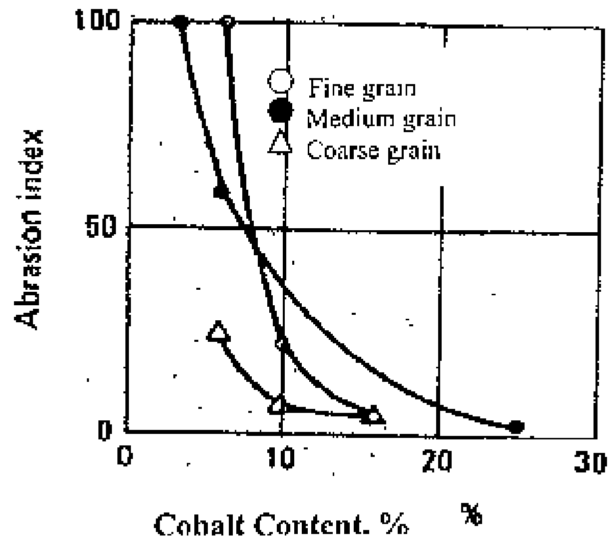



**Figure 2.4** Variations of abrasion index with cobalt content for straight grades of cemented carbides.

Transverse rupture strength of carbide increases with increasing of cobalt content and decreasing of grain size for straight grades of cemented carbides Fig. 2.5

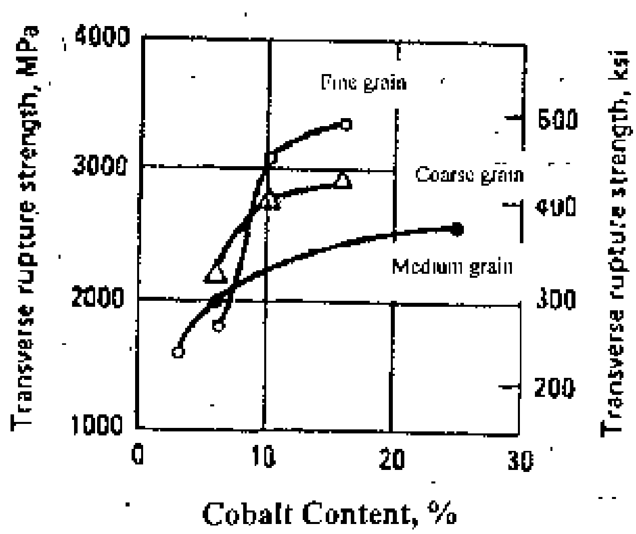



**Figure 2.5** Variations of transverse rupture strength with cobalt content for straight grades of cemented carbides.

## 2.6 PROPERTIES OF DIFFERENT GRADE TUNGSTEN CARBIDE

ASM committee showed [5] the composition and properties of six straight grades and two complex grades of cobalt-bonded carbides:

Table: 2.2 Properties of different grade tungsten carbide.

| Nominal composition | Grain size (in micron size) | Hardness HRA (60Kg) | Density $g/cm^3$ | Trans-verse strength, MPa | Compre-ssive strength, MPa | Modulus of elasticity GPa | Relative Abrasion Resistance | Thermal conducti-vity, W/m °K |
|---|---|---|---|---|---|---|---|---|
| 97WC3Co | Medium | 92.5-93.2 | 15.3 | 1590 | 5860 | 641 | 100 | 121 |
| 94WC6Co | Fine | 92.5-93.1 | 15.0 | 1790 | 5930 | 614 | 100 | ____ |
| 94WC6Co | Medium | 91.7-92.2 | 15.0 | 2000 | 5450 | 648 | 58 | 100 |
| 94WC6Co | Coarse | 90.5-91.5 | 15.0 | 2210 | 5170 | 641 | 25 | 121 |
| 90WC10Co | Fine | 90.7-91.3 | 14.6 | 3100 | 5170 | 620 | 22 | ____ |
| 90WC10Co | Coarse | 87.4-88.2 | 14.5 | 2760 | 4000 | 552 | 7 | 112 |
| 82.4WC-8.3TiC-3.3TaC-6C0 | ____ | 92 | 12.75 | 1725 | 3900 | 550 | 15 | ____ |
| 78 4WC-8.3TiC-3.3TaC-10Co | ____ | 90.8 | 12.50 | 2070 | 3900 | 515 | 10 | ____ |

## 2.7 EFFECT OF TUNGSTEN CARBIDE GRAIN SIZE AND COBALT CONTENTS ON HARDNESS

In 1989 ASM committee [3] on tooling materials suggested that of cobalt grade to have the greatest hardness and abrasion resistance properties that make it well suitable for wire drawing dies and for cutting tools in machining of cast iron and other abrasive or gummy materials. The 6% cobalt grade has moderate (Table 2.2) values of all properties and is a good for general purpose carbide material. The 25% cobalt grade has the greatest toughness, and is used for applications involving heavy impact. Because of its relatively low hardness and abrasion resistance, it is not used for cutting tools.

In 1990 Ralpha, W Stevenson [4] showed that hardness increases with decreasing of cobalt content and the finer the tungsten carbide particles, the higher the tool hardness and lower the tool toughness Fig. 2.6.

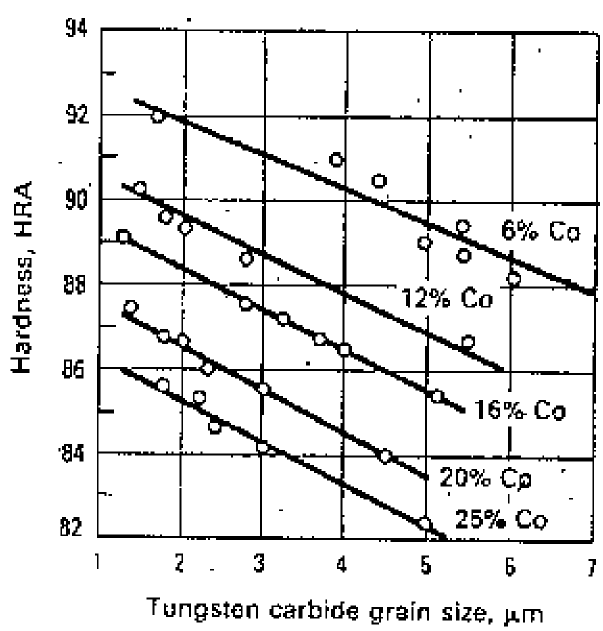



Figure 2.6 Effect of hardness on tungsten carbide grain size and cobalt contents.

## 2.8 EFFECT OF TITANIUM CARBIDE IN COMPLEX GRADE (TUNGSTEN CARBIDE/ TITANIUM CARBIDE / COBALT) CARBIDES

Ralpha W Stevenson [4] found that the complex/alloyed grades of cemented carbides are used in the machining of steel and other materials, yielding strong and continuous chips that contribute to the formation of craters on the top face of a cutting tool.

The most significant contribution of titanium carbide or a titanium carbide/ tungsten carbide solution in a carbide-cutting tool is the reduction of the tendency of chips to weld or adhere to the cutting edge. The weld strength of these alloyed grades is less than that of tungsten carbide/cobalt; consequently, adhesion does not occur, and the incidence of particle fracture from the cutting tool is reduced.

At high operating speed, temperatures developed at the tool/ chip interface are high, and tool wears results from diffusion between work and tool. Additions of titanium carbide to the basic carbide matrix reduce this diffusion wear process. Also, this addition delays the formation of craters in the rake face of the tool, which is the most common tool failure in steel cutting operations.

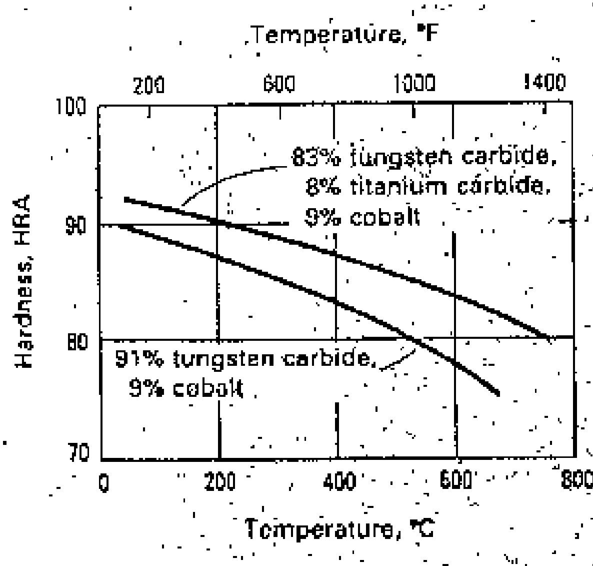



Figure 2.7 Effect of titanium carbide in complex grade (tungsten carbide/ titanium carbide / cobalt) carbides.

Hot hardness also is improved with additions of titanium carbide. Figure 2.8 shows relative hardness for two typical grades of carbides. Both grades contain 9.0 wt % Co. the alloyed compact is somewhat harder at room temperature. As temperature increases, however, the spread between the hardness of the two grades increases.

## 2.9 FACTORS CONSIDERED FOR MANUFACTURING CARBIDE INSERTS

Properties of cemented tools depend on many factors. Effect of these factors described in this literature review. From this review the main factor considered for manufacturing carbide inserts are: for maximum tool life and safety towards breakage, lowest cobalt content and finest grain size is useful. Use of titanium carbide reduces crater wear, seizing and chips welding to tool tip. When there is possibility of abrasion wears and crater wears, addition of tantalum carbide gives better results.

## 2.10 EFFECT OF SINTERING TEMPERATURE & SOAKING TIME IN MANUFACTURING OF CEMENTED CARBIDE

Ralpha, W Stevenson [6] showed increasing the sintering temperature decrease the amount of time required to achieve full density. Higher temperature also reduces the time between reaching full.density and over sintering. This relationship is shown in Fig. 2.8.

Amstead, B.H [7] found that the temperatures used in sintering are usually well below the melting point of the principal powder constituent, but may very over a wide range up to a temperature just below the melting point of binder material. Tests have proved that there is usually an optimum maximum sintering temperature for a given set of conditions with nothing to be gained by going above this temperature. The time varies with different metals, but in most the effect of heating is complete in a very short time and there is no economy in prolonging the operation.

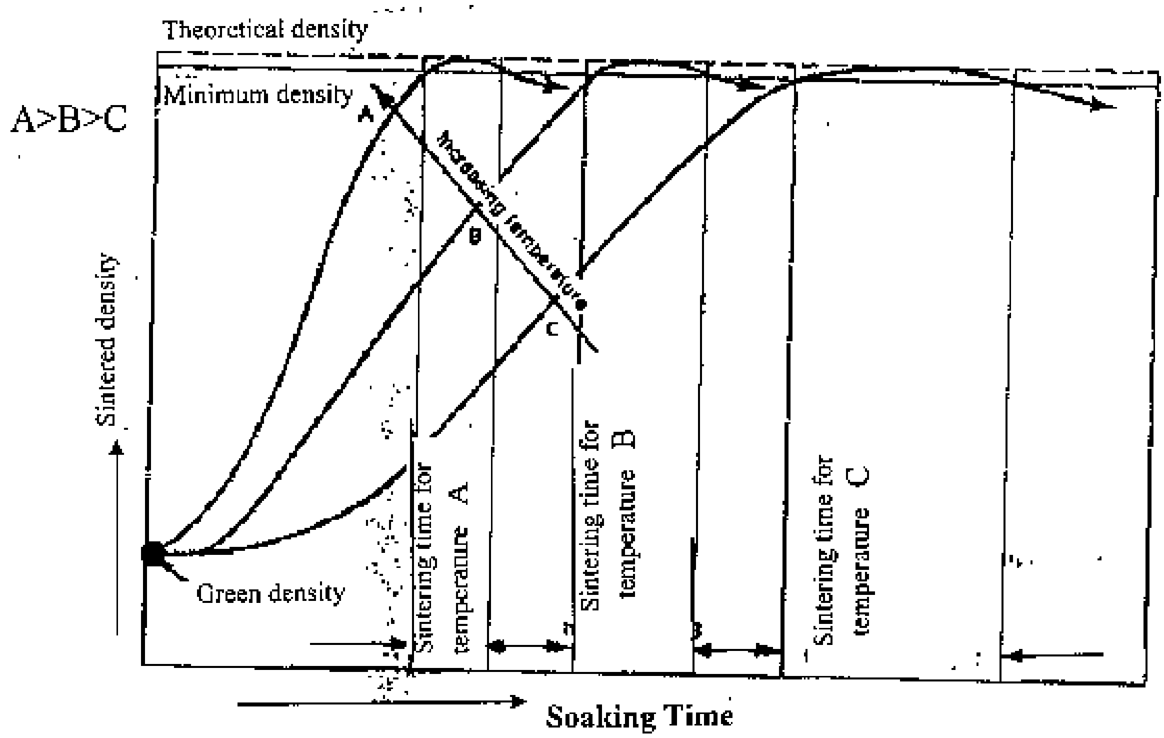



Figure 2.8 Relationship between sintering temperature & soaking time in manufacturing of cemented carbide.

Kalpakjian, Serope [8] showed that there is considerable range in the sintering temperature, but the following temperatures mentioned in Table 2.3 have proved satisfactory.

**Table 2.3** Sintering temperature and soaking time in manufacturing of cemented carbide and other materials.

| Material | Temperature (°C) | Time (Minute) |
|---|---|---|
| Copper, Brass, Bronze | 760~ 900 | 10- 45 |
| Iron & iron- Graphite | 1000~1150 | 8~45 |
| Stainless steel | 1100~1290 | 30~60 |
| Tungsten carbide | 1430~1500 | 20~30 |

## 2.11 PARTICLE SIZE, DISTRIBUTION AND SHAPE

### 2.11.1 PARTICLE SIZE AND SIEVE ANALYSIS

Kalpakjian Serope[8] mentioned that particle size is usually measured by screening, that is, by passing the metal powder through screens (sieves) of various mesh sizes. Screen analysis is achieved by using a vertical stack of screens, with the mesh size becoming finer as the powder flows downward through the screens. The larger the mesh size, the smaller is the opening in the screen. For example, a mesh size of 30 has an opening of 600 μm, size 100 has 150 μm, and size 400 has 38 μm. (This method is similar to the numbering of abrasive grains: The larger the number, the smaller the size of the abrasive particle.)

In addition to screen analysis, several other methods are also available for particle size analysis:

a. **Sedimentation,** which involves measuring the rate at which particles settle in a fluid.

b. **Microscopic analysis,** which may include the use of transmission and scanning electron microscopy.

c. **Light scattering** from a laser that illuminates a sample consisting of particles suspended in a liquid medium.

d. **Optical** means, such as particles blocking a beam of light that is then sensed by a photocell.

e. **Suspending particles** in a liquid and then detecting particle size and distribution by electrical sensors.

The size distribution of particles is an important consideration, because it affects the processing characteristics of the powder. The distribution of particle size is given in terms of a frequency distribution plot. The maximum frequency is called the mode size.

### 2.11.2 PARTICLE SHAPE

Particle shape has a major influence on processing characteristics. The shape is usually described in terms of aspect ratio or shape factor.

Aspect ratio is the ratio of the largest dimension to the smallest dimension of the particle. This ratio ranges from unity (for a spherical particle) to about 10 for flake like or needlelike particles.

Shape factor (SF), or shape index, is a measure of the ratio of the surface area of the particle to its volume, normalized by reference to a spherical particle of equivalent volume. Thus, for example, the shape factor for a flake is higher than that for a sphere.

## 2.12 SINTERING

According to Narang G.B.S [9] sintering is the process of heating of powder compacts at an elevated temperature in a furnace (Fig. 2.9) under controlled atmospheric conditions. It is the process by which solid bodies are bonded by atomic forces. The effectiveness of the surface tension reactions is increased and the metal powders particles are pressed into a more intimate contact by the application of heat.

Sintering can occur by a variety of mechanism e.g. solid-state, liquid-phase, and vapor-phase sintering. Each mechanism can work alone or in combination with other mechanism to achieve densification. Liquid phase sintering is the main mechanism for sintering of WC-Co. Liquid phase sintering has three stages e.g. rearrangement, solution-precipitation, and Oswald ripening. Most sintering furnaces employ three distinct zones. The first region, the burn-off or purge chamber, is designed to remove air, volatilize and remove lubricants or binders that would interface with good bonding, and slowly raise the temperature of the compacts in a manner that prevents the buildup of internal pressure from entrapped air and lubricant and the resulting swelling or fracture. The high temperature zone is the site of actual sintering between powder particles. The time must be sufficient to obtain the desired density and final properties, and usually varies from 10 minutes to several hours. Finally a cooling zone is required to lower the temperature and thereby prevent oxidation upon discharge into air and possible thermal shock.

All three zones usually operate with a controlled protective atmosphere. This is critical because the fine powder particles have large exposed surface areas and at elevated temperature rapid oxidation can occur and significantly impair the quality of particle bonding.

The atmospheres commonly based on hydrogen, dissociated ammonia or cracked hydro-carbons, are preferred since they can reduce any oxide already present on the particle surfaces and remove gases liberated during sintering.

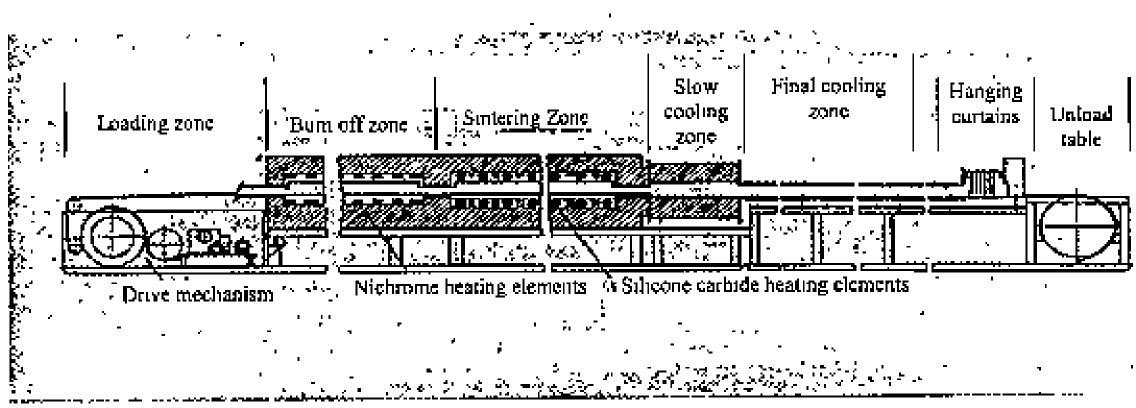



**Figure 2.9** Longitudinal section of a muffle type coutiuuous production furnace

## 2.13 TOOL WEAR AND TOOL WEAR MEASUREMENT

Kumar Dr. B, mentioned wear is loss of weight or mass. Thus when we say that is tool is worn out, we mean that the tool has lost some of its mass. The loss of mass occurs at two places on a cutting tool: at the cutting edge and the principal flank of the tool and at the rake face of the tool (Fig. 2.10). The wear at the flank is called flank wear and at the rake face crater wear.

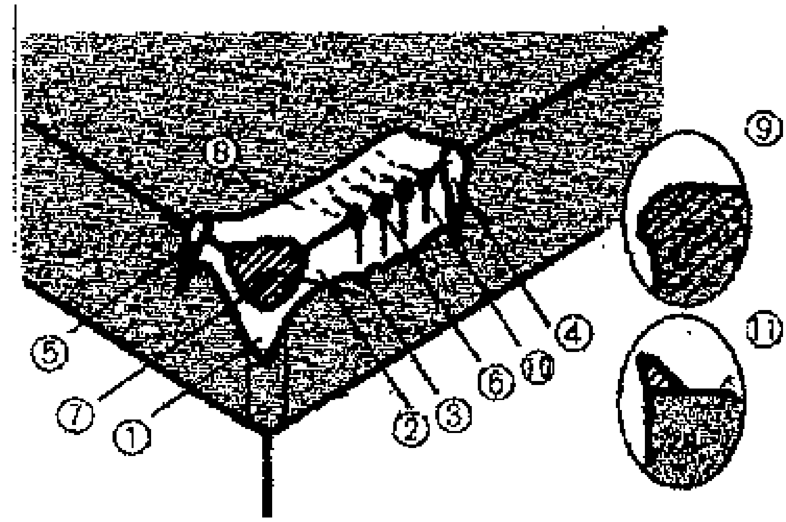



**Figure 2.10** Flank Wear and Crater Wear.

| | | |
|---|---|---|
| 2,3.4 | - | Principal flank wear |
| 5 | - | Auxiliary flank wear |
| 8 | - | Crater wear |

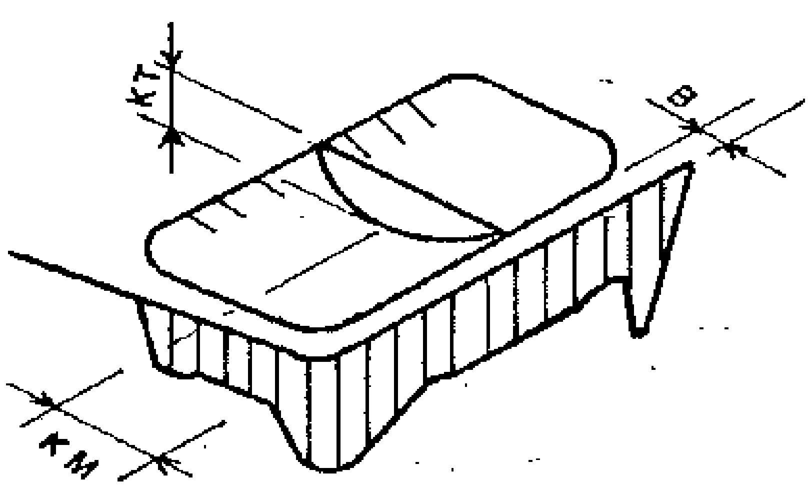



**Figure 2.11** Crater wear

KT - Depth of crater wear.

B - Width of Land.

### 2.13.1 MEASUREMENT OF TOOL WEAR

The flank wear is estimated by measuring height of wear land (Fig. 2.12) with instrumental microscope Fig. 4.2.

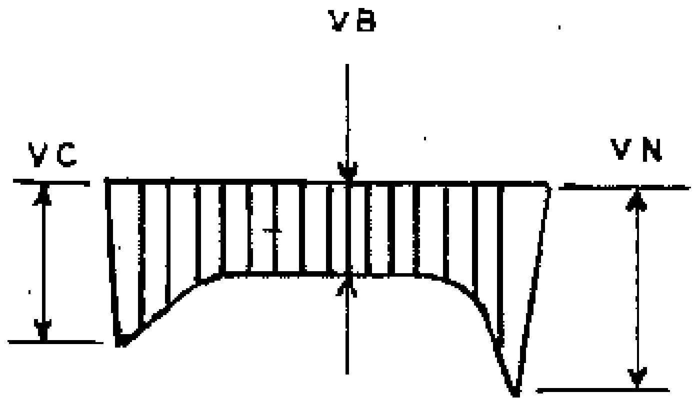



**Figure 2.12** Flank wear measurement.

$V_B$ - Width of flank wear (mean)

$V_C$ - Maximum wear of nose radius.

$V_N$ - Notch wear.

Ramkan MD. Gullur Shah mentioned that the relationship between tool wear and cutting time could be divided into three sections (Fig. 2.13). Section – I is the period of initial wear, during which heavy abrasion of the tool flank surface occurs. The smoother the friction surfaces, the lower the rate of wear. Section – II is the period of normal wear. It is characterized by gradual wear with the operation (abrasion time) when a certain degree of wear has been reached the friction conditions change (mainly due to the sharp rise in cutting temperature) and section – III begins. This can be called the period of rapid wear because of the high hardness of cemented carbide and very slight reduction in this hardness at high temperature. Initial tool wear is very fast. It then increases slowly until a limit is reached. From that limit point, wear increases substantially

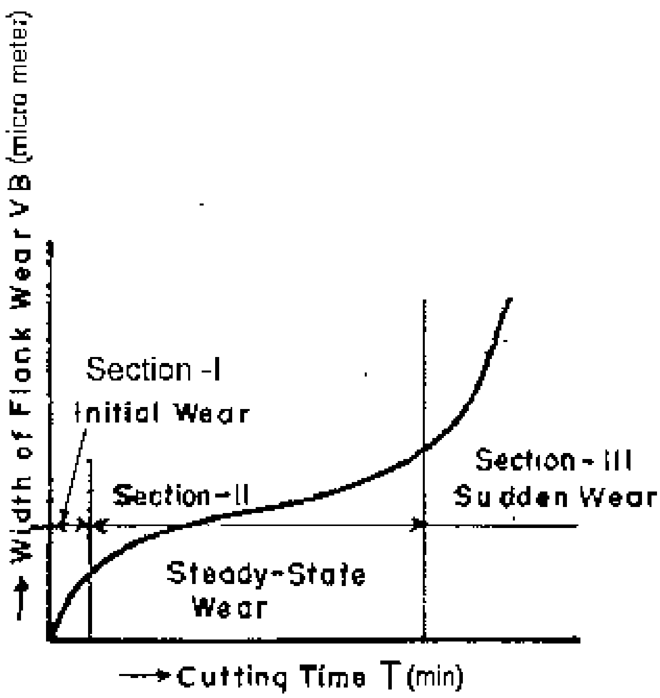



**Figure 2.13** Tool Wear vs. Time graph.

## 2.13.2 SURFACE ROUGHNESS MEASUREMENT

Amstead B.H [12] mentioned that several devices have been developed to measure surface roughness. Surface roughness can be measured by using surface roughness tester. 'Surtronic 3+' surface roughness tester is shown in Fig. 2.14. This is a direct reading instrument that measures the number roughness peaks per inch above a pre-selected height by passing a fine tracer point over the surface.

The unit consists of a tracer that converts the vertical movements of the tracing points into a small, fluctuating voltage that is related to the height of the surface irregularity, a motor driven device (profilometer) for operating the tracer, and the amplimeter. The amplimeter receives the voltage from the tracer, amplifies it, and integrates it so that it nay be read as digital values or shown on a strip chart recorder. The process is a continuous one, and the instrument shows the variation in average roughness from a reference line as illustrated in the magnified profile of a surface in Fig. 2.15. Height of roughness peaks of different

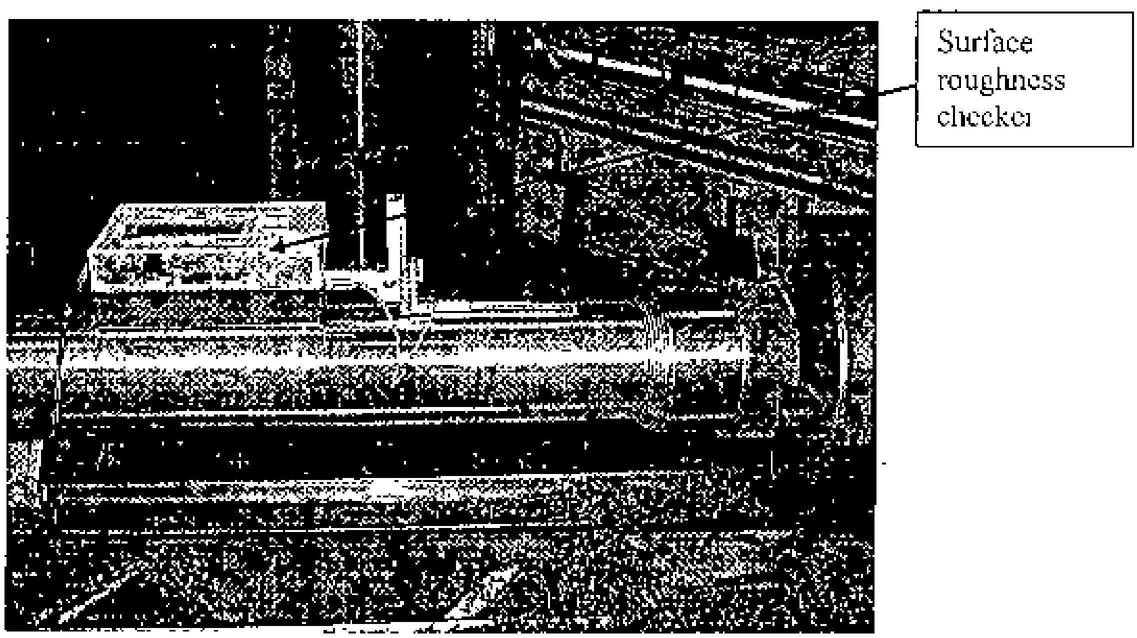



**Figure 2.14** "Surtronic 3+" surface roughness checker including transducer tracer, amplifier, and indicator for measuring surface roughness.

points are shown in Table 2.4 and roughness is calculated by the root mean square average value.

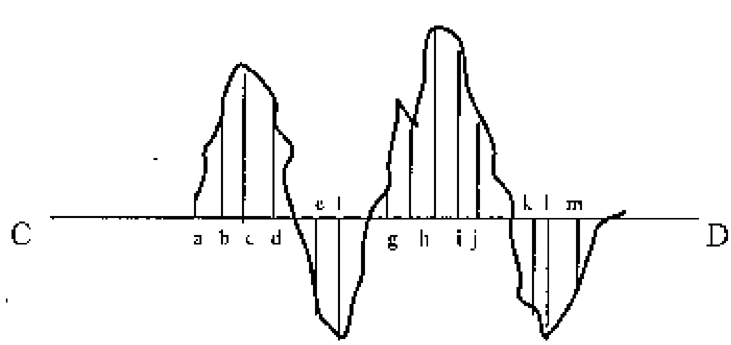



**Figure 2.15** Magnified profile of a surface shows the roughness peaks.

**Table: 2.4** Height of roughness peaks of different points of a surface.

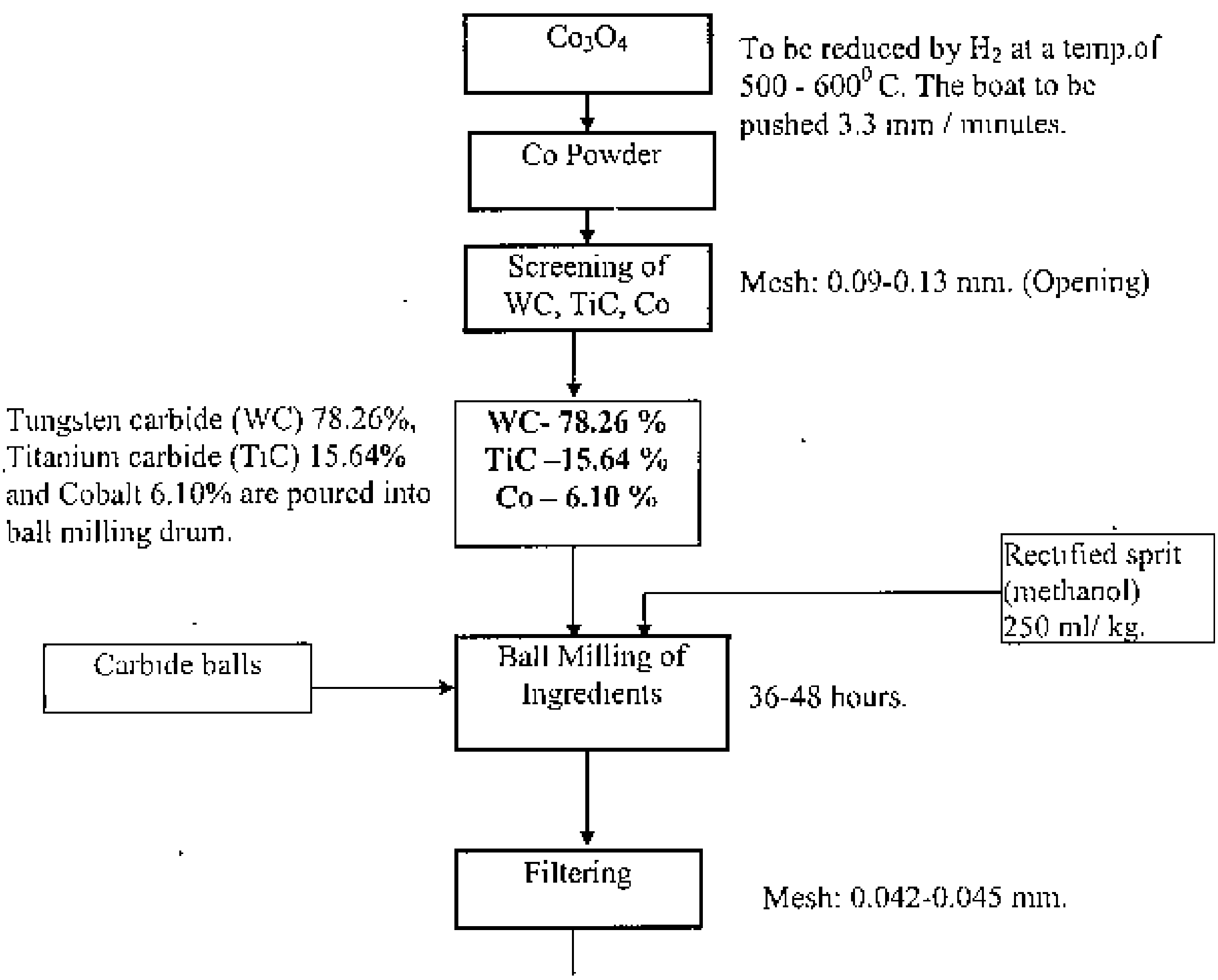
| Observation | Data symbol | Value | Square of Value |
|---|---|---|---|
| 1. | a | 4 | 16 |
| 2. | b | 19 | 361 |
| 3. | c | 23 | 529 |
| 4. | d | 16 | 256 |
| 5. | e | 31 | 961 |
| 6. | f | 20 | 400 |
| 7. | g | 27 | 729 |
| 8. | h | 20 | 400 |
| 9. | i | 31 | 961 |
| 10. | j | 13 | 169 |
| 11. | k | 23 | 529 |
| 12. | l | 15 | 225 |
| 13. | m | 6 | 36 |
| | Total = | 248 | 5572 |

Root mean square average = $\sqrt{5572/13}$ = 20.7 micro inches.

# Chapter-3

## FABRICATION PROCESS OF CARBIDE INSERT

### 3.1 FLOW CHART FOR THE EXISTING MANUFACTURING PROCESS OF CARBIDE INSERT [6]



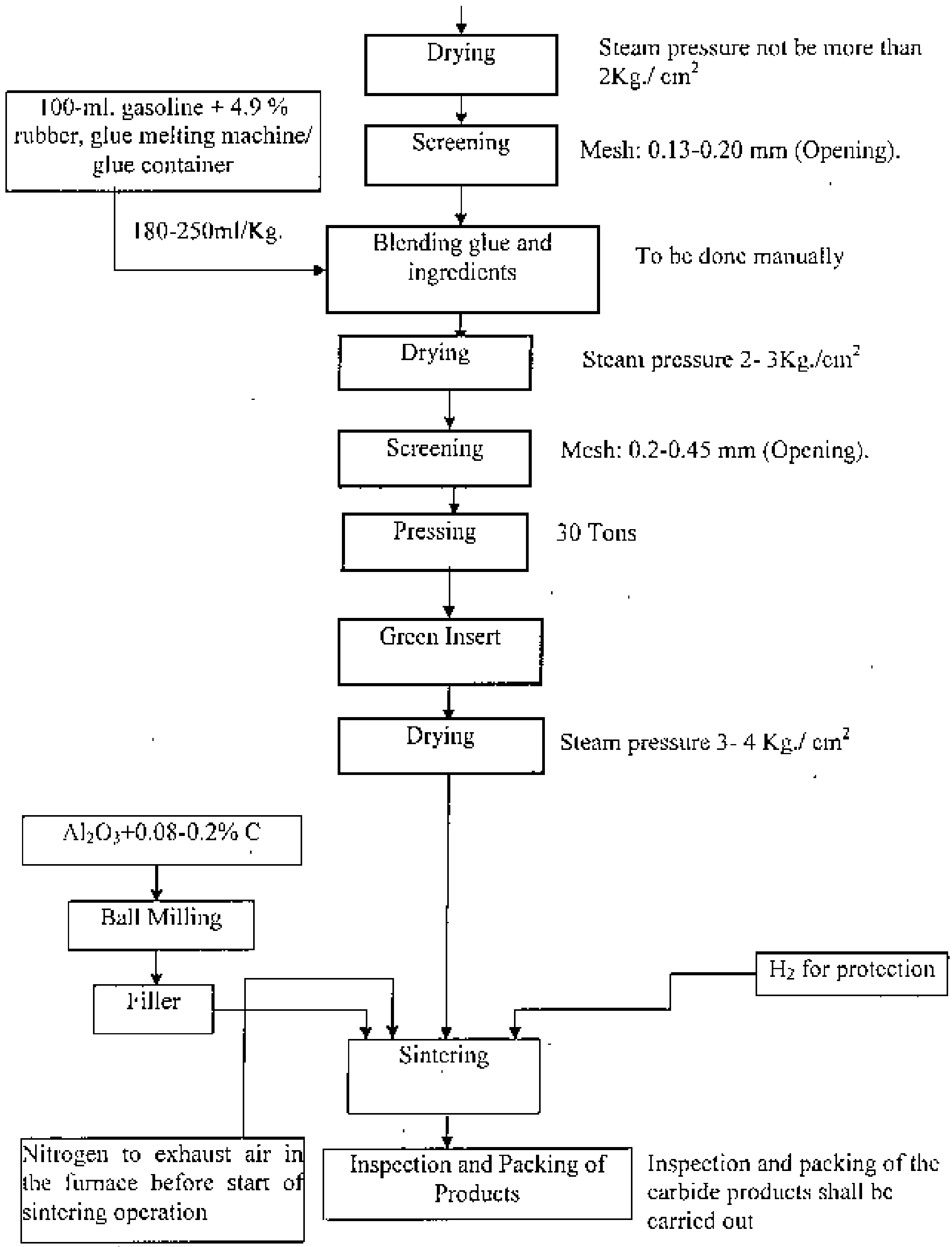



**Figure 3.1** Flow chart for the existing manufacturing process of carbide insert.

### 3.2 DESCRIPTION OF EXISTING MANUFACTURING PROCESS OF CARBIDE INSERTS

#### 3.2.1 COBALT OXIDE REDUCTION PROCESS

Pure cobalt required in the manufacturing process of cemented carbide. Cobalt is available in the market as $Co_3O_4$ (Cobalto cobaltic oxide). To get cobalt from $Co_3O_4$, it is reduced by hydrogen gas in the furnace at a temperature of 500°C~600°C. The reduction process takes place according to the reaction below. After reduction oxygen removed from $Co_3O_4$ and 73.4% Co by weight is received.

$$4H_2 + Co_3O_4 \xrightarrow{500^\circ C \sim 600^\circ C} 3Co + 4H_2O$$

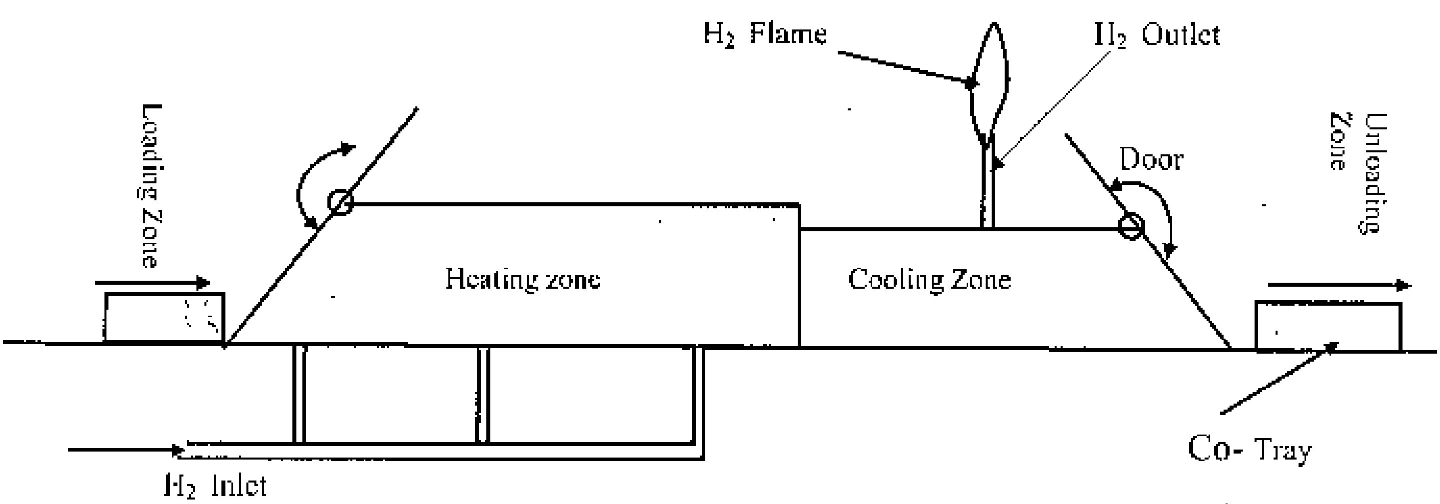



**Figure 3.2** Schematic Diagram of Reduction Furnace

The furnace is air sealed. During operation air did not enter into the furnace because it makes explosion with $H_2$ gas. During loading and unloading operation $H_2$ flow increased so that oxygen (air) did not enter into the furnace through the mouth. Then open the furnace mouth carefully and at the sometime burn the $H_2$ gas in the furnace mouth (Fig. 3.3).In this condition Cobalt tray unload from the furnace and in the same way loading of $Co_3O_4$ is done.

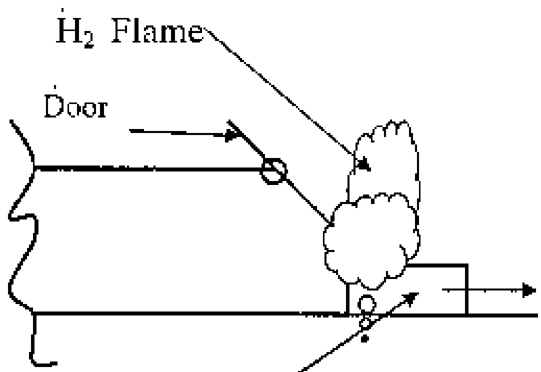



**Figure 3.3** Unloading process of reduction furnace.

After loading and unloading furnace mouth is closed. After reduction, cobalt powder is sieved on a vibrating sieve with 0.1~0.6 mesh. The oxygen content in cobalt powder should not be more than 0.7% and bulk density of powder should not exceed $0.75 g/cm^3$. The chemical composition of the powder should be Co-99.4%, Ni-0.4%, C-0.06%, O2 – 0.10%, Cu- 0.05%, Si- 0.03%, Fe-0.25%, moisture- 0.2% [6].

### 3.2.2 MIXTURE PREPARATION PROCEDURE AND BALL MILLING.

Tungsten carbide, titanium carbide and cobalt powders of specified quantity (wt.) are packed in ball milling drum. The drum is made of stainless steel and its inner side is covered by WC (tungsten carbide) layer (Fig. 3.5).

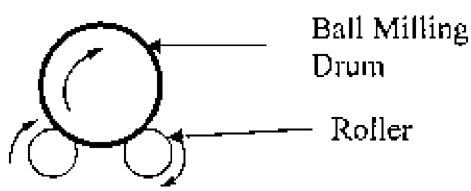



**Figure 3.4** Schematic view of ball milling

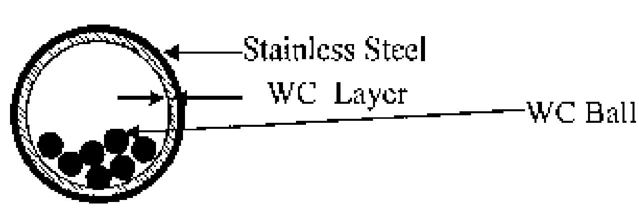



**Figure 3.5** Sectional view of ball milling drum

The drum is assembled on ball mill and ball milling (Fig. 3.4) is done so as to produce homogeneous mixture. Specification of mixture: WC-78.26%, TiC – 15.64%, Co-6.10%. According to specification, required amount (wt.) of powder of each item, WC ball and alcohol are taken into the ball-milling drum. The drum is covered tightly, it is mounted on the ball mill and the machine is put into operation. Ball milling is continued for 48~72 hours with one-hour rest after each two hours interval. When the milling time is up, the ball mill is stopped. For discharging, the ball-milling drum is taken down and it is uncovered. Then the mixture is filtered with double decked sieve with holes of 0.04~0.045 mm in diameter.

### 3.2.3 DRYING OF MIXTURE AFTER BALL MILLING.

After ball milling the mixture is dried in the steam oven. The temperature of the oven is maintained $70^0$C and the steam pressure will not be more than 2Kg/cm$^2$. Dried mixture is sieved with double-decked brass wire sieve having opening of 0.13 ~ 0.20 mm in diameter.

### 3.2.4 PROCEDURE OF RUBBERIZING OF MIXTURE.

To increase strength of the green inserts, rubber solution is added into the mixture. Technical specification of rubber solution is as follows: -

Concentration: 4~6%
Ash content: not more than 0.05%.

Butadiene sodium synthetic rubber {nCH=CH- CH= $CH_2$ – $Na_7$ (-CH- CH = CH-$CH_2$)$_{12}$} is cut into small pieces. Rubber solvent (Gasoline) and rubber pieces are put into the stirring tank and the mixture is stirred up until rubber pieces are dissolved completely. The solution is prepared according to the proportion that 4~6gm. of rubber is added into 100 ml. of rubber solvent. Silk cloth is used to filter the rubber solution.

Required volume of rubber solution is added into the powder mixture for rubberizing and stirred up uniformly to produce homogeneous mixture. The homogeneous mixture is dried in steam oven with temperature of 70~$80^0$C and pressure of 2~3 kg/cm$^2$

The dried mixture is sieved on the sieving machine with sieve having opening of 0.20–0.45 mm in diameter. The sieved mixture is packed in the air proof container with $CO_2$ [6].

### 3.2.5 GREEN INSERT MANUFACTURING OR PRESSING OF MIXTURE.

Rubberized mixture is weighed into pressing die (Fig. 3.6) and is pressed by a hydraulic press to produce green insert of required size. This green insert heated in the oven at 70–80$^{0}$C. This heating imparts sufficient strength to the green insert and it can be handled without difficulties. It is called presintering. These inserts are then given to the final sintering.

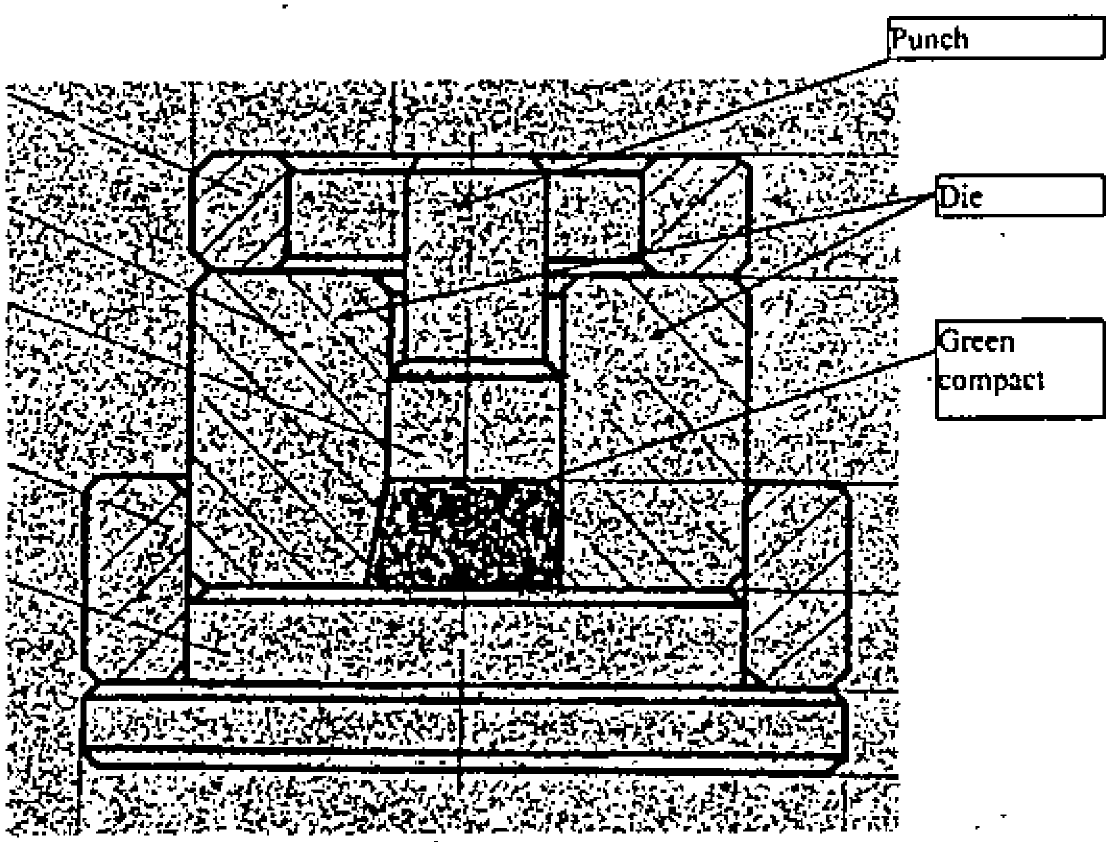



Figure 3.6 Die And Punch for Preparing the Green Insert.

### 3.2.6 SINTERING

Sintering is the process of heating of powder compacts at an elevated temperature in a furnace (Fig. 2.13) under controlled atmospheric conditions. Sintering is performed in a continuous 3-zone furnace, which is similar to the reduction furnace. The constructional features of reduction furnace and sintering furnace is same, only the difference in temperature capacity. Before raising temperature, furnace door closed properly so that air did not enter into or hydrogen gas did not come out. Then nitrogen gas passed into the furnace to exhaust the air from the furnace. After 20~30 minutes hydrogen gas is introduced into the furnace for about 10 minutes. Then hydrogen sample taken for explosion test. If air is present in the hydrogen sample then huge explosion sound heard When explosion test found satisfactory then hydrogen is ignited in the outlet valve and the furnace power on. The presintered inserts are placed into graphite boat with layer by layer. Mixture of aluminum oxide and carbon is filled between the layers so that the inserts did not come into contact during sintering.

When temperature reaches to 1360$^0$C graphite boat filled with green insert (Fig. 3.7a) is loaded through the furnace. The feeding rate is 2.5 mm/min. Feeding procedure is like as that of reduction furnace.

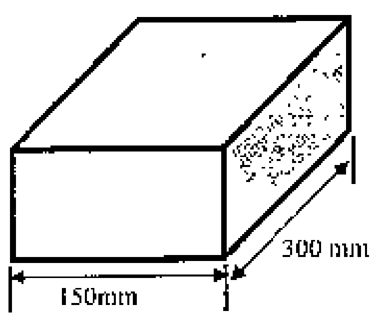



Figure 3.7(a) Graphite boat.

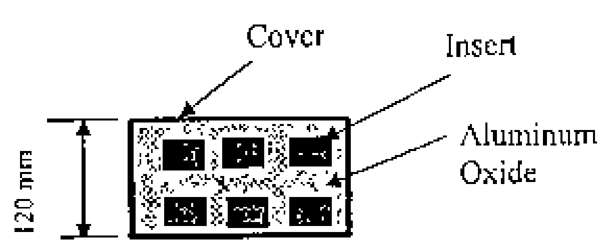



Figure 3.7(b) Sectional view of graphite boat.

### 3.2.7 INSPECTION AND PACKING

When sintering is finished graphite boats are then come out automatically from the unloading end of furnace. Inserts are taken out from the graphite boat and then inspect and packed for storage.

## 3.3 MANUFACTURING PROCESS OF NEWLY FABRICATED CARBIDE INSERT

### 3.3.1 DESCRIPTION OF MANUFACTURING PROCESS OF NEWLY FABRICATED CARBIDE INSERTS.

The properties of tungsten carbide are controlled by composition and microstructure; the hardness increases with decreasing Co (Cobalt) content and smaller particle size of tungsten carbide (Fig. 2.6). In this experimental carbide manufacturing process, grain size of WC(Tungsten carbide) used 0.02 mm instead of 0.042mm. The composition of powder used WC- 83 %, TiC-11 % and Co-6 % instead of WC- 78.2 %, TiC - 15.64% and Co-6.1 % . The specification of composition was determined by reviewing several papers, handbooks and properties of different grades of cemented carbide (Table 2.1, Table 2.2). Particle size is measured by using sieve. In this experiment, sieve used of opening 0.02~ 0.024 mm. Other parameters of existing WC fabrication process remain unchanged.

### 3.3.2 PHOTOGRAPHIC VIEW OF NEWLY FABRICATED CARBIDE INSERT

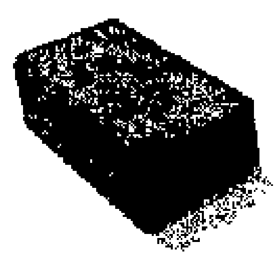


**Figure 3.8** Photographic view of the newly fabricated carbide insert.

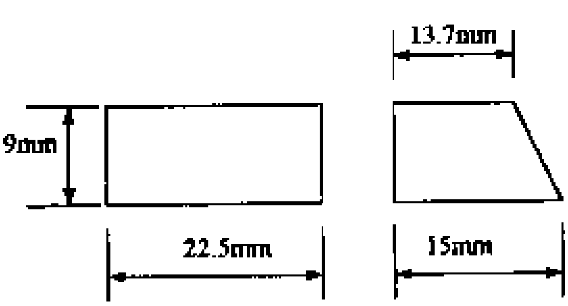



**Figure 3.9** Drawing of the newly fabricated carbide insert.

### 3.3.3 TURNING TOOL PREPARATION BY USING CARBIDE INSERT

Several turning tools are prepared for the performance measurement of newly fabricated insert and existing carbide insert. Sequence of operation for tool manufacturing procedures is given below:

1. Approximate size of shank making, 26×26×105 mm by shaper machine.
2. Cavity (for insert brazing) making by milling machine.
3. Insert brazing with the shank.
4. Tool shank final grinding.
5. Tool angles:
   a) Back rake angle = $-5^0$
   b) Side rake angle = $-5^0$
   c) End relief angle = $5^0$
   d) Side relief angle = $5^0$
   e) End cutting edge angle = $5^0$
   f) Side cutting edge angle = $15^0$
   g) Nose radius = 0.6 mm

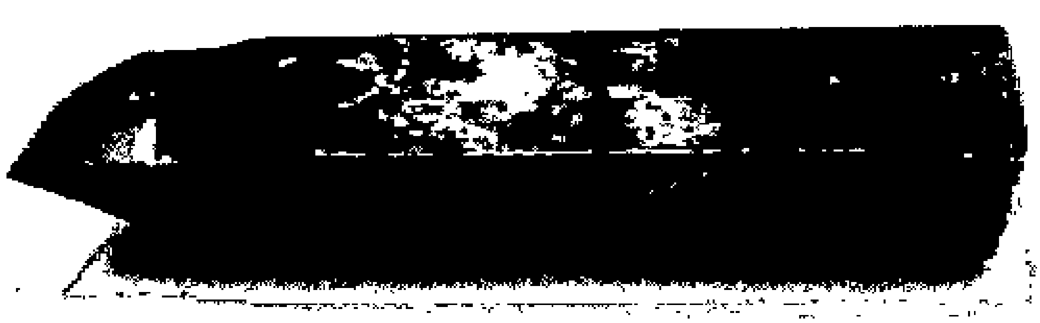


**Figure 3.10** Complete turning tool by newly fabricated carbide Insert.

# Chapter-4

## PERFORMANCE TEST AND RESULTS

### 4.1 PHYSICAL PROPERTIES TEST OF NEWLY FABRICATED INSERT AND EXISTING CARBIDE INSERT.

In this experiment both types of insert was fabricated in BOF. The physical properties of the inserts are shown in Table 4.1. From the data table it is observed that hardness and density of newly fabricated tool is slightly higher than that of existing tool.

**Table 4.1** Comparisons of physical properties of newly fabricated and existing carbide insert.

| Nomenclature | Hardness (HRA) (60Kg) | Density | Remarks |
|---|---|---|---|
| Newly fabricated insert (83 %WC, 11 % TiC, 6 %Co) | 91~92 | 12.38 | |
| Existing insert (78.2 %WC, 15.64 % TiC, 6.1 %Co) | 90~91 | 12.35 | |

## 4.2 TOOL WEAR MEASUREMENT

### 4.2.1 EXPERIMENTAL PROCEDURE FOR TOOL WEAR MEASUREMENT

Several methods are used in tool wear measurement. In this experiment, tool wear measurement is carried out in a lathe machine tool and 88mm diameter MS shaft was turned at approximately constant cutting velocity $V_c$ = 160m/min, depth of cut t=1mm, feed So=0.10 mm/rev, speed=590 rpm and cutting condition was dry. Tools wear was recorded by varying the machining time. The experimental setup is shown in Fig. 4.1 but here milli voltmeter was not connected.

In this experiment principal flank wear and auxiliary flank wear of tool was measured by using instrumental microscope (Fig. 4.2, Fig. 4.3). During machining the cutting tool was withdrawn after a certain machining time and then the salient features like, VB, VS etc. were measured under instrumental microscope (CARL ZEISS, model -19700, 351396, Germany). The microscope was fitted with micrometer of least count 1 μm.

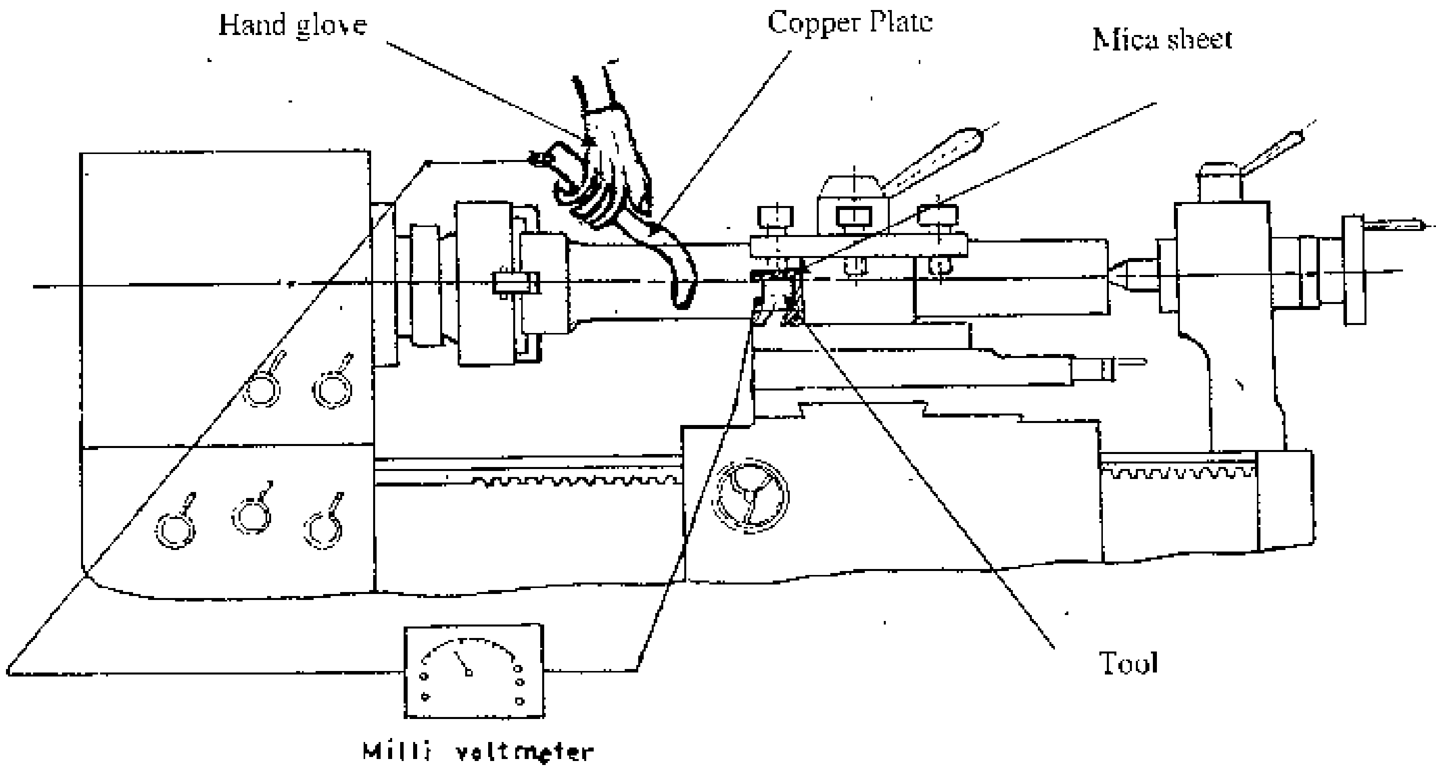



Figure 4.1 Experimental Setup, Tool wear measurement and Emf (Temperature) measurement

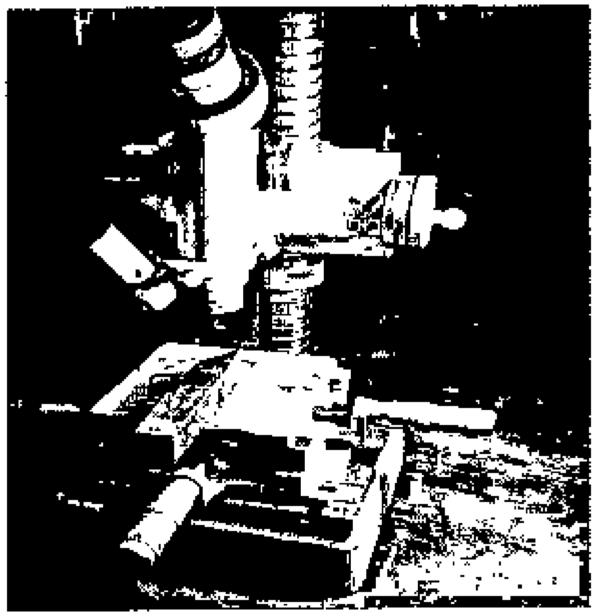


**Figure 4.2** Principal flank wear measurement by instrumental microscope, CARL ZEISS, model- 19700, 351396, Germany

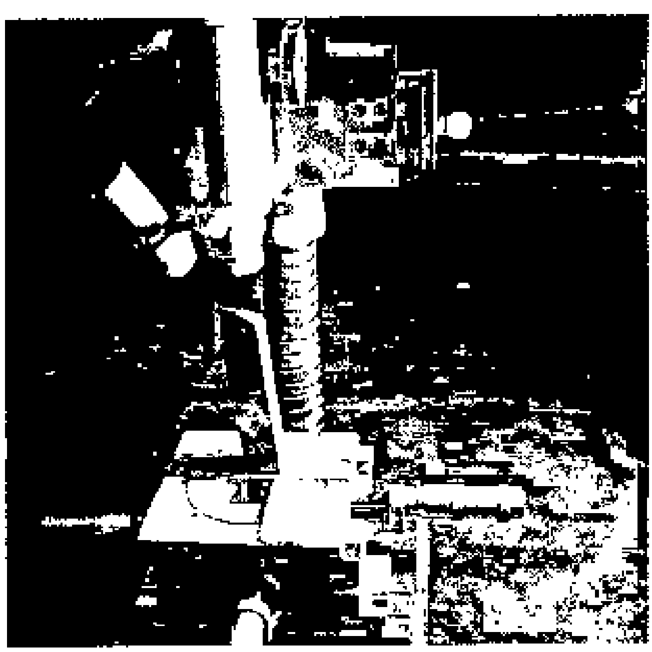


**Figure 4.3** Auxiliary flank wear measurement by instrumental microscope. CARL ZEISS, model- 19700, 351396, Germany.

### 4.2.2 RESULTS OF TOOL WEAR MEASUREMENT

Curves of principal flank wear Vs machining time and auxiliary flank wear Vs time machining has been plotted from the recorded data. From the graph it is found that flank wear increases with machining time. Both principal (Fig. 4.4) and auxiliary flank wear (Fig. 4.5) of experimentally fabricated tool is less than that of existing tool.

From Fig. 4.4 (principal flank wear Vs machining time) it is found that principal flank wears increases rapidly within first 05 minutes time period. From this time principal flank wear increases gradually up to 25 minutes machining time. After this time period tool wear increases substantially and finally life of the tool is finished.

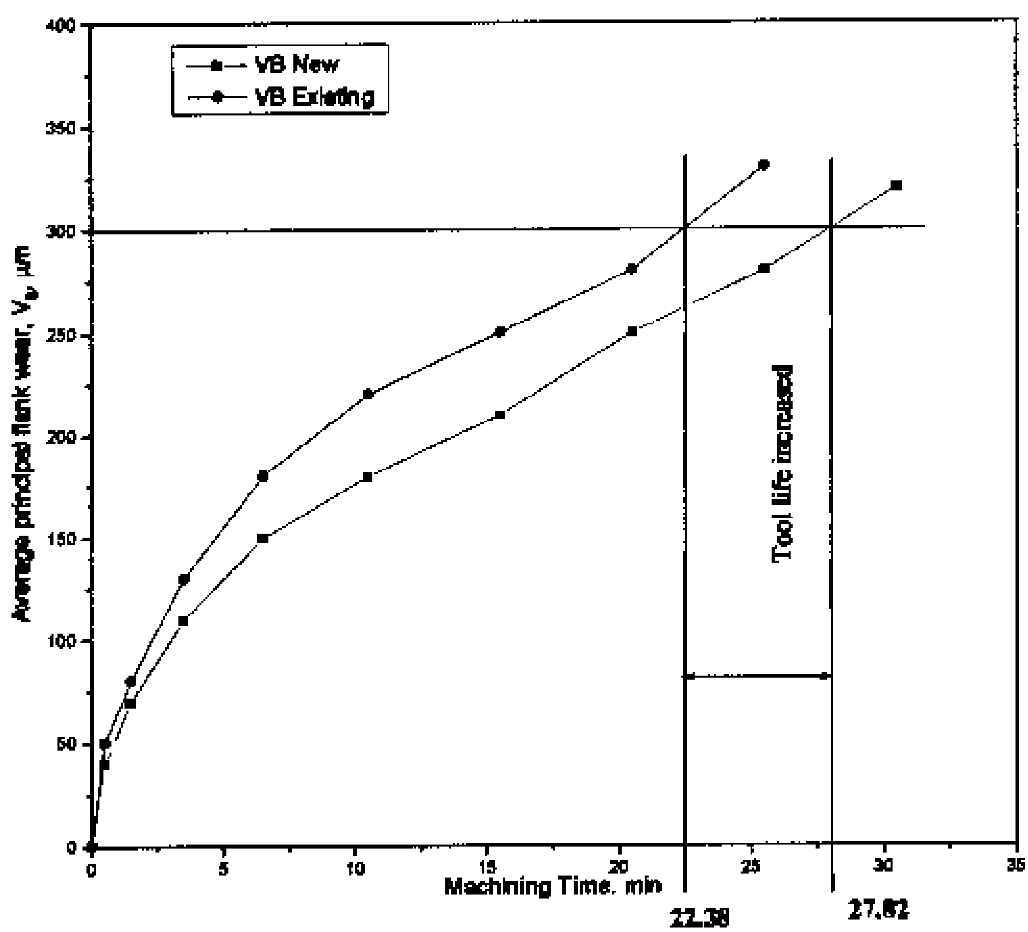



**Figure 4.4** Growth of average principal flank wear

For newly fabricated tool principal flank wear (Fig. 4.4) reached 300 μm within 27.82 minutes machining time. Again for existing tool principal flank wear reached 300μm within 22.38 minutes.

Tool life increased by [(27.82 - 22.38)/22.38] X 100 = 19.55 %

From Fig. 4.5 it is found that auxiliary flank wear increases rapidly within first 06 minutes machining time. After this time period tool wear increases gradually for experimentally fabricated tool and rapidly for the existing tool.

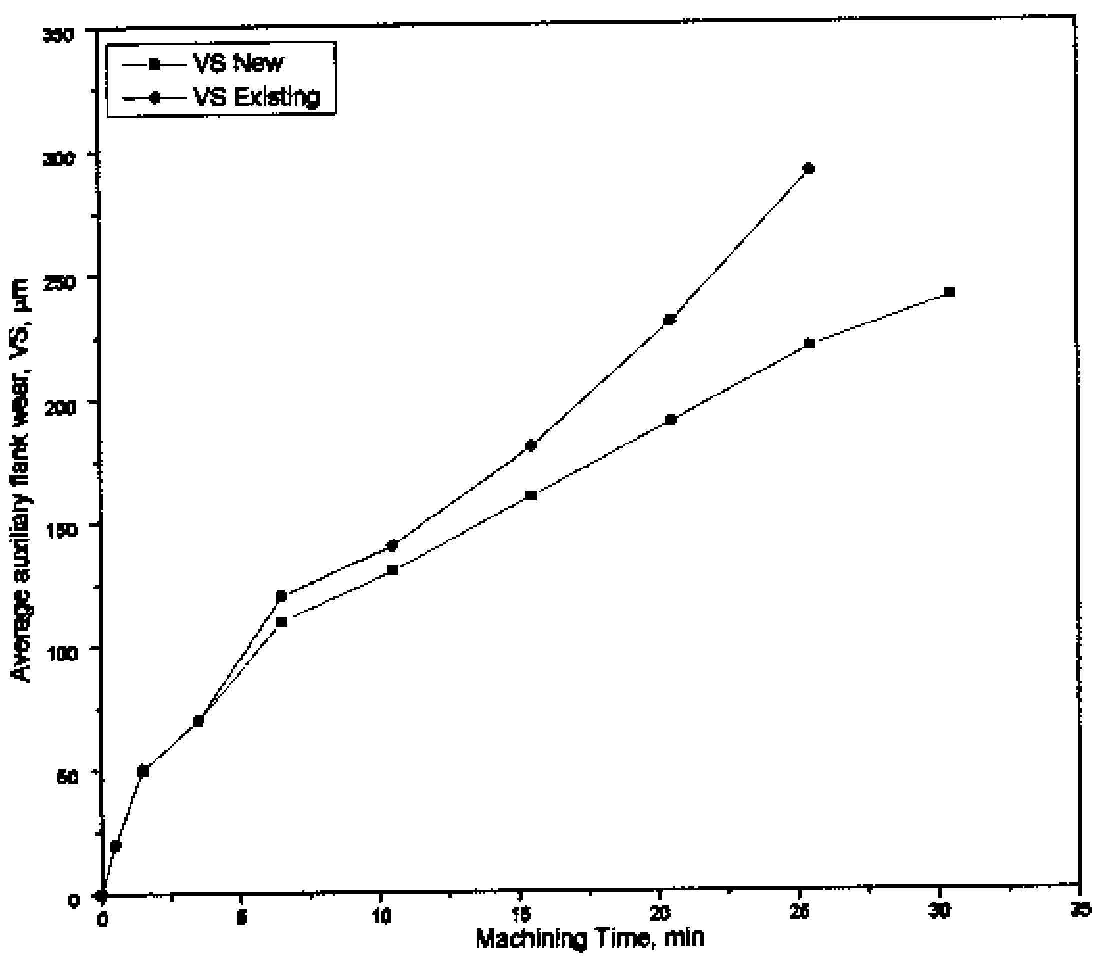



**Figure 4.5** Growth of average auxiliary flank wear

## 4.3 SURFACE ROUGHNESS MEASUREMENT

### 4.3.1 EXPERIMENTAL PROCEDURE FOR ROUGHNESS MEASUREMENT

Surface roughness of a job depends upon the quality of tool by which it machined. So to find out the performance of the experimentally fabricated tool, surface roughness measurement is important. There are several methods used for measuring the surface roughness. In this experiment "Surtronic 3+" surface roughness checker is used to measure roughness (Fig. 2.14). Roughness measurement is carried out on the same setup in which tool wear measurement is performed.

A solid shaft of diameter 82 mm and length 520 mm was turned at constant cutting velocity $V_c$ = 160 m/min (approximately), depth of cut t= 1 mm, feed $S_o$ = 0.10 mm/rev, speed =590 rpm and cutting condition was dry. Turning was interrupted after 0.5, 1, 2, 3, 4, 5, 5, 5, minutes respectively and surface roughness was measured. Roughness was measured three times for each data and average value was recorded for the final data.

### 4.3.2 RESULTS OF ROUGHNESS MEASUREMENT

Curves of surface roughness Vs machining time has been plotted from the recorded data. Figure 4.5 Shoes the effect of machining time on surface roughness for the two types of tool. From the graph it is found that roughness for the newly fabricated tool is less than that of existing tool.

From Fig. 4.6 it is found that surface roughness increases substantially within 30 seconds of machining time. From this point surface roughness decreases for a short period of time and after this roughness increases very slowly.

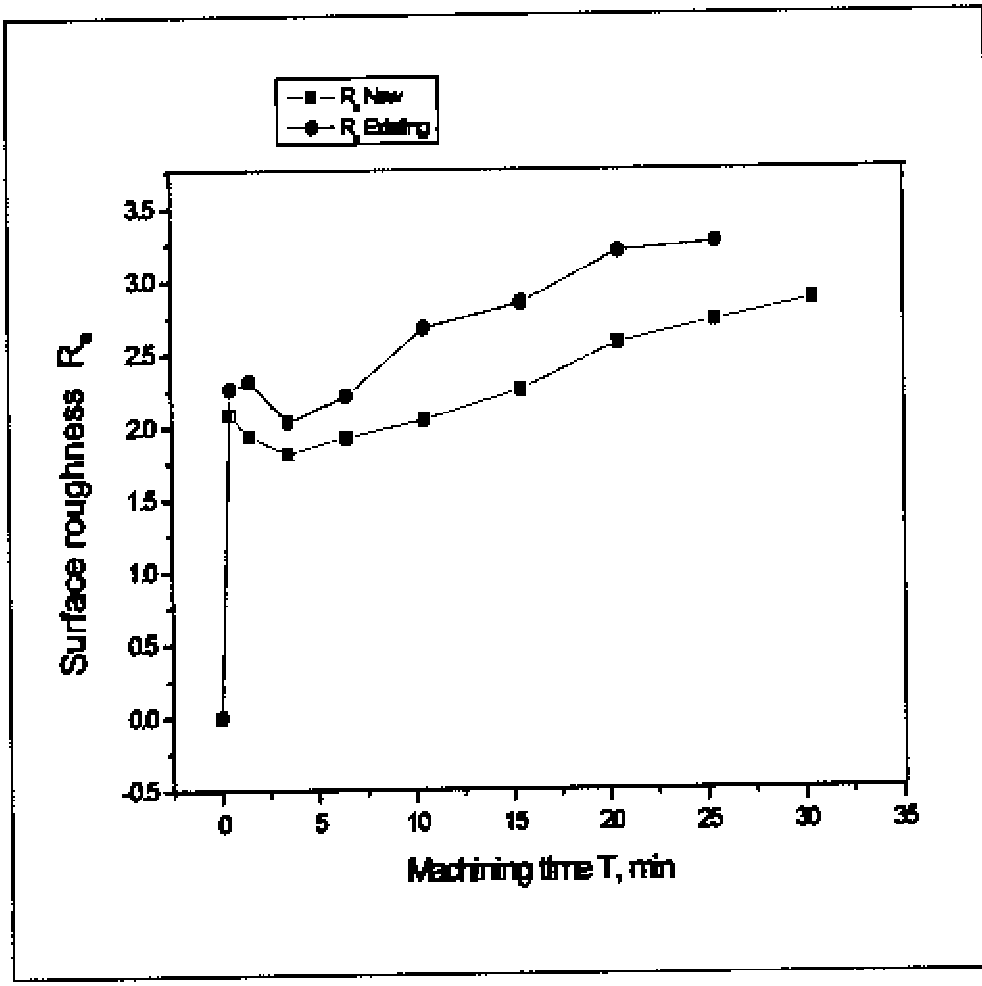



**Figure 4.6** Variation in average surface roughness

## 4.4 DETERMINATION OF EMF GENERATED AT VARIOUS FEEDS.

### 4.4.1 EXPERIMENTAL PROCEDURE FOR EMF MEASUREMENT

Many methods have been used to estimate the chip-tool interface temperature including radiation pyrometers, embedded thermocouples, temperature sensitive paints etc. Since tool life is mainly depending upon the temperature raised at the chip-tool interface. So the mill volts obtained directly from milli-voltmeter assesses the quality of a tool. Embedded thermocouple is used to measure emf in this experiment. The tool-work contact serves as the hot junction of thermocouple and the work piece other end serves as cold junction. The experimental setup is shown in Fig. 4.1.

The tool was covered by mica sheet and clamped in the tool post of a lathe machine Mica sheet is used to insulate the carbide tool from the lathe machine. Insulator is must to take mill voltmeter reading during turning the shaft.

A hole was made from the downward of the carbide tool (Fig. 4.7). A tungsten carbide rod was inserted through the hole in such a way that it touches the carbide tool insert. From the end of the carbide rod, a probe was connected o the mill voltmeter and another probe was connected to a small copper plate. During experiment this copper plate was touched to the work piece manually and the copper plate was insulated from hand by hand gloves Thus an electrical circuit was established beginning from tool insert and ended to work piece. Finally to perform the experiment a 78 mm diameter MS shaft was turned at different feeds So = 0.1,0.13,0.16,0.18,0.20 mm/rev, with constant cutting velocity $V_c$ = 145 m/min, dept of cut t = 1 mm, speed = 590 rpm and cutting condition was dry. Generated emf was recorded from milli voltmeter during turning the steel shaft at different feeds.

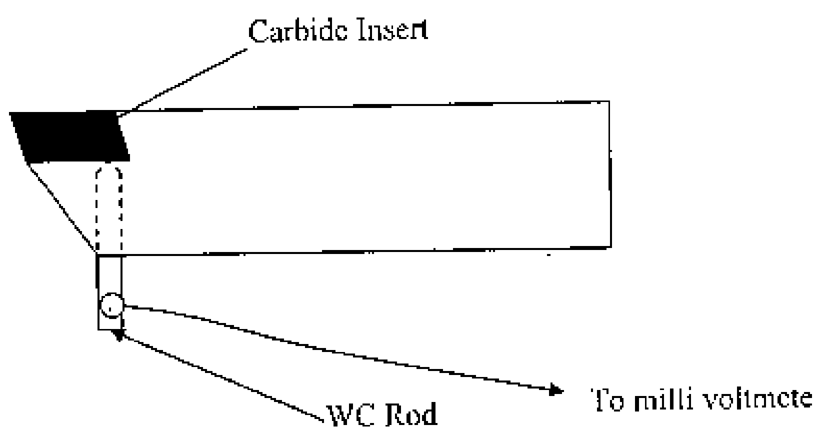



**Figure 4.7** Tool setup for emf measurement.

### 4.4.2 RESULTS OF EMF MEASUREMENT

Machining was performed about 10 seconds with each selection of feed and data (emf) was recorded for each feed. With those data curves of feed Vs emf has been plotted (Fig. 4.8). From the graph it is found that temperature increases gradually as the feed increases for both the tools. For the newly fabricated carbide tool temperature increases is lower than that of the existing tool.

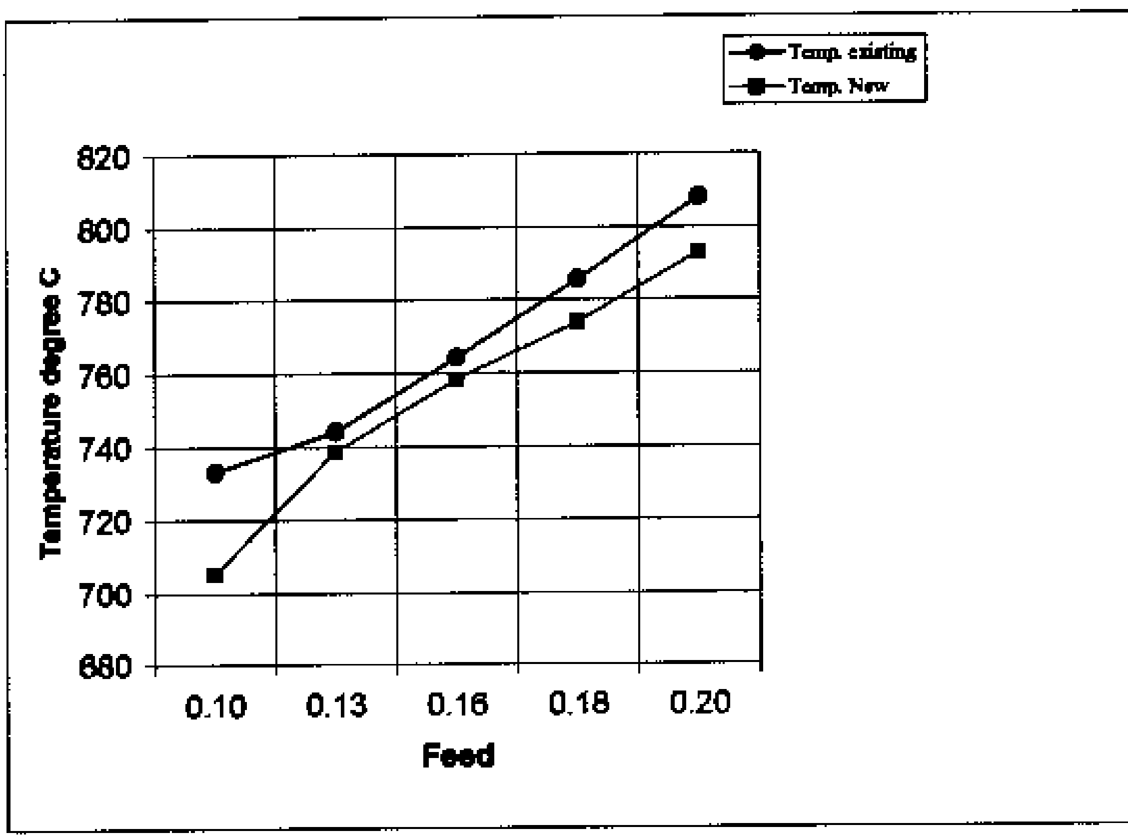



**Figure 4.8** Temperature Vs feed graph.

# Chapter-5

# Discussion on Experimental Results

Physical properties of experimentally produced and existing carbide inserts are illustrated in Table 4.1. From the data table it is observed that hardness of newly fabricated tool is slightly higher than that of existing tool. In the experimental fabricated tool grain size of WC is reduced from 0.042 mm to 0.02 mm and composition of powder changed ( WC- 83 %, TiC-11 % and Co-6 % instead of WC- 78.26 %, TiC - 15.64% and Co-6.1 %) as mentioned in 4.2. As the amount of TiC and grain size of powder reduced, it affects the properties of insert.

Reduction of grain size affects the increases of hardness and reduction the amount of TiC affects the decreases of hardness. But the physical properties test result shows that hardness of experimental tool increased slightly than that of existing tool. So it may be mentioned that the resultant affect of changing grain size and amount of TiC is found in this experiment. It can be concluded that the affect of decreasing grain size is higher than that of decreasing TiC amount.

Tool rejection criteria for finishing operation were employed in this investigation. The values established in accordance with ISO Standard 3685 for tool life testing. A cutting tool was rejected and further machining stopped based on one or a combination of rejection criteria [18]:

i. Average Flank Wear ≥ 0.3 mm
ii. Maximum Flank Wear ≥ 0.4 mm
iii. Nose Wear ≥ 0.3 mm
iv. Notching at the depth of cut line ≥ 0.6 mm
v. Average surface roughness value ≥ 1.6 μm
vi. Excessive chipping (flanking) or catastrophic fracture of cutting edge.

The machining responses have been monitored and studied using sophisticated and reliable equipments and techniques as far as possible.

Productivity and economy of manufacturing by machining are significantly affected by life of the cutting tools. Cutting tools may fail by brittle fracture, plastic deformation or gradual wear. Turning carbide inserts having enough strength, toughness and hot hardness generally fail by gradual wears. With the progress of machining the tools attain crater wear at the rake surface due to continuous interaction and rubbing with the chips. Again flank wear grows at the clearance surfaces due to continuous interaction and rubbing with the work surface, as schematically shown in Fig. 2.10 – Fig. 2.12.

Among the aforesaid wears, the principal flank wear ($V_B$) is the most important because it raises the cutting forces and the related problems. The life of carbide tools, which mostly fail by wearing, is assessed by the actual machining time after which the average value ($V_B$) of its principal flank wear reaches a limiting value of 0.3 mm [19]. Therefore, attempts should be made to reduce the rate of growth of flank wear ($V_B$) in all possible ways without much sacrifice in MRR.

Figure 4.3 clearly shows that average flank wear, $V_B$ decreased by the use of experimental carbide tool having a new composition rather than that is frequently used in BOF (Existing tool). Crater wear of carbide tools in machining steels occur particularly at higher cutting velocity ($V_c$) and feed ($S_0$) by adhesion and diffusion as well as post abrasion, whereas, flank wear occurs mainly by micro-chipping and abrasion and with increase in cutting velocity (Vc) and Feed (So) adhesion and diffusion also come into picture due to intimate contact with the work surface at elevated temperature.

The cause behind reduction in $V_B$ observed might reasonably be attributed to a small reduction in the cutting temperature, increase in hardness by the use of newly fabricated carbide tool having a new composition. Auxiliary flank wear ($V_S$), though occurs less intensively, also plays significant role in machining by aggravating dimensional inaccuracy and roughness of the finished surface. It appears from Fig. 4.4 that auxiliary flank wear ($V_S$) has also decreased size ably due to use of carbide tool having a new composition.

Surface roughness is an important index of machinability, which is substantially influenced by the machining environment for given tool-work pair and speed-feed combinations. Surface roughness has been measured every time when the tool wears were measured.

The major causes behind development of rough surface in continuous machining processes like turning, particularly of ductile metals are:

i. regular feed marks left by the tool tip on the finished surface

ii. irregular deformation of the auxiliary cutting edge at the tool-tip due to chipping, fracturing and wear

iii. vibration in the machining system

iv. built-up edge formation, if any.

The variation in surface roughness observed with progress of machining of AISI 1060 steel by the standard and manufactured inserts at a particular set of cutting velocity (Vc), feed rate (So) and depth of cut (t) under dry condition have been shown in Fig. 4.5. As average auxiliary flank wear is reduced and produced no notch wear on auxiliary cutting edge, surface roughness also grew very slowly in case of experimentally produced insert.

The machining temperature at the cutting zone is an important index of machinability and needs to be controlled as far as possible. Cutting temperature increases with the increase in specific energy consumption and material removal rate (MRR). During machining any ductile materials, heat is generated at the

(i) primary deformation zone due to shear and plastic deformation

(ii) chip-tool interface due to secondary deformation and sliding and

(iii) work-tool interfaces due to rubbing.

All such heat sources produce maximum temperature at the chip-tool interface, which substantially influence the chip formation mode, cutting forces and tool life. That is why; attempts are made to reduce this detrimental cutting temperature. The Fig. 4.7 is showing the variation on average chip-tool interface temperature at dry condition under different feed rates (So), as compared to existing tool and experimentally manufactured tool. However, it is clear from the aforementioned figures that with the increase in feed (So), average chip-tool interface temperature increased as usual, due to increase in energy input. The roles of variation of process parameters' on percentage reduction of average interface temperature have not been uniform. This may be attributed to variation in the chip forms particularly chip-tool contact length, which for a given tool widely vary with the mechanical properties and behavior of the work material under the cutting conditions. However, during machining at lower feed when the chip-tool contact is partially elastic there the temperature reduction is more.

# Chapter-6

# Conclusion & Recommendation

## 6.1 CONCLUSION

The following conclusions can be drawn the nature of effective performance of newly produced tungsten carbide insert based on the experimental results.

I. Tool wear was found less for the newly fabricated tool. Depending on the principal flank wear (upon which tool life depends) tool life increased by 19.55 % for the newly fabricated tool.

II. Average auxiliary flank wear is generally responsible for rough machined surface. In the present experiment average auxiliary flank wear was also reduced. As a result machined surface was good with out of feed mark.

III. Surface roughness for the newly fabricated tool was less than that of existing tool. This is due to lesser average auxiliary flank wear of newly fabricated tool

IV. Temperature generation during machining operation with newly fabricated tool was also less than that of recorded for existing tool.

V. Hardness and density of newly fabricated tool is slightly higher than that of existing tool. This is due to new composition and grain size of powder.

## 6.2 RECOMMENDATION

Followings are recommended for future work:

I. In this experiment performance of newly fabricated found satisfactory for machining steel (MS) shaft. But there is scope of further study by changing work material other than MS (High speed steel, alloy steel).

II. This experiment was performed in dry cutting condition i.e. without using cutting fluid. So there is scope of experiment, the effect of cutting fluid on the carbide insert.

III. In this experiment the performance of newly fabricated tool was compared with BOF existing tool. So there is scope of further study with other kinds of carbide tools to justify the validity of the result.

IV. In this study the tool geometry were kept constant throughout the experiment. Though these are recommended values for the used material, yet there remains a scope of further study by changing the tool geometry to conform the results.

V. Sieve cannot manufacture the grin size of powder. It can only separate the grain to a certain value (up to mesh size). Since grain size has vital role for the quality of carbide insert. So there is scope of study to measure the correct grain size of powder and fabricate new insert to conform this results.

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# Appendices

## A-1

Data table for Principal flank wear, Auxiliary flank wear and Surface roughness of newly fabricated tool.

Cutting Condition: Dry
Diameter of job : 88mm
Cutting Speed : 590 rpm

Process Parameter:

| | | |
|---|---|---|
| Cutting velocity | Vc = 163.0 m/min | $V_B$ = Principal flank wear |
| Depth of cut | t = 1.0 mm. | Vs = Auxiliary flank wear |
| Feed | So = 0.10 mm/rev. | Ra = Surface roughness |

Newly Fabricated Tool (Negative rake)

Composition of tool material: WC- 83 %, TiC –11 %, Co – 6 %

| No. of Observation | Time | Cumulative Time | Dia. of Job | Vc | $V_B$ | Vs | Ra |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 88 | 163.0 | 0 | 0 | 0 |
| 2 | 1/2 | 1/2 | 88 | 163.0 | 40 | 20 | 2.09 |
| 3 | 1 | 1.5 | 88 | 163.0 | 70 | 50 | 1.94 |
| 4 | 2 | 3.5 | 88 | 163.0 | 110 | 70 | 1.82 |
| 5 | 3 | 6.5 | 88 | 163.0 | 150 | 110 | 1.93 |
| 6 | 4 | 10.5 | 88 | 163.0 | 180 | 130 | 2.05 |
| 7 | 5 | 15.5 | 86 | 159.3 | 210 | 160 | 2.25 |
| 8 | 5 | 20.5 | 84 | 155.6 | 250 | 190 | 2.57 |
| 9 | 5 | 25.5 | 84 | 155.6 | 270 | 220 | 2 72 |
| 10 | 5 | 30.5 | 82 | 151.9 | 320 | 240 | 2.86 |

## A - 2

Data table for Principal flank wear, Auxiliary flank wear and Surface roughness of existing tool.

Cutting Condition : Dry
Diameter of job : 82mm
Cutting Speed : 590 rpm

Process Parameter:

| | | |
|---|---|---|
| Cutting velocity | Vc = 151.9 m/min | $V_B$ = Principal flank wear |
| Depth of cut | t = 1.0 mm. | Vs = Auxiliary flank wear |
| Feed | So = 0.10 mm/rev. | Ra = Surface roughness |

Tool Geometry: Existing Tool (Negative rake)

Composition of tool material:
WC- 78.26 %, TiC –15.64 %, Co – 6.10 %

| No. of Observation | Time | Cumulative Time | Dia. of Job | Vc | $V_B$ | Vs | Ra |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 82 | 151.9 | 0 | 0 | 0 |
| 2 | 1/2 | 1/2 | 82 | 151.9 | 50 | 20 | 2.26 |
| 3 | 1 | 1.5 | 82 | 151.9 | 80 | 20 | 2.31 |
| 4 | 2 | 3.5 | 82 | 151.9 | 130 | 70 | 2.02 |
| 5 | 3 | 6.5 | 82 | 151.9 | 180 | 120 | 2.21 |
| 6 | 4 | 10.5 | 80 | 148.2 | 220 | 140 | 2.67 |
| 7 | 5 | 15.5 | 80 | 148.2 | 250 | 180 | 2.84 |
| 8 | 5 | 20.5 | 78 | 144.5 | 290 | 230 | 3.19 |
| 9 | 5 | 25.5 | 78 | 144.5 | 330 | 290 | 3.25 |

## A-3

Data table for emf measurement of newly fabricated and existing tool.

| Feed | Emf existing | Emf-new | Temp. Existing* | Temp. new |
|---|---|---|---|---|
| 0.10 | 12.05 | 11.57 | 733.24 | 705.57 |
| 0.13 | 12.24 | 12.15 | 744.19 | 739.00 |
| 0.16 | 12.59 | 12.49 | 764.36 | 758.6 |
| 0.18 | 12.96 | 12 76 | 785.69 | 774.16 |
| 0.20 | 13.35 | 13.09 | 808.17 | 793.18 |

*Temperature, T = A+BX [20]

Where, A is a Constant = 38.71556

B is a Constant = 57.63693

X = emf