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The Influence of Cryogenic Treatment on the Tribological Properties of Tungsten Carbide

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Abstract - Improvement in wear resistance and hardness of cutting tool material is one of the most critical challenges in machining operations. This issue can be addressed by enhancing wear resistance and hardness through cryogenic treatment of tungsten carbide. This study investigates the effect of different soaking periods during cryogenic treatment on commercially available tungsten carbide. Experiments were conducted at a temperature of 88K with varying soaking periods of 8 hours, 20 hours, 24 hours, and 30 hours. To quantify and confirm the impact of different soaking periods on hardness and wear resistance, Rockwell hardness measurements and weight loss during wear tests were performed.
The results indicate a significant decrease in weight loss for the sample soaked for 8 hours compared to other soaking periods, although there was no change in bulk hardness. The reduced weight loss during the sliding wear test suggests that cryogenically treated tungsten carbide exhibits improved wear resistance due to an increased population density of carbides. Microstructural analysis of the worn surface reveals the mechanism behind the enhanced mechanical properties.

***Key Words*:** Cryogenics, dct, sct, microstructure, soaking period, tool life.

1.INTRODUCTION

The technique of cryogenic treatment is subjecting materials to temperatures below freezing in order to improve their characteristics. Applying this method to different tool steels has been the subject of extensive investigation, with studies examining the impacts of various thermal treatment phases followed by deep cryogenic treatment (DCT). Improvements in fatigue resistance, hardness, toughness, wear resistance, and, in certain situations, corrosion resistance have all been documented in these investigations. We'll go into more detail later on regarding the underlying mechanics that cause these enhancements in properties.

The effects of cryogenic treatment on hardened shrinkage (OHNS) steel were investigated by Prabhakaran et al. Using the Taguchi approach, their study improved treatment parameters to obtain notable reductions in wear rate and increases in hardness. Rather than traditional therapies, the authors credit the cryogenic procedure itself for these advancements.

The effects of shallow and deep cryogenic treatments on the cutting tool material made of tungsten carbide (WC-Co) were studied by Sert and Celik. They found a martensitic transition in the cobalt binder phase, with a more evident effect in samples that had undergone deep cryogenically treatment, despite the absence of microstructural alterations.

The impact of various soaking times on tungsten carbide during cryogenic treatment was investigated by Dhande et al. According to their research, the best soaking times result in less cobalt concentration, the creation of the η phase, and microstructure refinement, all of which enhance wear resistance.

The effects of deep cryogenic treatment followed by tempering on the microstructure and machining performance of WC-Co inserts were investigated by Sahoo et al. They noted notable increases in wear resistance and attributed these gains to higher cobalt concentration and stronger WC particle bonds.

2. Methods and Experimental Setup

2.1 Cutting tool materials

The classes of cutting tool materials currently in use for machining operation are high speed tool steel, cobalt-base alloys, cemented carbides, ceramic, and polycrystalline cubic boron nitride and polycrystalline diamond. The Ideal cutting tool material should have all of the following characteristics:

- Harder than the work it is cutting
- High temperature stability

- Resists wear and thermal shock
- Impact resistant
- Chemically inert to the work material and cutting fluid

To effectively select tools for machining, a machinist or engineer must have specific
information about:

- The starting and finished part shape
- The work piece hardness
- The material's tensile strength
- The material's abrasiveness
- The type of chip generated
- The work holding setup
- The power and speed capacity of the machine tool
- Some common cutting tool materials are described below:

1. Carbon steels:

Carbon steels have been used since the 1880s for cutting tools. However carbon steels start to soften at a temperature of about 180oC. This limitation means that such tools are rarely used for metal cutting operations. Plain carbon steel tools, containing about 0.9% carbon and about 1% manganese, hardened to about 62 Rc, are widely used for wood working and they can be used in a router to machine aluminium sheet up to about 3mm thick.

2. High speed steels (HSS):

HSS tools are so named because they were developed to cut at higher speeds. Developed around 1900 HSS are the most highly alloyed tool steels. The tungsten (T series) was developed first and typically contains 12 - 18% tungsten, plus about 4% chromium and 17-5% vanadium. Most grades contain about 0.5% molybdenum and most grades contain 4- 12% cobalt. It was soon discovered that molybdenum (smaller proportions) could be substituted for most of the tungsten resulting in a more economical formulation which had better abrasion resistance than the T series and undergoes less distortion during heat treatment. Consequently about 95% of all HSS tools are made from M series grades. These contain 5 - 10% molybdenum, 1.5 - 10% tungsten, 1 - 4% vanadium, 4% Chromium and many grades contain 5 - 10% cobalt.

HSS tools are tough and suitable for interrupted cutting and are used to manufacture tools of complex shape such as drills, reamers, taps, dies and gear cutters. Tools may also be coated to improve wear resistance. HSS accounts for the largest tonnage of tool materials currently used. Typical cutting speeds: 10 - 60 m/min.

3. Cast Cobalt alloys:

Introduced in early 1900s these alloys have compositions of about 40 - 55% cobalt, 30% chromium and 10 - 20% tungsten and are not heat treatable. Maximum hardness values of 55 - 64 Rc. They have good wear resistance but are not as tough as HSS but can be used at somewhat higher speeds than HSS. Now only in limited use.

4. Carbides:

Also known as cemented carbides or sintered carbides were introduced in the 1930s and have high hardness over a wide range of temperatures, high thermal conductivity, high Young's modulus making them effective tool and die materials for a range of applications. The two groups used for machining are tungsten carbide and titanium Carbide; both types may be coated or uncoated. Tungsten carbide particles (1 to 5 Micrometer) are bonded together in a cobalt matrix using powder metallurgy. The powder is pressed and sintered to the required insert shape. Titanium and niobium carbides may also be included to impart special properties. A wide range of grades are available for different applications. Sintered carbide tips are the dominant type of material used in metal cutting. The proportion of cobalt (the usual matrix material) present has a significant effect on the properties of carbide tools. 3 - 6% matrix of cobalt gives greater hardness while 6 - 15% matrix of cobalt gives a greater toughness while decreasing the hardness, wear resistance and strength. Tungsten carbide tools are commonly used for machining steels, cast irons and abrasive non-ferrous materials. Titanium carbide has a higher wear resistance than tungsten but is not as tough. With a nickel-molybdenum alloy as the matrix, TiC is suitable for machining at higher speeds than those which can be used for tungsten carbide. Typical cutting speeds are: 30 - 150 m/min or 100 - 250 when coated.

5. Coatings

Coatings are frequently applied to carbide tool tips to improve tool life or to enable higher cutting speeds. Coated tips typically have lives 10 times greater than uncoated tips. Common coating materials include titanium nitride, titanium carbide and aluminium oxide, usually 2 - 15 micro-m thick. Often several different layers may be applied, one on top of another, depending upon the intended application of the tip. The techniques used for applying coatings include chemical vapor deposition (CVD) plasma assisted CVD and physical vapor deposition (PVD). Diamond coatings are also in use and being further developed.

2.2 Types of Coating method:

1) PVD (Physical Vapour Deposition)

2) CVD (Chemical Vapour Deposition)

1) PVD (Physical Vapour Deposition)

refers to an assortment of thin film deposition techniques whereby a pure metal or alloy coating is put on electrically conductive materials via evaporating solid metal in a high vacuum environment. It can generate extremely pure and high-performance coatings, which are often far superior to electroplating in many applications since it transfer the coating material at the single atom or molecule level. With more traditional coating types through fluid intermediates and chemical reactions, PVD coating procedures may substantially lower the number of harmful substances that must be disposed of. PVD coating techniques can be environmentally friendly.

PVD Coatings, which are at the core of every microchip and semiconductor device, allow the solar panel sector to produce medical and surgical implants that require the highest levels of purity in addition to cleaner electricity. It creates coatings with exceptional toughness, longevity, and wear resistance. PVD coatings are widely utilized in the aerospace and automotive industries, as well as for cutting tools where long-term durability is a critical success factor. They reduce friction for high performance moving parts.

PVD is simply a vacuum coating technique where a metal is heated up into a plasma of atoms or molecules and then deposited on a variety of surfaces. Performed at 10-2 to 10-4 millibars in a high vacuum chamber that approximates space, the process usually takes place at temperature between 150 and 5000 C. In order to create an extremely strong bond between the coating and substrate when it is placed, reactive gases like nitrogen, oxygen, or acetylene are additionally added to the vacuum deposition chamber. PVD is the ideal option for high performance cutting tools and engine parts because, despite their thin film coatings' only microns' thickness, they generate a very adherent coating with high lubricity, reducing friction and heat.

2) CVD (chemical vapor deposition)

Chemical Vapor Deposition (CVD) is an atmosphere controlled process conducted at elevated temperatures (~1925° F) in a CVD reactor. During this process, thin-film coatings are formed as the result of reactions between various gaseous phases and the heated surface of substrates within the CVD reactor. As different gases are transported through the reactor, distinct coating layers are formed on the tooling substrate. For example, TiN is formed as a result of the following chemical reaction: $TiCl_4 + N_2 + H_2$ 1000° C → TiN + 4 HCl + H_2. Titanium carbide (TiC) is formed as the result of the following chemical reaction: $TiCl_4 + CH_4 + H_2$ 1030° C → TiC + 4 HCl + H_2. The final product of these reactions is a hard, wear-resistant coating that exhibits a chemical and metallurgical bond to the substrate.

Wear-resistant CVD coatings are utilized in a wide range of manufacturing applications, such as on plastic processing tools, wear parts, tungsten milling and turning inserts, etc. Nonetheless, metal-forming tools are the most popular use for CVD coating. Excellent resistance to the kinds of wear and galling that are typical during several metal-forming activities can be obtained by CVD coatings.

High temperature CVD coating innovations will work better than "cold" treatments like PVD, thin-dense chrome (TDC), nitriding, etc. in high stress metal-forming applications where the tool's tolerances and substrate permit. Adhesion qualities produced by the chemical/metallurgical bonding that arises from the CVD coating process are incomparable to those produced by a "cold" procedure. Because of this enhanced adhesiveness, forming tools are shielded from the intense shearing pressures that are produced in heavy metal forming applications, which can wear them out through sliding friction.

2.3 Types of Coating Material

1. Cermets:

These were invented in the 1960s and usually consist of 30% titanium carbide and 70% aluminum oxide. Tantalum, niobium, and molybdenum carbides are present in some formulations. Their performance lies in the middle of that of carbides and ceramics, and coatings don't seem to give plenty improvements. Cutting speeds range from 150 to 350 m/min.

2. Alumina:

Introduced in the early 1950s, two classes are used for cutting tools: fine grained high purity aluminium oxide (Al2O3) and silicon nitride (Si3N4) are pressed into insert tip shapes and sintered at high temperatures. Additions of titanium carbide and zirconium Oxide (ZrO2) may be made to improve properties. But while ZrO2 improves the fracture toughness, it reduces the hardness and thermal conductivity. Silicon carbide (SiC) whiskers may be added to give better toughness and improved thermal shock resistance. The tips have high abrasion resistance and hot hardness and their superior chemical stability compared to HSS and carbides means they are less likely to adhere to the metals during cutting and consequently have a lower tendency to form a built up edge. Their main weakness is low toughness and negative rake angles are often used to avoid chipping due to their low tensile strengths. Stiff machine tools and work set ups should be used when machining with ceramic tips as otherwise vibration is likely to lead to premature failure of the tip. Typical cutting speeds: 150-650 m/min.

3. Silicon Nitride:

A silicon nitride-based tool material was created in the 1970s; it may also contain titanium carbide, aluminum oxide, and yttrium oxide. SiN is not recommended for machining steels since it has its affinity for iron. 'Sialon' is one specific variation that has silicon, aluminum, oxygen, and nitrogen in it. This is advised for machining cast irons and nickel-based super alloys at moderate cutting rates since the material has a stronger thermal shock resilience than silicon nitride.

4. Cubic Boron Nitride (CBN):

This material, which first came into existence in the early 1960s and is the second hardest after diamond, is called CBN. CBN tools can be used as small solid tips or as a layer of polycrystalline boron nitride that is 0.5 to 1 mm thick and is sintered under pressure onto a carbide substrate. In the latter instance, the CBN layer offers extremely high resistance to wear and cutting edge strength, while the carbide component provides shock resistance. When it comes to machining alloy and tool steels with a hardness of 50 Rc or greater, cubic boron nitride is the recommended alternative. The cutter speeds: 30 to 310 m/min on median.

5. Diamond:

The hardest known substance is diamond. Although single crystal diamond has been used as a tool, they are brittle and need to be mounted at the correct crystal orientation to obtain optimal tool life. Single crystal diamond tools have been mainly replaced by polycrystalline diamond (PCD). This consists of very small synthetic crystals fused by a high temperature high pressure process to a thickness of between 0.5 and 1mm and bonded to a carbide substrate. The result is similar to CBN tools. The random orientation of the diamond crystals prevents the propagation of cracks, improving toughness. Because of its reactivity, PCD is not suitable for machining plain carbon steels or nickel, titanium and cobalt based alloys. PCD is most suited to light uninterrupted finishing cuts at almost any speed and is mainly used for very high speed machining of aluminium -silicon alloys, composites and other non - metallic materials. Typical cutting speeds: 200- 2000 m/min.

The demand for heat-resistant instruments for cutting has increased in tandem with the rates of metal removal. As a result, high-speed steels, carbide, ceramics, and other highly resistant materials have all been developed. Four times more rapidly as carbon steels, high-speed steels cut. Three primary groups constitute over thirty different grades of high-speed steel: tungsten, molybdenum, and molybdenum-cobalt based grades. Today's industry uses carbide tools instead of high-speed steels for most of its applications. When compared with high-speed steels, these carbide and coated carbide tools cut around three to five times quicker. A metallic powder product called cemented carbide is formed up of tiny carbide particles bound together with a cobalt binder. Tungsten carbide, titanium carbide, and tantalum carbide are among the primary kinds of hard carbide.

Cutting tools made of ceramic are more brittle than carbides, but they are also tougher and more heat-resistant. Cast iron, strong steels, and super alloys are among the materials they work well with. There are two distinct varieties of ceramic cutting tools: those made of silicon nitride and those made of alumina. High-speed semi- and final finishing of ferrous and some non-ferrous materials is carried out using alumina-based ceramics. Cast iron and super alloys are usually processed to increase roughness and density using ceramics based on silicon nitride.

2.4 CRYOGENIC TREATMENT

1. Introduction

Cryogenics is defined as the branches of physics and engineering that study very low temperatures, how to produce them, and how materials behave at those temperatures. The word Cryogenics is derived from the Greek words "Kryos" (meaning cold) and "Genes" (meaning born). The word cryogenics literally means "the production of icy cold".

2. Cryogenic Processing

Cryogenic processing is the utilization of cryogenic temperatures to modify a material or component. The field of cryogenics, according to the staff of the National Institute of Standards and Technology in Boulder, Colorado, is defined as involving temperatures lower than –180C (93.15 K). Materials endure alterations to their crystal structures during cryogenic processing. Deep stress relieving technology is the processing of metals and alloys at deep sub-zero (far below 0C). At absolute zero temperature, entropy is zero, in accordance with the third rule of thermodynamics. This idea can be utilized in cryogenic processing to release material tensions. The materials undergo extended exposure to extremely low temperatures, which causes equilibrium to evolve. As a consequence, the material's flaws reduce and its entropy approaching zero.

Metal cannot be permanently hardened by cryogenic processing alone; quenching and tempering are required. It does not take the place of heat-treating. It is a supplement to heat treatment. Cryogenic processing is unlikely to significantly change the hardness of most alloys. For the material to acquire the necessary hardness and toughness, cryogenically processing it and then tempering it is needed

.

3. Classification of Cryogenic Treatment

Cryogenic treatment has been classified into shallow cryogenic treatment (SCT) and deep cryogenic treatment (DCT) depending upon the temperatures in which the material is treated:

1) SCT- tool steel is keep in freezer at 193K for 5 h and then exposed to RT

2) DCT- material is brought down to 77K at 1.26 K/min, held there for 24 h and brought back to RT at 0.63 K/min.

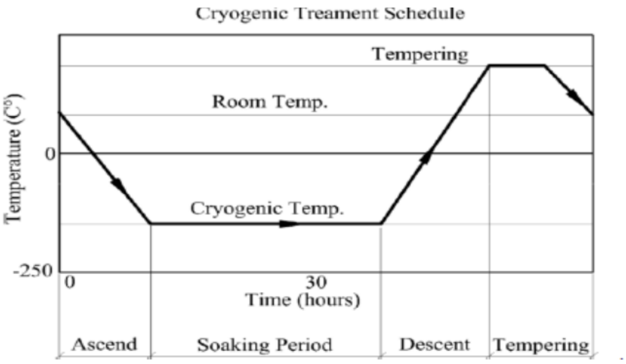

Figure a: Variations of temperatures during Cryogenic Treatment

The cryo-treatment took 8 hours and 4 hours to complete, employing carbide cutting tools at two separate cooling/heating rates of 0.5 °C/min and 1 °C/min. The results showed that the sample's wear resistance was higher at 0.5 °C/min, 8 hours, than it was at 1 °C/min, 4 hours.Thermal shock, a rapid drop in temperature, lowers the cost of cryotreatment but raises the possibility of microcracks developing in the specimen's microstructure, which might stop the specimen from operating as well.

Figure b: Cryogenic treatment arrangement

2.5 Modified Cryogenic system

This cryogenic apparatus is depicted in picture 3.4. It is made up of an insulated container that can hold materials. The gasses are moved around using a single circulating fan. The temperature is measured using a thermocouple. A computer system is in charge of the entire setup. This box is attached to a tank of liquid nitrogen via a solenoid valve.

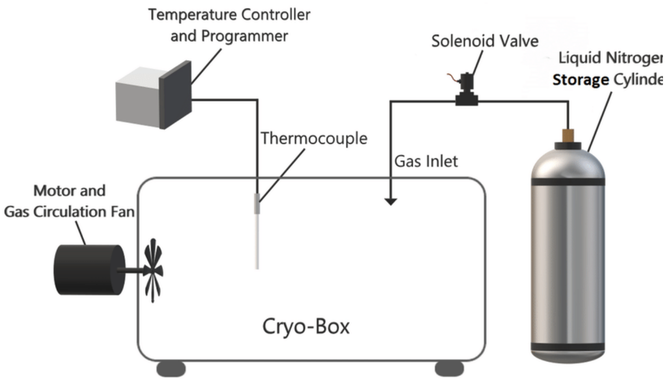

Fig.c: Advance Cryo-processer (vaporized liquid phase)

2.5.1. Parameters of cryogenic treatment

These parameters are cooling rate, soaking temperature, soaking period and warming rate. These parameters also have contribution in improvement in wear characteristics.

*A. **Cooling rate and warming rate***

Cooling rate is the rate at which the sample is slowly cooled down to soaking temperature. Warming rate is the rate at which sample is warmed slowly up to room temperature. It was observed that the slow cooling and warming rate of about 1-3 K/min were used to avoid the thermal micro cracking of material.

B. Soaking temperature

Soaking temperature is temperature at which sample is held for given soaking period. First users of CT applied the soaking temperature in the range 193 to 173 K. Now the recent application which is known as deep CT uses the temperature in the range 103 K to 77 K.

*C. **Soaking period***

Soaking period is that period at which sample is held at low temperature. From previous studies it was found that soaking period vary from 8hr to 40 hr. Das found in his work that from the different soaking period 36hr soaking period gives the better resistance properties to AISI D2 steel.

WC-Co insert generally have cobalt binder. Cobalt is present next to iron in periodic Table. Cobalt has same valance electron and forms same crystal structure as the iron. The iron and cobalt both are affected by the CT and has contribution in the enhancement of hardness. Hence it was stipulated that WC-Co which contains cobalt shows similar response to CT as that of the steels.

Many researches had studied the effect of CT on WC-Co tools and found interesting results like improvement in tools life improvement in mechanical properties etc.

2.5.2. Tempering Procedure:

Tempering frequently occurs after following cryogenic treatment. The process is mainly carried out to relieve the specimen's internal stresses, which result from excessive cooling during cryogenic treatment. The procedure is typically used on cutting tools, where the specimen is held at 150–200 °C for one to two hours. Double tempering was used in some earlier research to produce a finely dispersed distribution of carbide particles during cryogenic treatment (CT8).

Based on the findings of multiple investigations, tempering does, in fact, optimize the increase in tool life following DCT (86% with tempering and 126% without). Research has shown that tempering beforehand actually reduces wear resistance rather than increases it. In retrospect, it's been found that tempering continuously after DCT has an adverse impact rather than improving wear resistance. In comparison to CT and HCT samples, there has also been a drop in wear resistance following several cycles of tempering.

Fig.d: Tempering process setup

2.6. SELECTION OF RAW MATERIALS

A] *Need for Research*

It is evident from the comprehensive literature review that OHNS steel is lacking. Power transmitting elements and die manufacturing businesses are the main uses for this OHNS. Thus, it has been chosen to use this OHNS material as a working material.

B] ***OHNS (OIL HARDENED NON SHRINKAGE STEEL)***

The material used for this work is OHNS steel. OHNS steel is a general purpose tool steel that is typically used in applications where alloy steels cannot provide sufficient hardness, strength and wear resistance.

Chemical composition of OHNS material.

Sr. No.	Element name	Composition (%)
1	Carbon (C)	0.96
2	Manganese (Mn)	1.36
3	Chromium (Cr)	0.51
4	Nickel (Ni)	0.10
5	Molybdenum (Mo)	0.06
6	Tungsten (W)	0.45
7	Sulfur (S)	0.017
8	Phosphorus (P)	0.020
9	Silicon (Si)	0.32

Table2.6

From the metallurgical testing, the hardness of OHNS material is in the range of 91-92 HRB. This material are used to making a die.

OHNS steel hardens between 7900 and 8200 degrees Celsius. Steel that does not shrink is called OHNS steel. This phrase describes low-temperature hardened and tempered steels that exhibit minimal volume change from their annealed state. These steels are needed for master tools, gauges, and dies which require to keep the same size after annealing and hardening by machining.

2.6.1. Mechanical Properties of OHNS Steel

I. Strength and Hardness: Generally the strength increases as the carbon and manganese content increases. Given the high percentage of both of those, OHNS becomes strong. OHNS has 58 RC to 64 RC hardness

II. Toughness and Brittleness: Toughness of a material determines whether it can be subjected to shock conditions, and the extent to which it may undergo deformity in shape but still not snap. OHNS steel tends to be very tough. As opposed to toughness, brittleness measures whether a material will snap instead of getting deformed, when load is applied. OHNS steels are less brittle than cast or pig iron because of the presence of magnesium.

III. Ductility and Malleability: Ductility is a material's ability to be drawn into wires without breaking. Ductility decreases with increasing carbon, and because OHNS steel has very high carbon content, it is not very ductile. On the other hand, malleability determines a material's ability to be rolled into sheets without getting ruptured. OHNS steel is quite malleable and can be worked upon even at low room temperatures.

2.6.2. Applications of OHNS Steel

It is to be considered as die steel. It is used for manufacturing of blanking and stamping dies, rotary shear blades, thread outing tools, milling cutters, measuring tools, gauging tools, wood working tools, reamers, etc.

Fig.no.4.2: OHNS Material Sample

2.7. SELECTION OF RAW MATERIALS

We are selected the cutting tool material as tungsten carbide from research paper. This insert is coated type insert. The coating on insert is Titanium aluminide (TiAl). There is no one done the experiment TiAl insert on die material as OHNS material.

Grade of insert: APMT1135PDER-T

Coating method: PVD

Fig.no.4.5: Coated Tungsten carbide cutting tool insert

2.7.1. Tungsten carbide

The substance tungsten carbide (WC-Co) is widely utilized in cutting tools. It offers a variety of tool grades with varying degrees of hardness. Various grades are employed for distinct materials. The composite known as WC-Co is made up of tungsten, cobalt (6%), titanium, and niobium. The result of mixing tungsten carbide powder with a cobalt binder is WC-Co, a byproduct of powder metallurgy. To create the finished product, this mixture is subjected to blending, compacting, and sintering processes. Refectory material is WC-Co. It wears resistant and has a high hardness.

2.7.2. Manufacturing process of WC-Co tools

Powder metallurgy technique was used by Schroeter in 1923 for obtaining the fully consolidated product of tungsten carbide.

I. Schroeter blended fine WC powder with a small amount of Iron, Nickel, or Cobalt powder.

II. This blended mixture was pressed and compacted under high pressure.

III. Finally compacted mixture was sintered at approximately 1573^0 K.

IV. This WC-Co material is used in a wide range of applications, including metal cutting, mining, construction, rock drilling, metal forming, structural components, and wear parts. Approximately 50% of all carbide production is used for metal cutting applications.

2.7.3 Important properties of Tungsten Carbide

Tungsten Carbide-Cobalt alloys are commonly referred as straight grades. These alloys have excellent resistance to simple abrasive wear and thus have many applications in metal cutting operations. The microstructures of WC-Co alloys contain the phases as given below

1. Angular WC grains and
2. η Phase (Shaded gray phase)

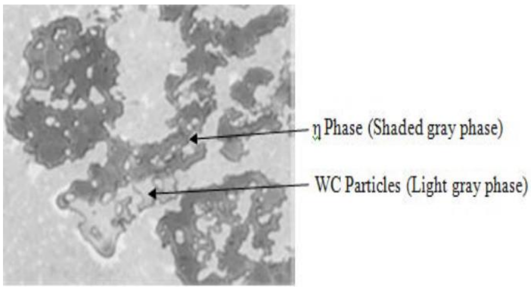

Fig. g : Microstructure of WC-Co material

Above figure shows the η Phase (CO6W6C) which appears as shaded gray with clearly defined grain boundaries. Bright phase WC particles are surrounded by η phase because of the solubility of WC-Co in the binder. Due to insufficient amount of carbon in WC-Co material during manufacturing there is formation of a series of double carbides (Co3W3C or Co6W6C).

This new formed group is commonly known as η phase. The formation of η phase involves the dissolution of the original carbides into the cobalt binder. Eta (η) phase appears as gray phase in microstructure.

2.7.4 Tool Life

Tool life is a broad term that refers to how long a cutting tool will function effectively before it is determined to be defective. While tool life is usually measured in minutes of machining time, different studies define it differently. In certain industries, however, additional methods are used as well, contingent on the specific situation, for assessing tool life, including

I. Number of pieces of work machined
II. Total volume of material removed
III. Total length of cut.

2.8. Milling Machine and Milling Operation

We are used vertical milling machine for machining. The milling operation selected for trial is rough or plunge milling operation.in the milling operation the material removal rate is more required for die manufacturing. Plunge milling is very good method for rough machining process of complex shape.it is also called as z-axis milling.

Advantage of CNC plunge milling over conventional milling

I. The radial cutting forces, which is responsible for the deformation of the tool and the work piece, is very small.
II. The material which is difficult to cut can be rough machined easily.
III. The vibration can be avoided in the machine so that is suitable for deep cavity machining like mould and cavity making.

Fig. h : VMC Machine

2.9. Weight Measurement

The material removal rate (MRR) of the work piece is measured. During the machining process, material is removed by turning the tool in relationship to the work piece. The difference between the work piece's pre- and post-milling weights divided by the amount of time spent machining is known as the MRR.

Fig. i : Weight measuring machine

2.10. Surface Roughness Measurement

Roughness measurement has been done using a portable surface roughness tester, SURFTEST (Mitutoyo).

The surface roughness values like Ra, measured using surface roughness tester with model no. SJ 210 178-561-01A for measurement. The detector with instrument is 0.75 mN type with stylus tip radius 2 µm with measuring force 0.75 mN. Surface roughness measurement has been shown in Figure

Fig. j : Surface Tester

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3. Result and Discussion

3.1. Selection of Parameters and Levels

3.1.1. OVAT (one variable at a time) analysis

OVAT analysis is very much important tool utilized widely in engineering analysis. A control factors and there levels are selected for experimentation by using OVAT analysis. The main purpose of performing OVAT analysis is to clear that whether the selected process parameters having influence on quality characteristic. OVAT analysis perform by varying one process parameter from lower to higher value by keeping all other process parameter constant, and measure the effect on quality characteristic. Before going to the main experimentation, some discussion with company peoples and with the help of research paper was selected three input parameter like speed, feed, and depth of cut.

From the basis of research paper, experience and catalogue, we are select the three different range of speed, feed and depth of cut.

Speed range: (1000-4000) rpm

Feed range: (0.1-0.8) mm/rev

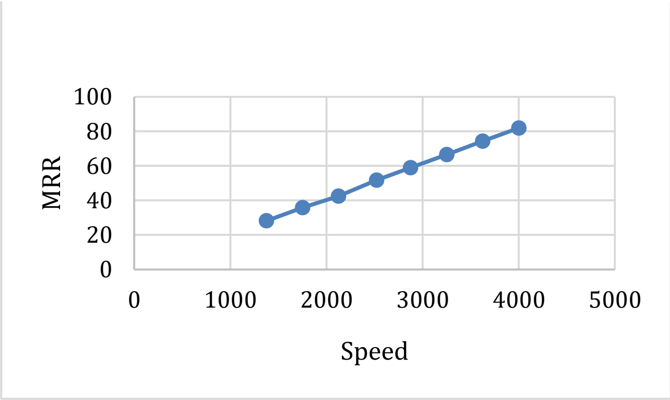
Depth of cut range: (0.1-0.8) mm

3.1.1.1. Speed

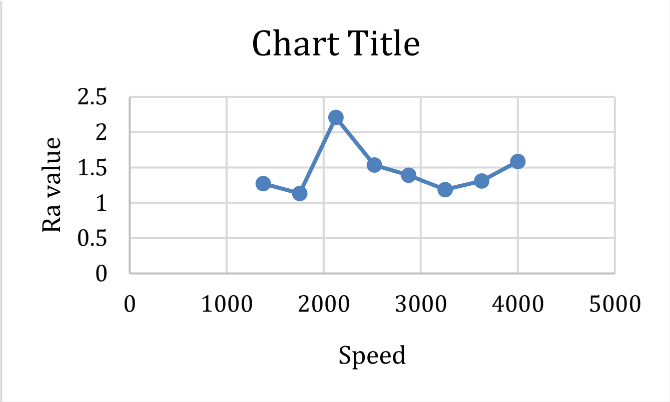
The specified speed ranges from 1000 to 4000 rpm. Variations in speed, constant parameters such as feed and depth of cut, and measurement of surface roughness as a result Ra values typically drop as speed increases, however under certain circumstances, they do not. The table displays it. due to the fact that the cut and feed depths are maximum for the conditions. However, as you can see from the table, the material removal rate increases as speed does.

Table no. 3.1.1.1 :- OVAT analysis of Speed

a) Graphical analysis



Graph no: a) Speed vs MRR



Graph no: b) speed vs Ra value

The variation in MRR and Ra value are shown in above graph. When maximum speed then the MRR is maximum. Ra value vary with respect to speed variation is shown in graph.

3.1.1.2. Depth of cut

The levels of depth of cut 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, are selected. Depth of cut changing and remaining parameter speed, feed are same and result surface roughness are taken and from table it is clear that as depth of cut increases the surface roughness increases .Hence depth of cut is influencing factor on surface roughness.

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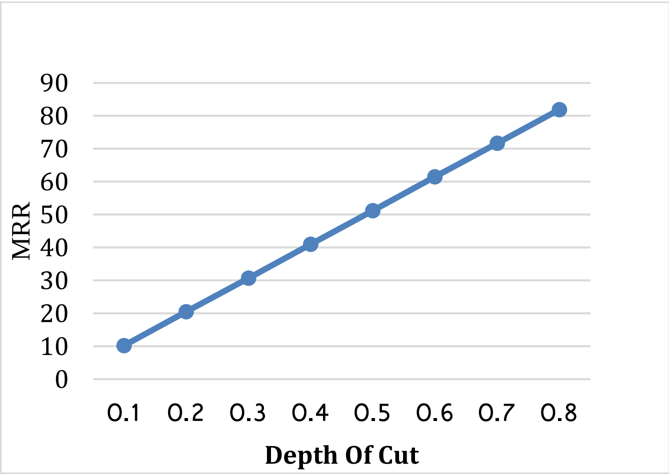
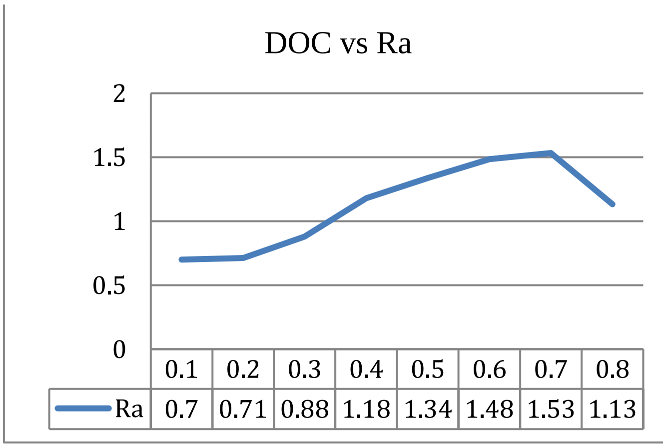
sr.no	Speed(rpm)	Feed(mm/rev)	DOC(mm)	MRR(mm3/min)	Ra
1	4000	0.8	0.1	10.24	1.058
2	4000	0.8	0.2	20.48	1.126
3	4000	0.8	0.3	30.72	1.331
4	4000	0.8	0.4	40.96	1.174
5	4000	0.8	0.5	51.2	1.302
6	4000	0.8	0.6	61.44	1.126
7	4000	0.8	0.7	71.68	1.258
8	4000	0.8	0.8	81.92	0.969

Table no.3.2.1.2: OVAT analysis of depth of cut





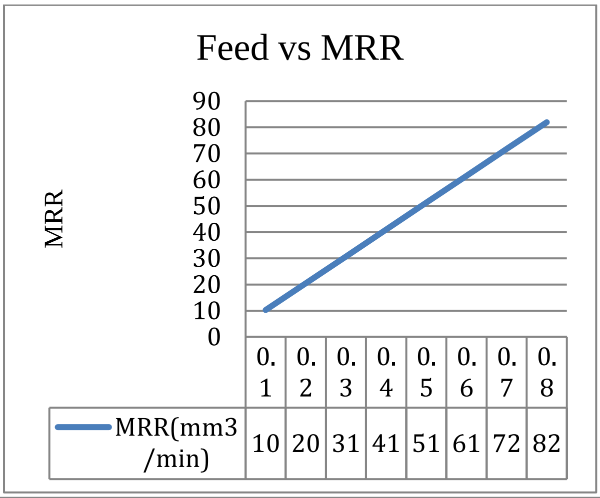
The variation in MRR and Ra value with respect to depth of cut as shown in above graph. We are seen that when depth of cut is maximum the MRR also maximum and when depth cut is maximum then Ra value minimum.

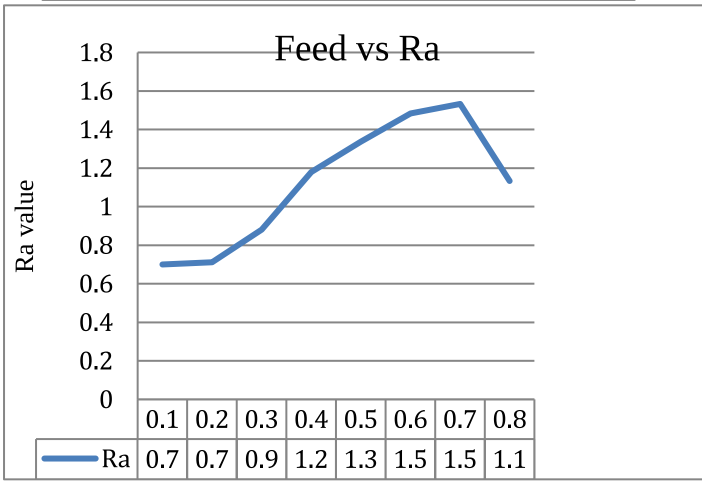
3.1.1.3. Feed

The levels of Feed 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 are selected. Feed changing and remaining parameter speed, depth of cut putting mean and result surface roughness are taken and from table it is clear that as feed increases the surface roughness increases. Hence feed is influencing factor on surface roughness.

Sr. No	Speed	Feed	DOC	MRR	Ra Value
1	4000	0.1	0.8	10.24	0.7
2	4000	0.2	0.8	20.48	0.712
3	4000	0.3	0.8	30.72	0.881
4	4000	0.4	0.8	40.96	1.179
5	4000	0.5	0.8	51.2	1.338
6	4000	0.6	0.8	61.44	1.484
7	4000	0.7	0.8	71.68	1.533
8	4000	0.8	0.8	81.92	1.133

Table no. 2.11.1.3 : OVAT analysis of feed





The variation in MRR and Ra value with respect to feed are shown in graph.in graph show at minimum feed the Ra value also minimum and at maximum feed the MRR is maximum.

3.2. Result from OVAT analysis

From the OVAT analysis we are found the different level of parameter. We are seletct optimum parameter of speed, feed and depth of cut.

The optimum level parameter are shown in table.

Sr. no	Speed(rpm)	Feed(mm/rev)	Depth of cut(mm)	MRR(mm3/min	Ra value(um)
1	3250	0.6	0.6	66.56	1.189
2	3625	0.7	0.7	74.24	1.31
3	4000	0.8	0.8	81.92	1.13

Table no.3.2: Optimum parameter level

3.3. Taguchi Method

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there is an intermediate number of a variable (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

To take optimum level from OVAT analysis and to make a 27 array by using Mini Tab software.

3.3.1 27 array for Design of Experiment

Sr. No	Speed(rpm)	Feed(mm/rev)	Depth of cut(mm)	MRR(mm3/min)	Ra value(um)
1	3250	0.6	0.8	49.92	2.721
2	3250	0.6	0.8	49.92	1.2
3	3250	0.6	0.8	49.92	1.417
4	3250	0.7	0.7	50.96	1.299
5	3250	0.7	0.7	50.96	1.626
6	3250	0.7	0.7	50.96	1.418
7	3250	0.8	0.6	49.92	1.999
8	3250	0.8	0.6	49.92	3.085
9	3250	0.8	0.6	49.92	1.637
10	3625	0.6	0.7	48.72	2.201
11	3625	0.6	0.7	48.72	1.425
12	3625	0.6	0.7	48.72	1.679
13	3625	0.7	0.6	48.72	1.664
14	3625	0.7	0.6	48.72	1.291
15	3625	0.7	0.6	48.72	1.291
16	3625	0.8	0.8	74.24	1.864
17	3625	0.8	0.8	74.24	1.447
18	3625	0.8	0.8	74.24	1.292
19	4000	0.6	0.6	46.08	0.642
20	4000	0.6	0.6	46.08	0.828
21	4000	0.6	0.6	46.08	1.406
22	4000	0.7	0.8	71.68	2.208
23	4000	0.7	0.8	71.68	1.085
24	4000	0.7	0.8	71.68	1.394
25	4000	0.8	0.7	71.68	2.049
26	4000	0.8	0.7	71.68	1.36
27	4000	0.8	0.7	71.68	0.966

Table no. 3.3.1 : 27 Array of DOE

We are focusing on maximum MRR. In this table we are seen that different mrr with corresponding level. From this table find maximum MRR reading and also corresponding Parameter.

3.2.2 Result from taguchi method

The optimum level of parameter from DOE is followed

Sr. No	Speed(rpm)	Feed(mm/rev)	Depth of cut(mm)	MRR(mm3/min)	Ra value(um)
1	3625	0.8	0.8	74.24	1.292

3.4 Rockwell Hardness test

Sample no.	Soaking period	1	2	3	Avg. Hardness(HRB)
1	4	25.5	26.5	26	26
2	12	21	26	26	24.33
3	20	26	27	26	26.33
4	28	24	24	25	24.33
UT	-	17	16	16	16

Table no. 3.4: Hardness test

3.5. Tool life analysis

We are observing the cutting tool insert samples that have been treated and those that have not. The wear resistance of the material determines the tool life. The wear of the tool can be readily determined by measuring the machining of both treated and unsealed cutting tool inserts. We may comprehend the improved wear resistance cutting tool insert from this observation.

Type of sample	Soaking period(hrs)	Weight loss of insert in (gm)	% weight loss of insert
UT	-	0.170	-
CT	20	0.020	0.35

Table no.3.5: wear analysis

4. CONCLUSION

4.1 Conclusion from OVAT analysis

The different categories of characteristics are discovered using the OVAT analysis. We have chosen the ideal specifications for cut depth, feed, and speed.
The optimum level parameters are shown in table.

Sr. no	Speed(rpm)	Feed(mm/rev)	Depth of cut(mm)	MRR(mm3/min	Ra value(um)
1	3250	0.6	0.6	66.56	1.189
2	3625	0.7	0.7	74.24	1.31
3	4000	0.8	0.8	81.92	1.13

4.2 Conclusion from taguchi method

The optimum level of parameter from DOE is followed

Sr. No	Speed(rpm)	Feed(mm/rev)	Depth of cut(mm)	MRR(mm3/min)	Ra value(um)
1	3625	0.8	0.8	74.24	1.292

4.3 Conclusion from tool life

The study's findings allow for the drawing of the following conclusions about the impact of varying soaking times on wear characteristics and the process by which wear characteristics improve following tungsten carbide CT.

I. Improvement in the wear characteristics is also observed due to refinement of the structure, formation of stable structure and proper alignment of particle.

Type of sample	Soaking period(hrs)	Weight loss of insert in (gm)	% weight loss of insert
UT	-	0.170	-
CT	20	0.020	0.35

5.4 Conclusion from hardness test

Sample Name	Soaking period	Avg. Hardness(HRB)
CT	20	26.33
UT	-	16

From the table we can see that

To increase in hardness of treated insert as compared to untreated insert.

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