CASTING OF THROWN AWAY TOOL STEEL BITS IN THE CENTRIFUGAL CASTING ROUTE

A THESIS SUBMITTED IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

METALLURGICAL & MATERIALS ENGINEERING

By

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CERTIFICATE

This is to certify that the thesis entitled **"Casting of thrown away tool steel bits in the centrifugal casting route"** submitted by Sri Surendra Kumar M partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Metallurgical & Materials Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been carried out in any other University/ Institute for the award of any degree or diploma.

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The experimental work was assisted by **Mr. Samir Pradhan, Mr. Rajesh Pattnaik, Mr. Pradhan** and **Mr. Hembrem** and their cooperation is highly appreciated.

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ABSTRACT

Cutting tools get worn out due to wear and are ground in order to use them again. This wear may be due to abrasive wear, diffusion wear, fatigue wear, adhesive wear. Wear of tool steels leads to shortening of the length, so small that the tool bits are no more usable. These waste and thrown away tool bits were collected which may include steel waste, pig iron, molybdenum iron, chromium iron, vanadium iron, tungsten iron and other waste material. This mixture was melted in induction furnace at temperature about 1600^{o}C to 1700^{o}C. After that the casting of the melt was done through the centrifugal route at speeds of 200 rpm and 250 rpm. The cast obtained is in the shape of tool steel cylinder. Then the samples were prepared for the hardness test, machinability test and SEM analysis. The hardness was measured across the radius of the cast cylinder by using Rockwell hardness test machine in C-scale. The machinability test specimens were taken from the outer zone of the cast cylinder and the test was carried out in Lathe by keeping the variables such as rotation speed (420 rpm), feed rate (0.15 KM), rack angle (10^{0}) material to be machined (mild steel) and time of machining (5 minutes 40 seconds) constant. The machinability of the centrifugally cast samples were compared with the as-cast samples. SEM micrographs were taken for the outer region of the cast cylinder and a comparative study was made with the as-cast samples. We found that there is an increase in hardness values with the distance from the centre to the outer periphery of the cast samples also the hardness values are higher for speed 250 rpm than 200 rpm. The Machinability of the centrifugally cast samples was better than generally used tool steels.

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Chapter 1

INTRODUCTION

Cutting tools get worn out due to wear and are ground in order to use them again. This wear may be due to abrasive wear, diffusion wear, fatigue wear, adhesive wear. This shortens the length of the tool and finally the length may become so small that the tool bit is no more usable. In addition the tools may be rendered useless due to electrochemical and oxidation effect.

A newly ground tool has sharp cutting edges and smooth flanks. When put into operation, it gets subjected to cutting forces that are concentrated on a relatively small contact area on the rake face and the flank. Each time the tool enters or exits from the cut, it is subjected to mechanical as well as thermal shock. Under such adverse conditions, the hard tool materials like HSS and carbides, gradually wear out and even fracture, necessitating a tool change. Due to these reasons, the tool steel becomes small and are not useful for further machining purposes.

The present project aims at collecting these short and thrown away tool bits, melting it in a induction furnace, casting it in the centrifugal casting rout, examining the structure and effect of centrifugal casting on the cast tool bits, testing its hardness and comparing its machining abilities visa-vice that of freshly obtained tool bits. Therefore, in short, the aim of the project is to examine if reusable tools can be fabricated using the thrown away tool bits.

Chapter 2

LITERATURE SURVEY

2.1 Tool Steels

2.1.1 Introduction

Tool steels are large group of carbon or alloy steels which upon being heat treated, exhibit a high strength, hardness and wear resistance, i.e. the properties required in tools for cutting, shaping, machining or plastic forming and blanking of materials at either ordinary or elevated temperatures. They are usually melted in electric furnaces and produced under tool steel practice to meet special requirements.

2.1.2 Composition of Tool Steels

Of the elements found in tool steels, iron is the most prominent. It is the ability of the iron to undergo the allotropic transformation from ferrite (alpha) to austenite (gamma) during heating, and back to ferrite again during cooling, which makes it possible for the tool steels to develop high hardness and wear resistance. Other than iron, generally carbon, manganese, phosphorus, sulfur, silicon, nickel, chromium, vanadium, tungsten, molybdenum and cobalt are present in the tool steels. Also some amounts of aluminum, titanium and zirconium are added to the steel for the purpose of deoxidizing the melt and controlling the grain size of the steel.

<u>Carbon</u>

Carbon is the most important for the development of high hardness by heat treatment. Carbon is present in tool steels in amounts from as little as about 0.6% to as much as 1.5%. When the steel of different carbon content are heat treated so that the resultant microstructure is entirely martensite, the hardness of the martensite increases with increasing carbon content. Also Wear resistance of steel is generally proportional to the hardness of the steel (figure 2.1).

Also it can be said that the hardenability of 1% carbon steel is low but high hardness whereas a 0.35% carbon, 5% chromium steel has relatively low hardness but high hardenability. The maximum hardness attainable is steel by heat treatment is dependent on its carbon content. As figure1 shows that only 0.60% carbon is required in a steel to make it capable of being hardened to a very high level. Also many tool steels are made with much more than 0.60% carbon. This is because carbon forms compounds with a number of elements commonly used in steels such as vanadium, tungsten, molybdenum and chromium, as well as iron. These compounds are called carbides. The carbides are quit insoluble in steel at low temperatures, but they dissolve to some degree in austenite, the high temperature form of iron. During hardening heat treatment, many of the carbide particles in high carbon steels remain undissolved and are embedded in martensite, the matrix of the hardened steel. Since the carbide particles are themselves appreciable harder than the matrix, they provide additional wear resistance to the hardened steel. Thus carbon is essential in tool steels to provide high attainable hardness and to produce carbides which increase the wear resistance of the hardened steel.

<u>Manganese and Silicon</u>

These are found in all tool steels in quantities from about 0.15 to 3.0%. In small quantities these elements are primarily effective in deoxidizing the steel in the final stage of melting. Manganese also combines with the sulfur in the steel to form the relative innocuous nonmetallic inclusion, manganese sulfide. In quantities higher that 0.3%, both manganese and silicon increase the hardenability of the steel, but manganese is much more effective in this respect than silicon. These elements are primarily in solid solution in the steel both at low and high temperatures. Manganese may also occur in carbides to some degree. When silicon is present in amounts of 1.0% or more, it tends to lower the scaling rate of the steel at high temperatures.

<u>Nickel</u>

Relatively few tool steels contain nickel in amounts over approximately 0.5%. However, most steel contains small quantities of nickel, which enter the melt from scrap. Nickel is effective in increasing the hardenability of steel.

<u>Chromium</u>

Chromium is used in many tool steels in amounts from about 0.2% up to 12%. It is effective in raising the hardenability of steel. It is also a carbide forming element, and in the high carbon, high chromium steels, remarkable wear resistance is imparted by the presence of numerous chromium carbide particles embedded in the matrix of the hardened steel.

<u>Vanadium</u>

Vanadium is used in tool steels principally as a carbide former. It is an important element in the high speed tool steels for the development of red hardness, that is, the ability of the steel to retain a great deal of its hardness even when the steel is heated to relatively high temperatures. Small amounts of vanadium, about 0.2% are effective in inhibiting grain growth in heat treated steel. When used in amounts between about 2.0 and 5.0%, it exists in the steel in relatively large, extremely hard particles of vanadium carbide, which impart outstanding wear resistance to the hardened steel.

Tungsten and Molybdenum

Tungsten is used in tool steels in quantities from about 0.5 to 20.0% and molybdenum from about 0.15 to 10.0%. Both are carbide forming elements and contribute red hardness and wear resistance to the heat treated steel. However tungsten is replaced by molybdenum, which is less expensive than tungsten and also the effect produced by tungsten can be duplicated by only one half as much molybdenum also the atomic weight of molybdenum is only about half that of tungsten. Molybdenum is quit effective, and much more so than tungsten, in increasing the hardenability of steel.

Cobalt

It is mostly used in high speed steels. Here the cobalt contributes to the red hardness of high speed steels. Unlike the other elements which provide red hardness in steels, cobalt is not carbide former. Cobalt is generally used in relatively large quantities, that is, from about 5.0 to 12.0%.

2.1.3 Classification of tool steels

Tool steels have properties that permit their use as tools for cutting and shaping metals and other materials both hot and cold. It is important to classify tool steels into a relatively small number of groups for purposes of comparison and evaluation and to facilitate the selection of steel for a particular application. Because tool steels are of such diverse compositions, it has never been easy to fit them into one category of the alloy steel system. Tool steels have narrow limits on the amounts of alloying elements, and entire series of steels are based on the variation in carbon content. The methods used most frequently for classification of tool steels are the "Society for Automotive Engineers" (SAE) and "American Iron and Steel Institute" (AISI) methods. The AISI method is more popular because it makes tool steel classification more simple and understandable. The tool steel classifications system is based on use characteristics. There are six major categories one of which contains grades intended for special purposes (figure 2.2).

Water Hardening Tool Steels (W series)

These steels are essentially plain carbon steels (carbon varies from 0.60 to 1.40%), and thus are least expensive. These steel have the lowest alloy content and therefore the lowest hardenability of any of the tool steels. As a result, the W tool steels frequently require water quenching and heavy sections harden only to shallow depths. Thin sections can be hardened by oil quenching to minimize quench cracking and distortion.

Shock-Resisting Tool Steels (S series)

These steels have 0.45 to 0.55 % carbon. The alloys, silicon, and nickel are ferrite strengtheners. Chromium increases wear resistance and hardenability. The S-series of tool steels were originally developed for chisel-type applications, but the number of alloys in this category has evolved to include steels with a broad range of tool applications. This class of steels has very good shock resistant qualities with excellent toughness. They are used in form tools, chisels, punches, cutting blades and springs, trimming, and swaging dies, concrete and rock drills, bolt cutters.

Mold Steels (P series)

These steels have 0.10 to 0.35 % carbons and also contain Cr and Ni as the main alloying elements with Mo and Al as minor additions. They show high toughness. These steels withstand heavy pressure along with abrasive action of the molding powders. Some of these steels may be used after giving a hard chrome-plated surface to impart good finish.

Cold Work Tool Steels (O, A, D series)

This groups forms the most important group of tool steels as majority of tool applications are from this group. These steels are used for making tools for cold work applications when the tool surface temperature does not rise more than 200^{o}C, and thus has wide range of applications. These classes each have high carbon content for high hardness and high Wear resistance in cold work applications, but differ in alloy content, which affects hardenability and the carbide distributions incorporated into the hardened microstructures. These are divided into three sub-groups:

Oil Hardening Tool Steels (O-Series)

These steels are hardenable by oil quenching, and contain 0.90 to 1.45 % Carbon with Mn, Si, W, Mo, and Cr to improve hardness. Hardenability and wear resistance. They contain graphite in the hardened structure along with martensite. (Graphite acts as a lubricator and also makes machining easier). Tungsten forms tungsten carbide which improves the abrasion resistance and edge retention in cutting devices. These steels are relatively inexpensive. Such steels are used for taps, solid threading dies, form tools and expansion reamers.

Air Hardening Steels (A- Series)

These steels are hardened by air cooling. The carbon content is about 1% with Mn, Cr, Mo as the main alloying elements with sometimes addition of tungsten. These elements impart high wear resistance and induce high hardenability. These steels have fair toughness, red hardness and resistance to decarburization. These steels are used for blanking, forging, trimming, thread rolling dies.

High Carbon High Chromium Steels (D-Series)

These steels are either oil, or hardened. Normally these steel contains 1.4-2.3% carbon and 12-14% Cr, V, Mo, Co may be present as alloying elements. Presence of large amount of chromium increases the hardenability of these steels to obtain martensite even by air cooling. These steels are used for blanking and piercing dies.

Hot Work Tool Steels (H series)

These tool steels are used mainly for high temperature metal forming operations such as hot stamping, piercing, hot forging, hot drawing, etc., where the operating temperature is above 200^{o}C to around 800^{o}C. These steels have high toughness as the carbon content is on the lower side around 0.3 to 0.5% and small content of alloying elements such as W, Mo, Cr, V, Co, etc. There are about 12 hot-worked tool steels. They are categorized by major alloying elements into three subgroups.

Hot Work Chromium Type Tool Steels

Apart from 3.25% chromium, these steels also contain amounts of vanadium, tungsten, molybdenum. Thus, these steels have high red-hardness, and very high hardenability.

Hot Work Tungsten Type Tool Steels

These steels too contain low carbon. These have atleast 9% tungsten and 2-12% chromium. As the alloy content increases, resistance to high temperature softening i.e., red-hardness increases but brittleness increases. These steels are used for punches, mandrels and extrusion dies for brass, steel and nickel alloys.

Hot Work Molybdenum Type Tool Steels

These steels contain more carbon with 8% molybdenum, 4% chromium with some tungsten and vanadium. These steels have similar properties as hot work tungsten type steels but are cheaper and higher toughness.

High Speed Steels (M and T series)

These are the classes of steel that deep harden, retain that hardness at elevated temperatures, and have high resistance to wear and abrasion. The carbon content of these steels varies from 0.85 % to 1.50 %.

M-type

The M-type tool steels are high in molybdenum content and are used for lathe centers, blanking dies, hot forming dies, lathe cutting tools, drills, taps, etc. They are used in almost all cutting tools.

T-type

The T-type high speed tool steels with high carbon content have high wear resistance and very high hardness. The ones with lower carbon content are tougher than but not as hard as the former group. As the amount of tungsten increases, the toughness decreases. This class of tool material has a substantial amount of wear-resistant carbides in a very high heat resistant matrix. These steels are used in machine cutting tools such as tool bits, milling cutters, taps, reamers, drills, broaches. In some instances it is used where high temperature structural steel is needed.

Special Purpose Tool Steels (L and F series)

The L-type steels are low alloy steels with about 1 % Cr that makes them a good low cost substitute for cold work steels. The F-type steels are high in carbon tungsten. They have high wear resistance, good toughness, and medium hardenability. The L-type steels are used in gages, broaches, drills, and taps, threading dies, ball and roller bearings, clutch plates, knurls, files. The F-type steels are used as finish machining tools. They have good wear resistance and will maintain a sharp cutting edge. They may be used in dies, cutting tools, form tools, knives, etc.

2.1.4 Tools wear mechanisms

Some of the important tools wear mechanism of a hard metal (tool), which is in contact with a softer but deforming metal (work piece) sliding past the former at a fairly high speed as described below:

Shearing at high temperature

The strength of hard metals decreases at high temperature. Therefore its shear yield stress becomes much smaller than what it is at room temperature though the metal sliding over it has lower yield stress, nevertheless the chip may get so much work hardened as to be able to exert frictional stress sufficient to cause yielding by the shear of the hard tool metal. The higher the temperature at the interface greater is the effect (figure 2.3).

Diffusion wear

When a metal is in sliding contact with another metal and the temperature at the interface is high, conditions may become right for the alloying atom from the harder metal to diffuse in to the softer matrix thereby increasing the latter’s hardness and abrasiveness. On the other hand atoms from the softer metal may also diffuse in to the harder media, thus weakening the surface layer of the latter to such an extent that the particles on it are dislodged/ torn and are carried away by the flowing chip materials (figure 2.4).

Adhesive wear

Let a softer metal slide over a harder metal such that it always presents a newly formed surface to the same portion of the hard metal. On account of friction, higher temperature and pressure, particles of the softer material adhere to a few high spots of the harder metal. As a result flow of the softer metal over the surface of the hard metal becomes irregular or less laminar and contact between the two becomes less continuous. More particles join up with those already adhering and so called built up edges form. Sooner or later some of these fragments, which may have grown up to macroscopic size, are torn from the surface of the hard metal. When this process continues for some time it appears as if the surface of the hard metal has been nibbled away and made uneven (figure 2.5).

Abrasive wear

The softer metal sliding over the surface of the harder metal may contain appreciable concentrations of hard particles. For example, casting may have pockets of sand in them. In these conditions, the harder particles act as small cutting edges like those of the grinding wheel n the surface of a hard metal which in due course, is worn out through abrasion. In addition the particles of hard tool metals, which intermittently get torn out from its surface are dragged along the tool surface or rolled over. These particles plough grooves in to the surface of the hard tool metal.

Fatigue wear

When two surface slide in contact with each other under pressure, asperities on one surface interlock with those of the other. Due to the frictional stress, compressive stress is produced on one side of each interlocking asperity and tensile stress on the other side. After the asperities of the given pair have moved over or through each other, the above stresses are relived. New pairs of asperities are, however, soon formed and the stress cycle is repeated. Thus the material of the hard metal near the surface undergoes cyclic stress. This phenomenon causes surface cracks which ultimately combines with one another and lead to crumbling or hard metal. Further, the hard metal may also be subjected to variable thermal stress owing to temperature changes brought about by cutting fluid, chip breakage and variable dimension of cut, again contributing to fatigue wear (figure2.6).

Electrochemical effect

It has been argued that since sufficiently high temperatures exist on the tool interface, a thermo electric EMF is setup in the close circuit due to the formation of a hot junction at the chip tool interface between the dissimilar tool and work materials. This current may assist the wear process at the rake face in some way for example, by aiding the diffusion of carbon ions from the carbide tool to the flowing chip.

Oxidation effect

There is evidence to suggest that the formation of grooves or notches at the rake face and the flank is on account of the sliding of portions of chip and the machine surface which have reacted with the oxygen in the atmosphere to form abrasive oxides. For e.g., when machining a steel work piece with HSS or cemented carbide tools, groove formation is greatly accelerated if the cutting zone is subjected to a jet of oxygen. On the other hand, it is retarded or even eliminated if the cutting zone is subjected to a neutral atmosphere using jets of nitrogen or argon (figure 2.7).

2.2 Testing of tool steels

2.2.1 Hardness test

Rockwell Hardness

This hardness test uses a direct-reading instrument based on the principle of differential depth measurement. The test is carried out by slowly raising the specimen against the indenter until a fixed minor load has been applied this is indicated on the dial gauge. Then the major load is applied through a loaded lever system. After the dial pointer comes to rest, the major load is removed and, with the minor load still acting, the Rockwell hardness number is read on the dial gauge (figure 2.8). Since the order of the numbers is reversed on the dial gauge, a shallow impression on a hard material will result in a high number while deep impression on a soft material will result in a lower number. There are two Rockwell machines, the normal tester for relatively thick sections and the superficial tester for thin section. The minor load is 10 kg on the normal tester and 3 kg on the superficial tester. A variety of indenters and loads may be used, and each combination determines a particular Rockwell scale. Indenters include hard steel balls 1/16, 1/8, ¼, and ½ inch in diameter and a 120 deg conical diamond point. Major loads are usually 60, 100 and 150 kg, on the normal tester and 15, 30 and 45 kg on the superficial tester. Most commonly used Rockwell scales are the B (1/16 inch ball indenter and 100 kg load) and the C (diamond indenter and 150 kg load), both obtained with the normal tester. Because of the many Rockwell scales the hardness number must be specified by using the symbol HR followed by the letter designating the scale and preceded by the hardness numbers. For example, 82 HRB means a Rockwell hardness of 82 measured on the B scale.

2.2.2 Wear test

It is versatile equipment designed to study frictional and sliding wear process. Sliding occurs between a stationary pin and a rotating disc (figure 2.9). Normal load, rotational speed and wear track diameter can be varied. Frictional force and wear monitored with electronic sensors. Both of these parameters are available for continuous recording and study the function of load, speed, temperature, lubrication and environmental conditions.

It essentially consists of a machine, a controller and oil recirculation pomp. The machine is the combination of pin and disc, where the disc rotates with the help of a motor and the pin is presses against the disc. The pin is held by a collect attached to the lever which is connected with the loading arrangement. The assembly of pin in collect is shown in figure 9. Load ranging from 0-200 N can be applied through the arrangement to press the pin against the disc. As the pin is held stationary and the disc rotates, the sliding contact occurs and the wear of both pin and disc take place as load is applied for the test duration. A controller is attached to the machine which reads out frictional force arise at the contact. The speed of the disc or motor rpm can be varied through the controller. An oil recirculation pump is attached for the purpose of lubricating the contact surface at the time of test if required.

Wear rate measurement

The wear behavior obtained was characterized by defining a wear rate which relates mass loss to sliding distance (L) as:

$W = \Delta m/L$ (1)

Volumetric wear rate is obtained is relates to mass loss to density (ρ) and time (T) as

$W_v = \Delta m/\rho L$ (2)

Dividing equation (2) by the sliding velocity (V) and normal load (N) yields the specific wear rate. Often the wear resistance of a material is referred to which is simply the inverse of the specific wear rate.

$W_s = W_v / V_s N$ (3)

The coefficient of friction μ of the composite was calculated from the equation

$\mu = F_t/F_n$

Where F_t is the frictional force, F_n is the normal force.

2.3 Characterization

2.3.1 Scanning Electron Microscopy (SEM) Analysis

The Scanning Electron Microscope (SEM) is a microscope that uses electrons rather than light to form an image. There are many advantages to using the SEM instead of a light microscope.

The SEM has a large depth of field, which allows a large amount of the sample to be in focus at one time. The SEM also produces images of high resolution, which means that closely spaced features can be examined at a high magnification. Preparation of the samples is relatively easy since most SEMs only require the sample to be conductive. The combination of higher magnification, larger depth of focus, greater resolution, and ease of sample observation makes the SEM one of the most heavily used instruments in research areas today.

In the SEM, the image is formed and presented by a very fine electron beam, which is focused on the surface of the specimen. The beam is scanned over the specimen in a series of lines and frames called a raster, just like the (much weaker) electron beam in an ordinary television. The raster movement is accomplished by means of small coils of wire carrying the controlling current (the scan coils). A schematic drawing of an electron microscope is shown in Figure 2.10. At any given moment, the specimen is bombarded with electrons over a very small area. Several things may happen to these electrons. They may be elastically reflected from the specimen, with no loss of energy. They may be absorbed by the specimen and give rise to secondary electrons of very low energy, together with X- rays. They may be absorbed and give rise to the emission of visible light (an effect known as cathodoluminescence). And they may give rise to electric currents within the specimen. All these effects can be used to produce an image. By far the most common, however, is image formation by means of the low-energy secondary electrons. The secondary electrons are selectively attracted to a grid held at a low (50 volt) positive potential with respect to the specimen. Behind the grid is a disc held at about 10 kilovolts positive with respect to the specimen. The disc consists of a layer of scintillant coated with a thin layer of aluminum. The secondary electrons pass through the grid and strike the disc, causing the emission of light from the scintillant. The light is led down a light pipe to a photomultiplier tube which converts the photons of light into a voltage. The strength of this voltage depends on the number of secondary electrons that are striking the disc. Thus the secondary electrons produced from a small area of the specimen give rise to a voltage signal of a particular strength. The voltage is led out of the microscope column to an electronic console, where it is processed and amplified to generate a point of brightness on a cathode ray tube (or television) screen. An image is built up simply by scanning the electron beam across the specimen in exact synchrony with the scan of the electron beam in the cathode ray tube. The SEM does not contain objective, intermediate and projector lenses to magnify the image as in the optical microscope. Instead magnification results from the ratio of the area scanned on the specimen to the area of the television screen. Increasing the magnification in an SEM is therefore achieved quite simply by scanning the electron beam over a smaller area of the specimen. This description of image formation in the SEM is equally applicable to elastically scattered electrons, X-rays, or photons of visible light - except that the detection systems are different in each case. Secondary electron imaging is the most common because it can be used with almost any specimen.

2.3.2 X-Ray Diffraction (XRD)

A characteristic of crystalline materials is their ability to diffract x-rays. As a beam of X-rays passes through a randomly oriented microcrystalline structure, a pattern of rings or diffraction patterns results. The resultant diffractogram is useful in confirming the identity of a solid material such as a pharmaceutical powder. The phenomenon of diffraction occurs when penetrating radiation, such as X-rays, enters a crystalline substance and is scattered. The direction and intensity of the scattered (diffracted) beams depends on the orientation of the crystal lattice with respect to the incident beam. Any face of a crystal lattice consists of parallel rows of atoms separated by a unique distance (d-spacing), which are capable of diffracting X-rays. The condition for diffraction from planes with spacing, d, is given by Bragg’s Law:

$$\lambda = 2d \sin(\theta)$$

Where, θ is the angle between the atomic planes and the incident x-ray beam. That is, in order for a beam to be 100% diffracted, the distance it travels between rows of atoms at the angle of incidence must be equal to an integral multiple of the wavelength of the incident beam.

d-spacings which are greater or lesser than the wavelength of the directed X-ray beam at the angle of incidence will produce a diffracted beam of less than 100% intensity. Thus the interplanar spacings of the unknown materials can be determined. Samples are analyzed as powders with grains in random orientations to insure that all crystallographic directions are "sampled" by the beam. When the Bragg conditions for constructive interference are obtained, a "reflection" is produced, and the relative peak height is generally proportional to the number of grains in a preferred orientation. The x-ray spectra generated by this technique, thus, provide a structural fingerprint of the unknown. Mixtures of crystalline materials can also be analyzed and relative peak heights of multiple materials may be used to obtain semi-quantitative estimates of abundances. A glancing x-ray beam may also be used to obtain structural information of thin films on surfaces. In addition, changes in peak position that represent either compositional variation (solid solution) or structure-state information (e.g. order-disorder transitions, etc.) are readily detectable. Peak positions are reproducible to 0.02 degrees.

The sample is prepared for analysis by packing a small amount of sample into a shallow cup. Sometimes the sample can be introduced as slurry and placed on a quartz slide. The sample is subjected to x-rays while the sample rotates during the analysis to reduce any heating to the sample.

2.4 Centrifugal casting

2.4.1 Introduction

The centrifugal casting process uses rotating molds to feed molten metal uniformly into the mold cavity. Directional solidification provides for clean, dense castings with physical properties that are often superior to those of the static casting process. The centrifugal force of the rotating mold forces the molten metal against the interior cavity of the mold under constant pressure until the molten metal has solidified. As a result of this a uniform thickness of metal is deposited all along the inside surface of the mould and the impurities being lighter remain nearer to the axis of rotation. Centrifugal casting is the most economical method of producing superior quality castings with regard to casting yield, cleaning room cost, and mold cost. Centrifugal casting can be described as isotropic, that is, having equal properties in all directions. This is not true of a forging. By utilizing the outstanding advantage created by centrifugal force of rotating mold, casting of high quality and integrity can be produced because of their high density and freedom from oxides, gases, and other nonmetallic inclusions. An economic advantage of centrifugal castings is the elimination or minimization of gates and risers.

2.4.2 Processes

True centrifugal casting

The main feature of a true centrifugal casting is that the axis of rotation of the mould and that of the casting are the same. The process can be either vertical or horizontal, and the need for a centre core is completely eliminated. End cores are usually employed at the two ends of the mould to prevent the molten metal from being thrown out at the ends. Castings produced in metal molds by this method have true directional cooling or solidification from the outside of the casting toward the axis of rotation. This directional solidification results in the production of high quality defect free castings without shrinkage, which is the largest single cause of defective sand castings (figure 2.11).

Semi-centrifugal casting

In this method the mould is rotated about a vertical axis and the metal is poured through a central sprue. Here several moulds can be stacked together, one over the other, and fed simultaneously through a common central sprue. This provision increases the rate of production considerably. The centrifugal force is used to feed the metal outwards to fill the mould cavities completely. Cores may be necessary if the casting is to have hallowed sections. The speed rotation of these moulds is much lower than that of true centrifugal casting. This leads to the development of low pressure and the impurities are not directed towards the centre as effectively as in true centrifugal casting. Thinner casting sections can be produced with this method than with static casting (figure 2.12).

Centrifuge centrifugal casting

This is also sometimes known as pressure casting. It mainly differs, unlike the latter two, the axis of rotation and that of the moulds do not coincide with each other, as the moulds are situated at a certain distance from the central vertical axis of rotation all around the same. Shapes of the castings do not carry any limitations in this method and a variety of shapes can be cast. Centrifugal force provides the necessary pressure on the molten metal in the same manner as in semi-centrifugal casting (figure 2.13).

2.4.3 Process details

Casting inside diameters

When making casting on a vertical centrifugal casting machine, the inside diameter of the casting will be tapered in accordance with the following formula:

$$n = 264\sqrt{h/r_1^2 - r_2^2}$$

Where, 'n' is speed of rotation (in revolutions per minute)

'r_1' is the inside radius at the top of the casting (in inches)

'r_2' is the inside radius at the bottom of the casting (in inches)

'h' is casting height (in inches)

If the length of the casting does not exceed approximately twice its inside diameter, the amount of taper will be negligible. The optimal speed of rotation results in a centrifugal force of 75g (75 times the force of gravity) on the inside diameter. From the equation, too slow a speed of rotation will result in excessive taper on the inside diameter of the casting. There are castings for which it is desirable to cast the inside diameter with a predictable taper. Using equation 1, the exact speed can be calculated to produce an approximate given taper on the inside diameter of the casting.

Speed of rotation

To establish a temperature gradient of the molten metal from the outside diameter toward the centre of rotation (that is, directional solidification), it is usually necessary for the mold to be spinning when the metal is poured. In some cases, in order to eliminate defects such as erosion and dirt in sand moulds, it is desirable to pour at a slow speed of rotation. Equation 2 can be used to calculate the spinning speed:

$g = 0.0000142Dn$

Where, 'g' is the centrifugal force (in pounds per pound or number of times gravity),

'D' is the inside diameter of the casting (In inches)

'n' is the speed of rotation (in revolutions per minute).

Mold speed curves

These are determined by the inside diameter of the castings to be made (figure 2.14). The mold speed curve shown is based on the inside diameter of the casting. The length of the casting is not considered in determining mold speed.

Pouring techniques

For permanent molds, the metal is generally poured 40 ^{o}C higher than the temperature used for the same casting if pored statically in a sand mould. This is because of the more rapid chilling effect of permanent molds. The pouring rates required for the successful permanent mold centrifugal casting are quit high compared to those for static casting in sand molds. It is particularly important that the initial rate of pour at the beginning be very high to prevent cold laps and cold shuts. When pouring into a vertically spinning mold, it is important to introduce the molten metal into the mold in such a way as to prevent or minimize turbulence of the molten metal, which can cause splashing, spraying, or droplets and can result in undesirable casting defects. Also a pouring funnel can be used. With a pouring funnel, the nozzle can be lined to the required diameter so that, with a certain riser height of molten metal in the funnel, a controlled pour rate can be obtained for a particular casting weight. In addition, with a pouring funnel, the entry of molten metal into the mould can be made to impinge upon the body of the mold with initial metal flow in the direction of mold rotation. This type of pouring will provide superior casting quality by minimizing or eliminating any upsetting turbulence in the flow of metal that might cause defects. Figure shows a pouring funnel and funnel position.

2.5 Literature survey

Authors	Aim & material	study	conclusion
U. K. Mohanty et.al [1]	Centrifugal Casting of Al-13%Si alloy	Effect of rotation speed on impact properties	1) Distribution of phases depends upon the density difference. 2) At lower speed grain refinement is not pronounced. 3) There exists an optimum speed of rotation resulting in optimization of properties of the casting.
H. G. Fu et.al [2]	High Speed Steels	Wear rate and hardness measurement	1) Mechanical properties greatly improved 2) Segregation of alloys can be decreased by adding niobium which forms multi element carbide, which has a density near to that of steel. Optimum speed should be selected.
Li Changyun et.al [3]	Model experiment of mold Filling process in vertical centrifugal casting process (Ti-alloy)	Forward filling and backward filling	1) During the forward filling, liquid cross-sectional area decreases with the increase of forward filling length and rotational velocity. But cross-sectional area is unchangeable in the cavity during the back filling. 2) Forward filling is an accelerated velocity process and back filling is a uniform velocity filling process.
F. C. Nunes et.al [4]	Centrifugal casting of HP-type stainless steels	effect of yttrium addition on fragmentation of carbides	1) Improvement in creep properties on addition of yttrium. 2) Fragmentation of carbides was more near the internal wall due higher content of yttrium. 3) First yttrium carbides Solidify and serves as heterogeneous nucleation sites for the other carbides.
Guo-Shang Zhang et.al [5]	Centrifugal casting of WC/Hadfield steel composites	Micro-hardness and impact wear test	1) Formation of diffusion layer showing excellent bonding between WC particles and steel hadfield matrix. This leads to superior impact wear resistant properties. 2) The smaller the WC particles, the better the impact wear resistant properties.
QIU Yi-qing et.al [6]	Electromagnetic centrifugal casting of lCr25NiZOSi2 tube blank	Effect of magnetic flux density on the casting	1) The higher magnetic flux density, the smaller the dendrite spacing and the larger the volume fraction of equiaxed zone.
Nairobi B. Duque et.al [7]	Functionally graded aluminum matrix composites produced by centrifugal casting	Microstructure study, hardness and corrosion rate measurement	1) The centrifugally cast composites exhibited in their external zones a greater volume fraction of reinforcement particles and higher superficial Rockwell hardness than the internal zones. 2) Corrosion rate is found to be greater in as-received samples as compared to centrifugally cast samples.

Zhongze Du et.al [8]	A study of ceramic-lined compound copper pipe produced by SHS–centrifugal casting	Effect of additives on densification degree and toughness	1) Separation was by density difference that is lower density forms inner layer and higher density metal forms outer layer. 2) Adding SiO_2 and CrO_3 improves densification degree. 3) Adding ZrO_2 can improve the toughness of the ceramics. The highest fracture toughness of ceramic layer is obtained at 7 wt% of ZrO_2. It is two times as high as that of primitive ceramics.
Wang Qudong et.al [9]	Centrifugally cast Zn–27Al–*x*Mg–*y*Si alloys and their in situ (Mg2Si + Si)/ZA27 composites	Effect of mold temperature and rotating speed on micro-structure	1) With mould temperature increasing, grain size of inner layer, middle layer and outer layer increases apparently, especially in outer layer. 2) With the rotating rate increasing, thickness of inner layer increases but thickness of outer layer decreases 3) The size of the particles decreases as the rotating speed increases both in outer and inner layer.
Yinhong Wei, et.al [10]	In situ surface composites of (Mg_2Si+Si)/ZA27 fabricated by centrifugal casting	Hardness and wear measurement of different zones of fabricated composite	1) Exhibits varying hardness at inner, middle and outer layer of the centrifugally fabricated composite. 2) Higher hardness at inner and outer layer due to segregation of Mg_2Si and Si than middle layer having small amount of Mg_2Si and Si. 3) Wear resistance was measured low in the middle as compared to outer and inner layer.
Kyung-Hee Kim et.al [11]	Centrifugal casting of alumina tube for membrane application	Micro-structural analysis and pore size measurement	1) The inner surface was relatively dense consisting of fine particles whereas the corresponding outer surface was relatively porous consisting of coarse particles. This non-uniformity of the microstructure suggests that differential settling occurred during centrifugal casting. 2) The differential settling also results in the formation of very smooth inner surfaces of tubes.
R. Rodrı´guez-Castro et.al [12]	Microstructure and mechanical behavior of functionally graded Al A359/SiCp composite	Tensile and hardness measurement of the composite	1) The centrifugal force progressively increases the volume fraction of the SiC reinforcement within the Al matrix along the radial direction, owing to the density difference between the two materials. 1. There was a continuous increase in tensile and yield strengths with SiC volume fractions along the radial direction. 2. A strong dependence of the hardness variation in the composite with respect to the SiC volume fraction variation that is hardness increases along the radial direction.

A. Halvaee et.al [13]	Effect of process variables on microstructure and segregation in centrifugal casting of C92200 alloy	Effect of pouring temperature, mold rotational speed and mold cooling rate	1) Raising the pouring temperature causes grain size to increase and segregation to intensify. 2) Increasing the mould cooling rate, diminishes the segregation of lead and tin and reduces grain size 3) Raising the mould rotation speed leads to high segregation of lead and tin and increases the grain size.
Z. Humberto Melgarejo et.al [14]	Centrifugal casting of Aluminum matrix composites reinforced with aluminum dibromide particles	Hardness and wear rate measurement	1) Higher densities of AlB_2 particles in outer regions as compared to inner regions of the casting. 2) Hardness values increases as a function of distance from the internal zone to the external zone. 3) Wear volume measured is smaller in external zone as compared to internal zone. 4) Gravity cast composites displayed an intermediate behavior as the diborides was evenly distributed.
Wu Shi ping et.al [15]	Centrifugal casting of Ti-6Al-4V alloy	Microstructure evaluation	1) The cast samples shows fine to coarse microstructure from the inner mould surface to the outer. 2) The area of equiaxed zone increases with mould rotation speed.

Chapter 3

EXPERIMENT

3.1 Objective

Casting of Thrown Away Tool Steel bits in the Centrifugal Casting Route.

3.2 Introduction

Cutting tools get worn out due to wear and are ground in order to use them again. This wear may be due to abrasive wear, diffusion wear, fatigue wear, adhesive wear. This shortens the length of the tool and finally the length may become so small that the tool bit is no more usable. In addition the tools may be rendered useless due to electrochemical and oxidation effect.

A newly ground tool has sharp cutting edges and smooth flanks. When put into operation, it gets subjected to cutting forces that are concentrated on a relatively small contact area on the rake face and the flank. Each time the tool enters or exits from the cut, it is subjected to mechanical as well as thermal shock. Under such adverse conditions, the hard tool materials like HSS and carbides, gradually wear out and even fracture, necessitating a tool change. Due to these reasons, the tool steel becomes small and are not useful for further machining purposes.

The present project aims at collecting these short and thrown away tool bits, melting it in a induction furnace, casting it in the centrifugal casting rout, examining the structure and effect of centrifugal casting on the cast tool bits, testing its hardness and comparing its machining abilities visa-vice that of freshly obtained tool bits. Therefore, in short, the aim of the project is to examine if reusable tools can be re-fabricated using the thrown away tool bits.

3.3 Experiment

First the waste and thrown away tool bits were collected which may include steel waste, pig iron, molybdenum iron, chromium iron, vanadium iron, tungsten iron and other waste material. This mixture was melted in induction furnace at temperature about $1600^{o}C$ to $1700^{o}C$. After that the casting of the melt was done through the centrifugal route (figure 3.1) at speeds of 200 rpm and 250 rpm. The cast obtained is in the shape of tool steel cylinder. Then the samples were prepared for the hardness test, machinability test and SEM analysis. The hardness was measured across the radius of the cast cylinder by using Rockwell hardness test machine in C – scale. The machinability test specimens were taken from the outer zone of the cast cylinder and the test was carried out in Lathe bye keeping the variables such as rotation speed (420 rpm), feed rate (0.15

KM), rack angle (10^0) material to be machined (mild steel) and time of machining (5 minutes 40 seconds) constant. The machinability of the centrifugally cast samples were compared with the as-cast samples. SEM micrographs were taken for the outer region of the cast cylinder and a comparative study was made with the as-cast samples.

3.4 Results and Discussion

For casting of waste tool bits the centrifugal casting rout is chosen. This is because the waste tool bits are used one. They may contains oxides, slag and other non metallic impurities which have lower density than the steel matrix and alloying elements present in tool steel. Hence, the centrifugal force will provide the necessary separation of these unwanted impurities from the required tool steel. Due to lower density of impurities they will segregate at the centre which can be removed easily by machining afterwards. Also due to centrifugal force provides directional solidification which results in clean, dense castings with physical properties that are often superior to those of the static casting process.

<u>Hardness results:</u>

The graph (figure 3.2) shows increase in hardness values with the distance from the centre to the outer periphery (table 3.1, table 3.2). Also the hardness values are higher for speed 250 rpm than 200 rpm. Lower hardness value at the centre may be due to the segregation of impurities (such as oxides) due to centrifuging action because of their lighter density as compared to steel matrix and carbides. The increase in hardness with the distance from the centre shows the densitization of the matrix and segregation of carbides towards the outer periphery which increases with the speed of rotation. The bar chart (figure 3.3) compares the hardness at different distances from the centre of castings obtained with different speeds of rotation of the mould. The chart indicates an increase in hardness values with the increase in speed of rotation and also with the distance from the centre of the casting cylinder. This may be due to increase in the amount of densitization of the matrix from the centre to the outer periphery of the sample.

<u>Machinability test results:</u>

The machinability test was carried out for the specimens taken from the outer zone of the cast cylinder in Lathe bye keeping the variables such as rotation speed (420 rpm), feed rate (0.15 KM), rack angle (10^0) material to be machined (mild steel) and time of machining (5 minutes 40 seconds) constant. The table 3.3 shows the percentage loss of material for the as-cast sample, 200rpm cast sample and 250 rpm cast sample. The loss of material was represented by the bar chart (figure 3.4). It is seen that the % loss in material decreases with the increase in speed of rotation. This may attributed to less wear of the samples due to segregation of carbides at the periphery which increases with the speed of rotation.

SEM analysis:

The figure 3.5 shows the SEM micrographs of as-cast sample. The white phase represents the carbides in the steel matrix. These carbides may of three types namely alloy carbides, complex carbides and iron carbides. The micrograph shows the carbide particles of bigger size which try to accommodate in tri-axial grain boundary region. The micrograph shows non uniform distribution of carbide particles.

Figure 3.6 shows SEM micrograph of 200 rpm cast sample at the outer zone. The carbide particles try to group together but proper bonding is not seen in the structure. The carbides form cotton like structure. Also it shows segregation of carbides due to centrifuging action.

Figure 3.7 shows SEM micrograph of 250 rpm cast sample at the outer zone. Here the carbides are more consolidated than the cast sample at 200 rpm and also the cracks are seen in the soft phase in presence of hard phase. It is expected that if there is further increase in speed of rotation of the sample, more consolidated structure would be obtained.

3.5 Conclusion

There is an increase in hardness values with the distance from the centre to the outer periphery of the cast samples. The hardness values are higher for speed 250 rpm than 200 rpm. The Machinability of the centrifugally cast samples was better than generally used tool steels. SEM micrographs support the findings. However, the project could not be carried out to its logical end because of some limitations concerning availability of materials and experimental facilities.

It is seen from the experiments we have done that if further experimentations, varying the speed of rotation are carried out then better results could be obtained enhancing the value of the centrifugally cast tool steel bits.

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Figures

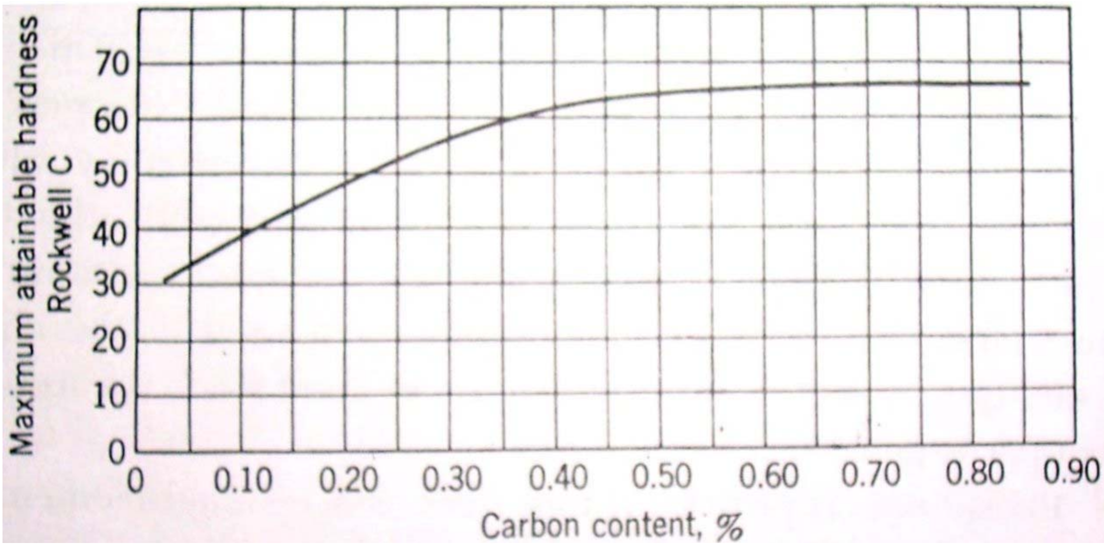


Figure 2.1: effect of carbon content on the attainable hardness of steel

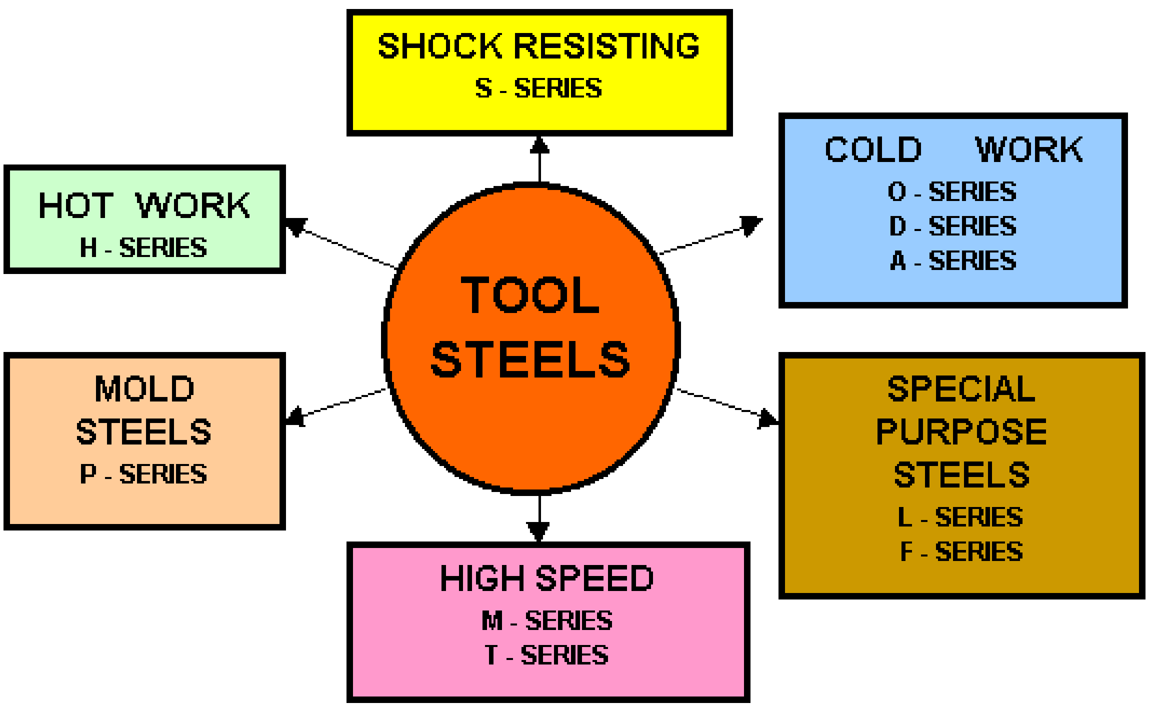


Figure 2.2: Classification of tool steels by AISI methods

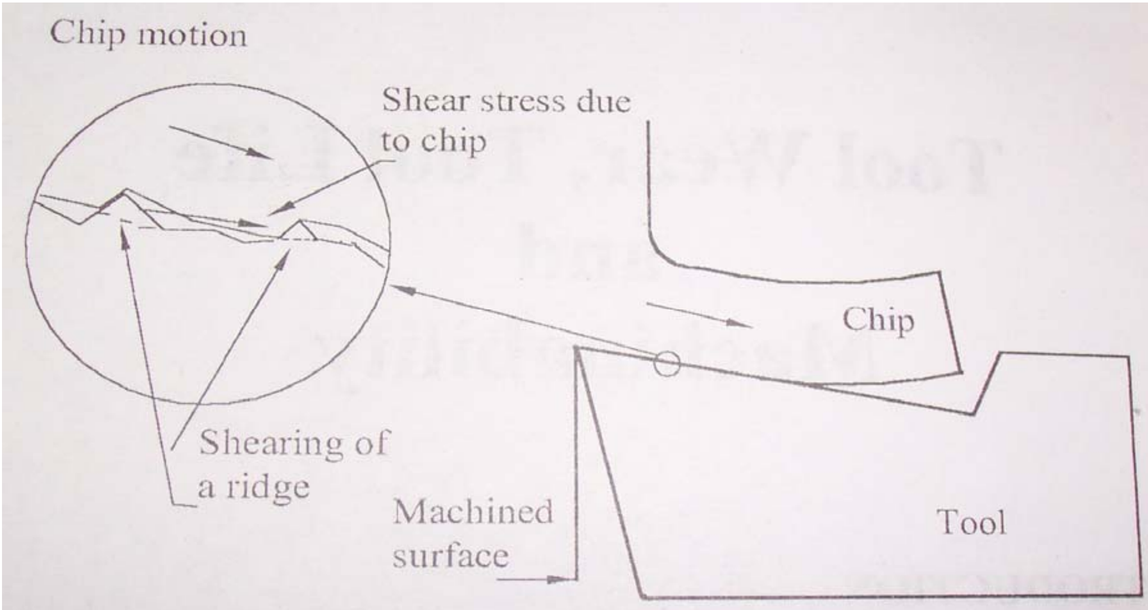


Figure 2.3: Wear by plastic yielding and shear

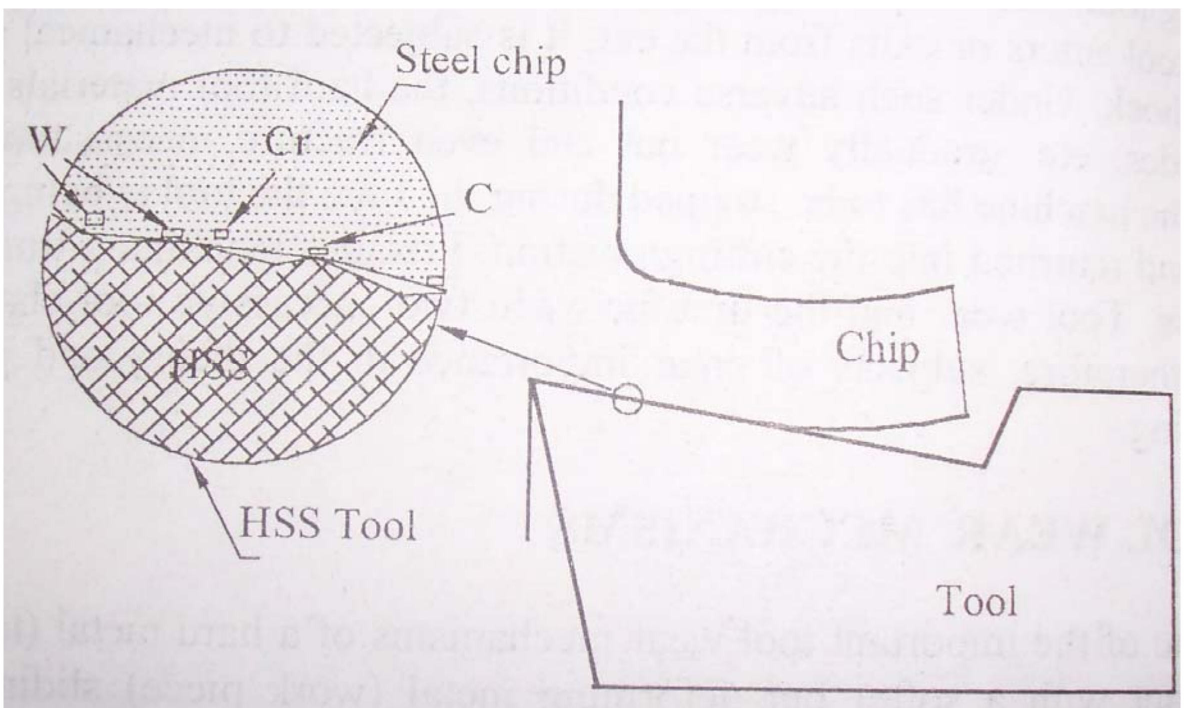


Figure 2.4: Diffusion wear process

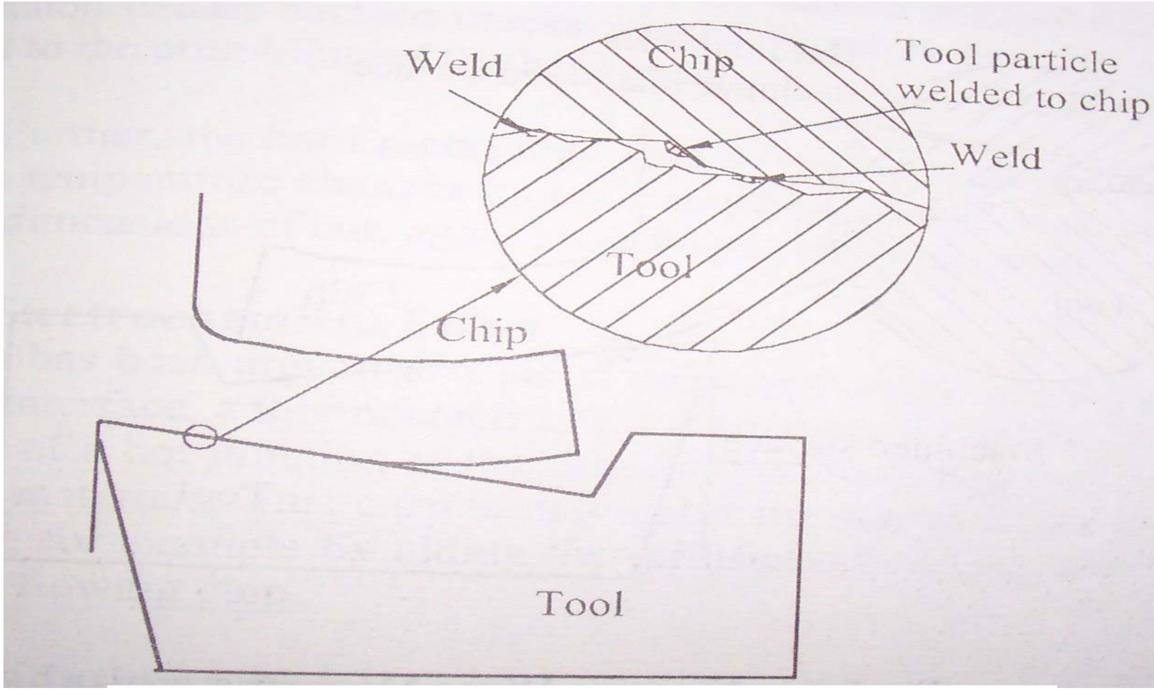


Figure 2.5: Adhesive wear mechanism

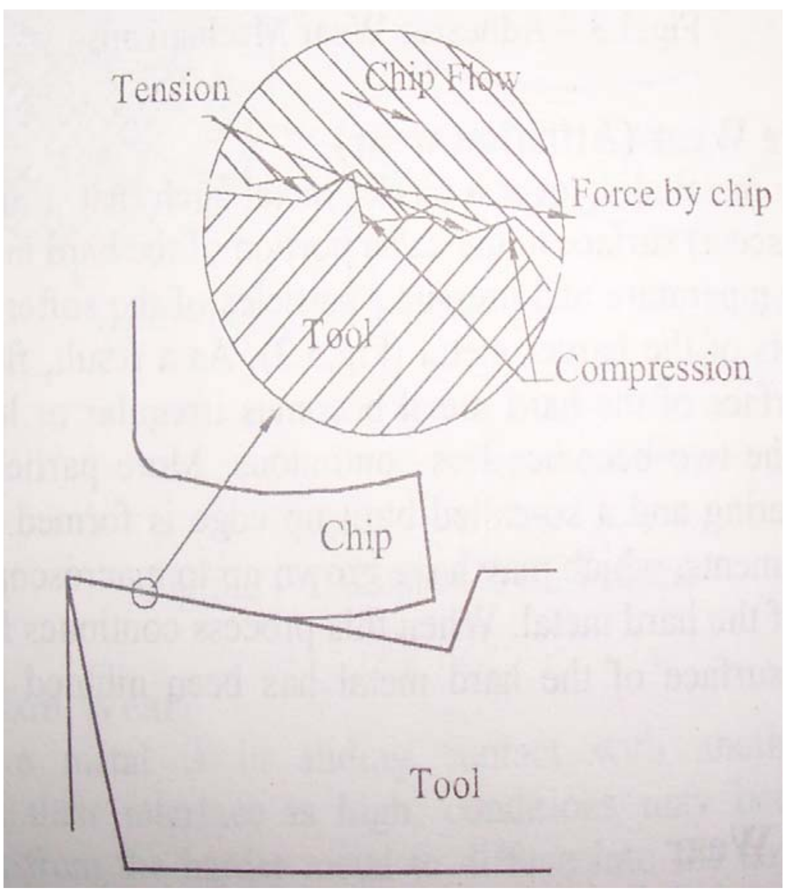


Figure 2.6: Fatigue wear mechanism

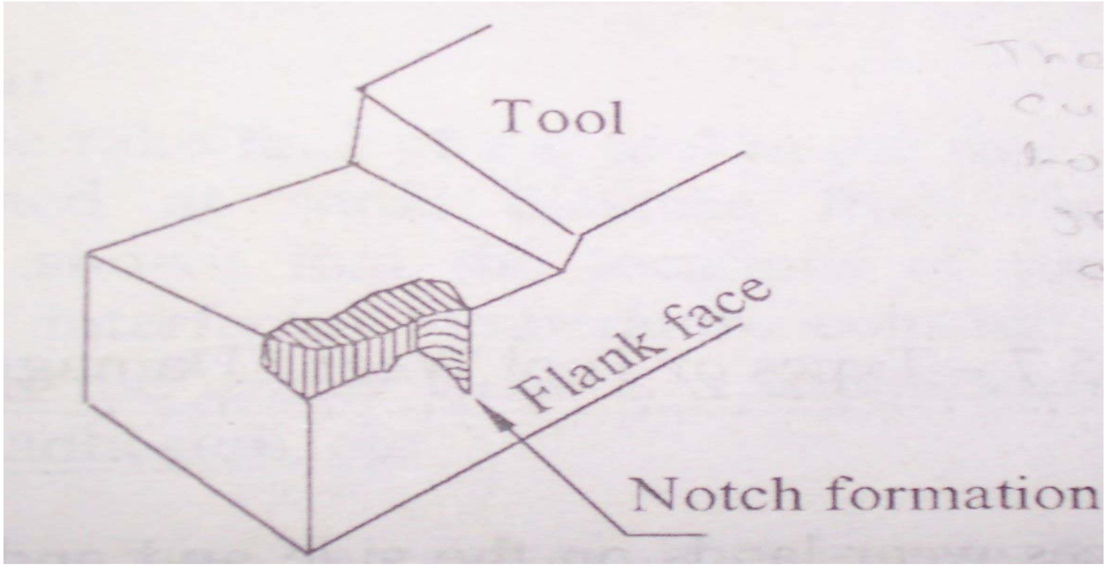


Figure 2.7: Formation of notch or groove

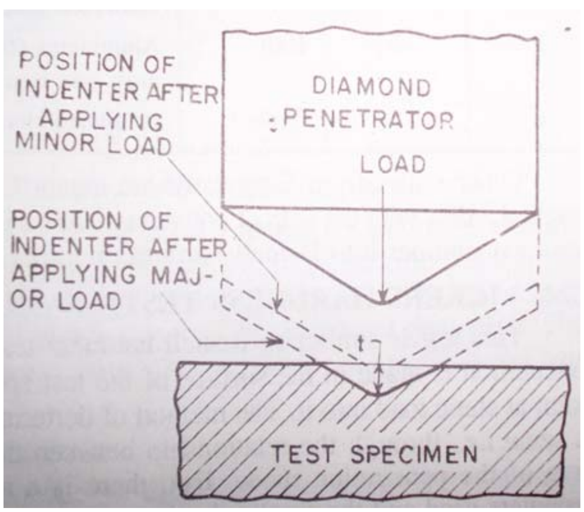


Figure 2.8: Principle of Rockwell testing

Figure 2.9: Pin on disc

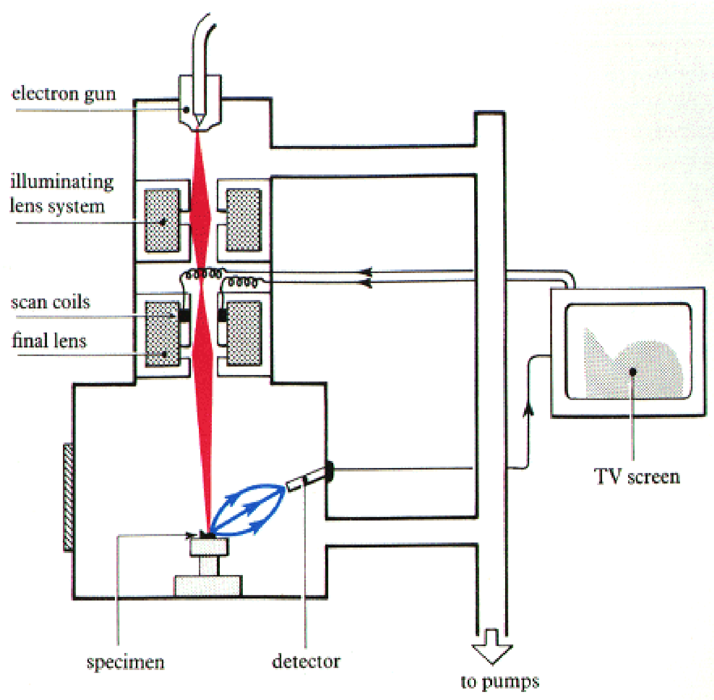


Figure 2.10: schematic drawing of an electron microscope

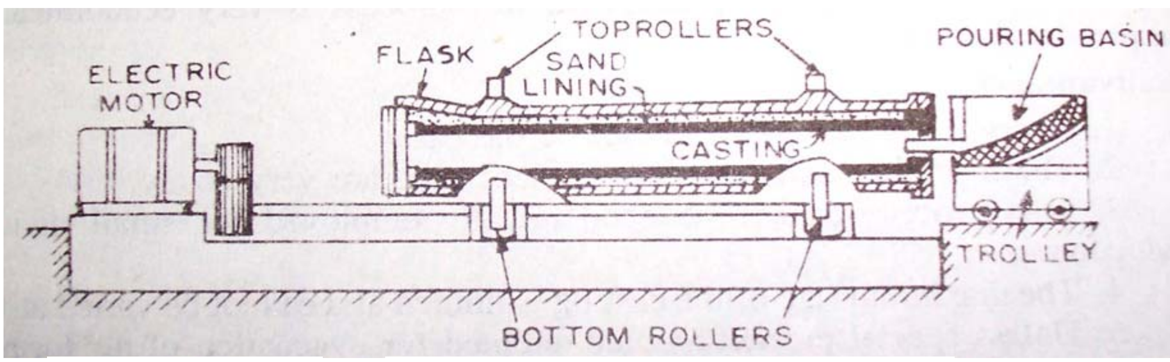


Figure 2.11: True centrifugal casting

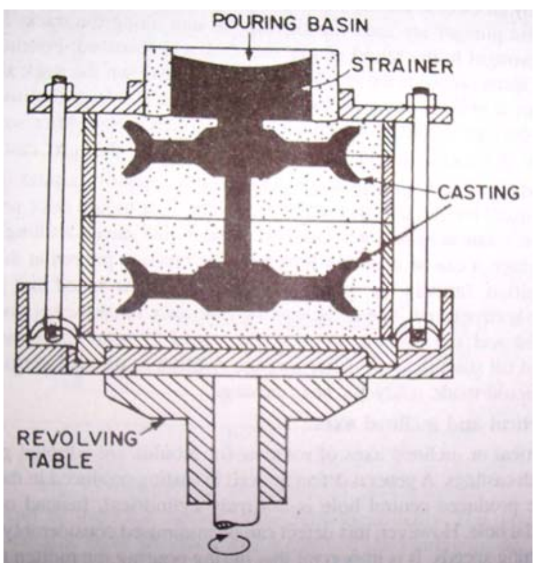


Figure 2.12: Semi centrifugal casting

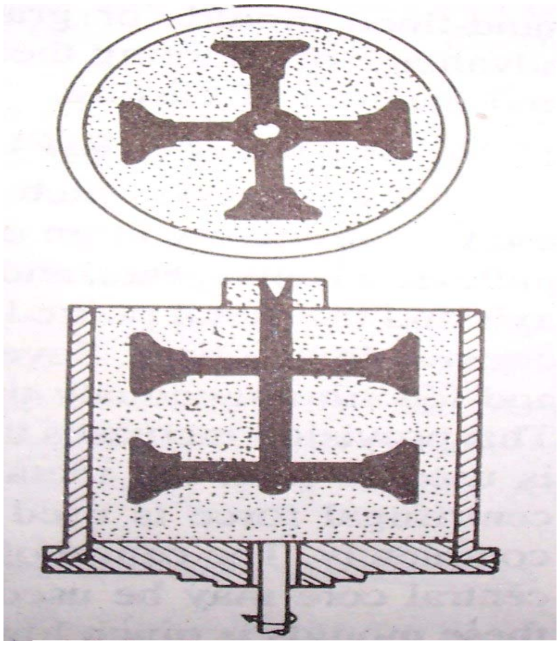
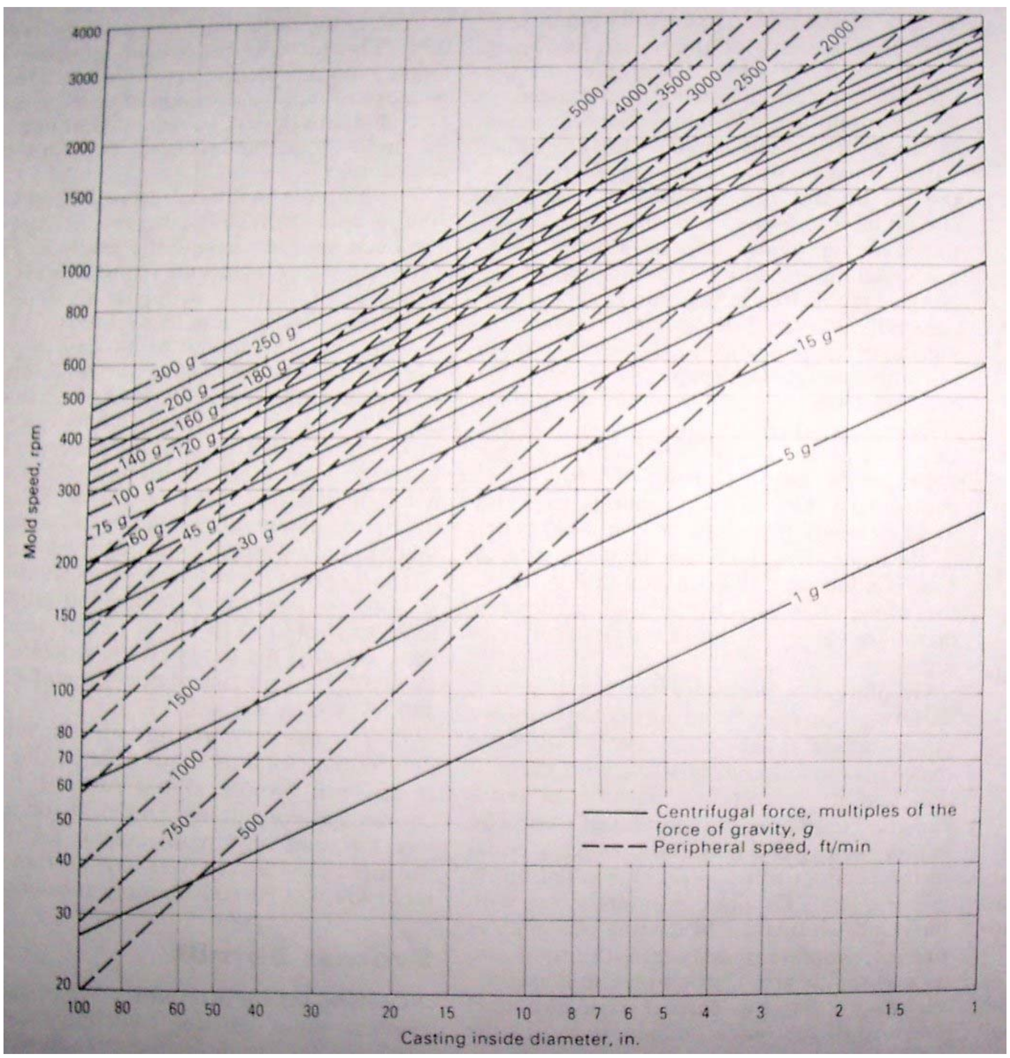


Figure 2.13: centrifuge centrifugal casting

Figure 2.14: Mold speed curves



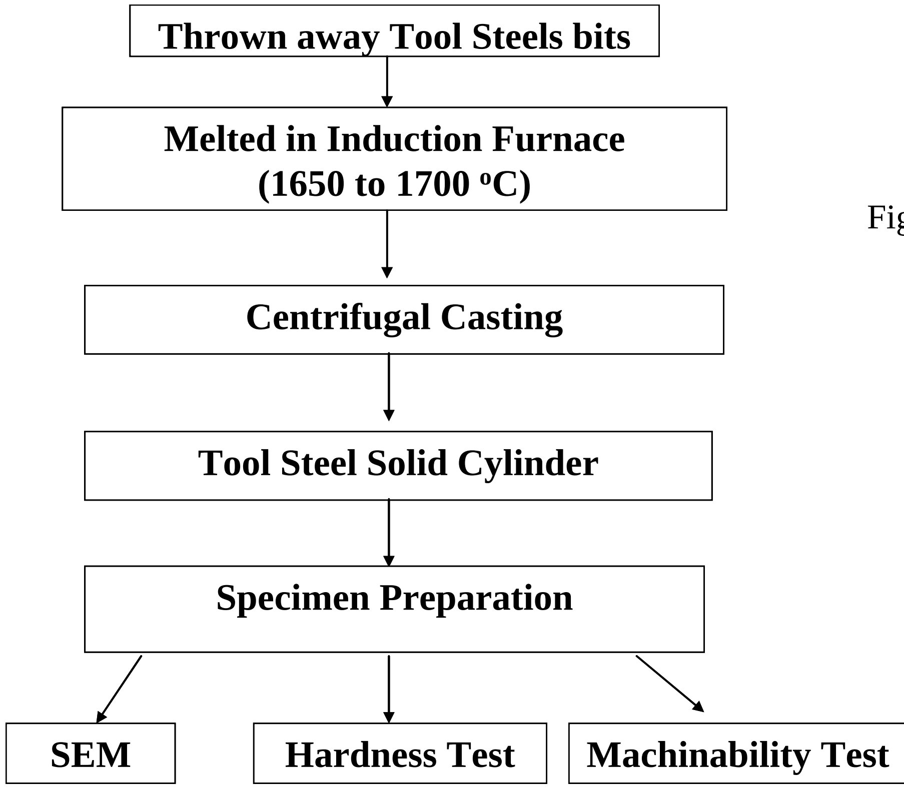


Figure 3.1: Flow chart of the experiment

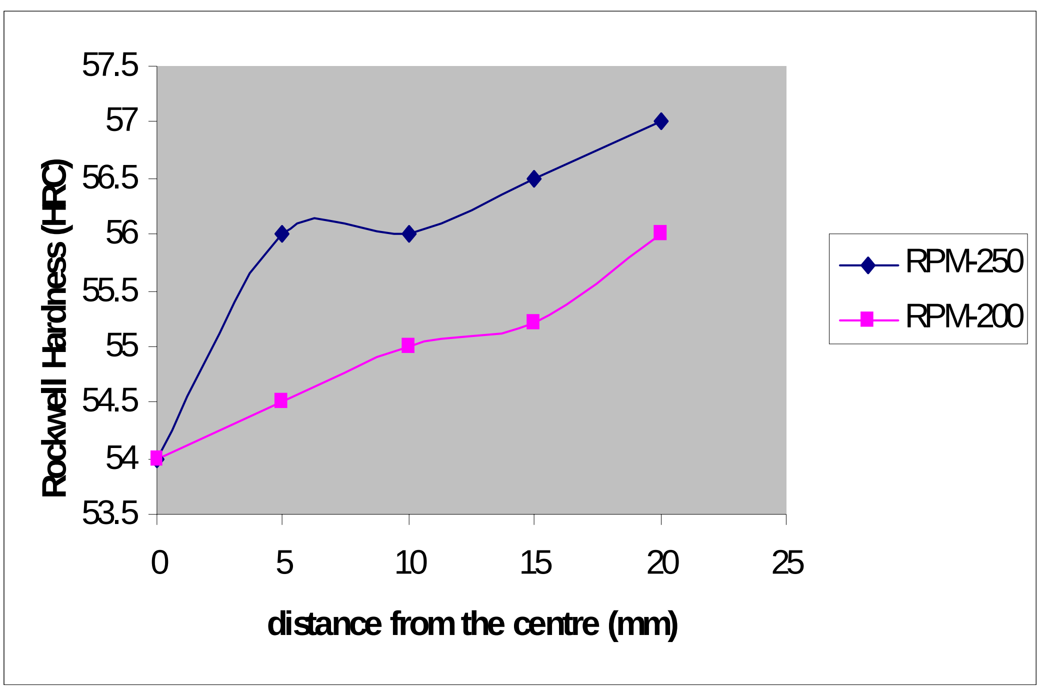


Figure 3.2: Graph between Rockwell hardness (HRC) and the distance from the centre (mm)

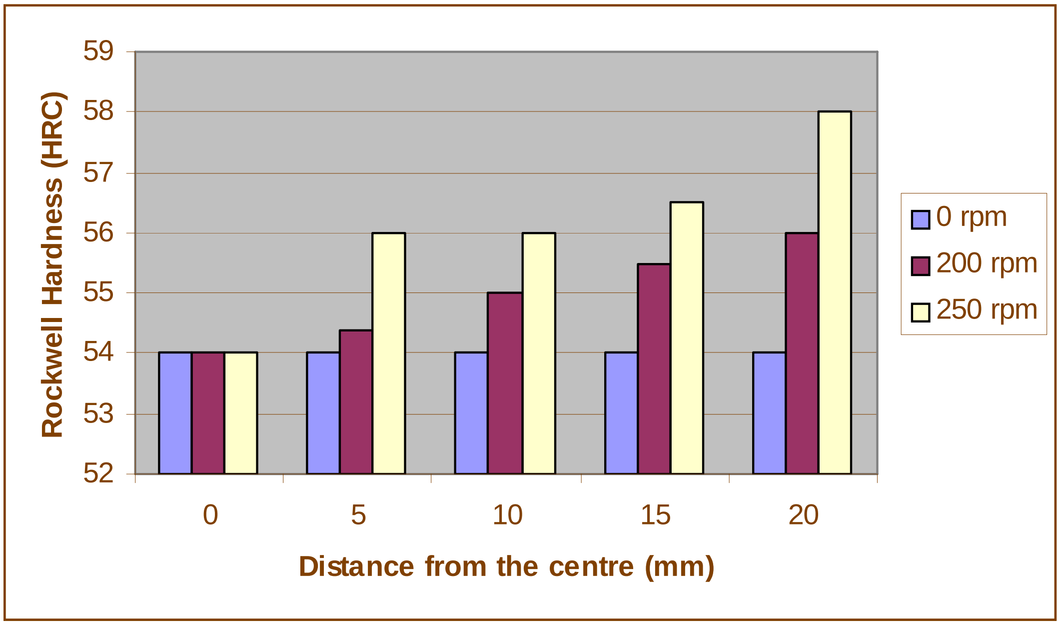


Figure 3.3: Variation of hardness at different distances from the centre of castings obtained with different speeds of rotation of the mould

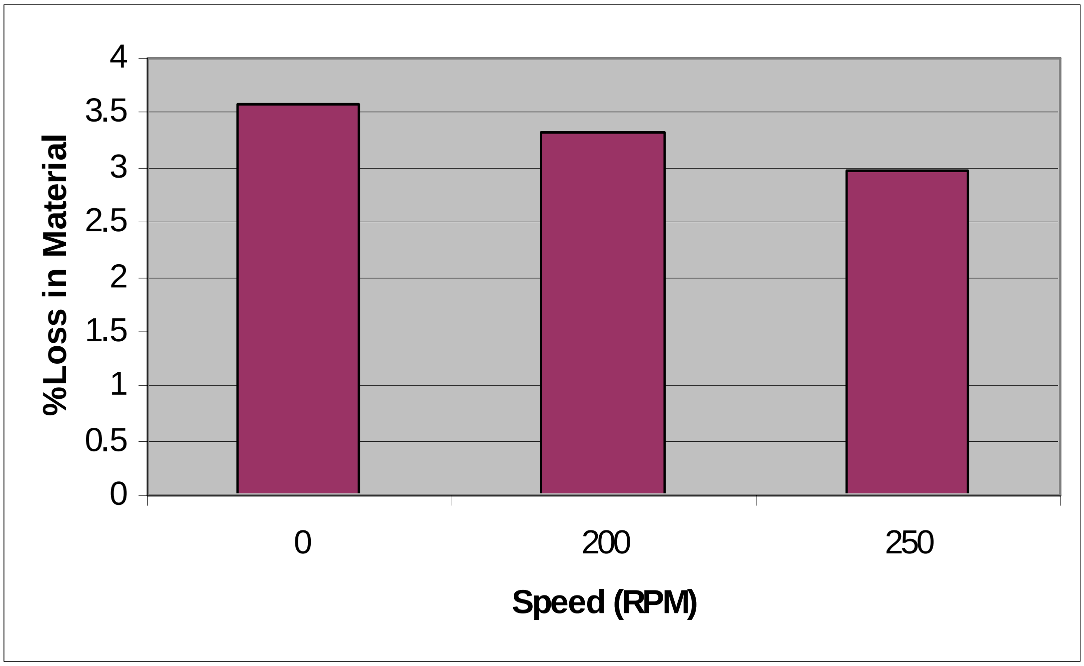


Figure 3.4: Bar chart showing percentage loss of material (wear) of fabricated tool bits obtained from castings with different speeds of mould rotation

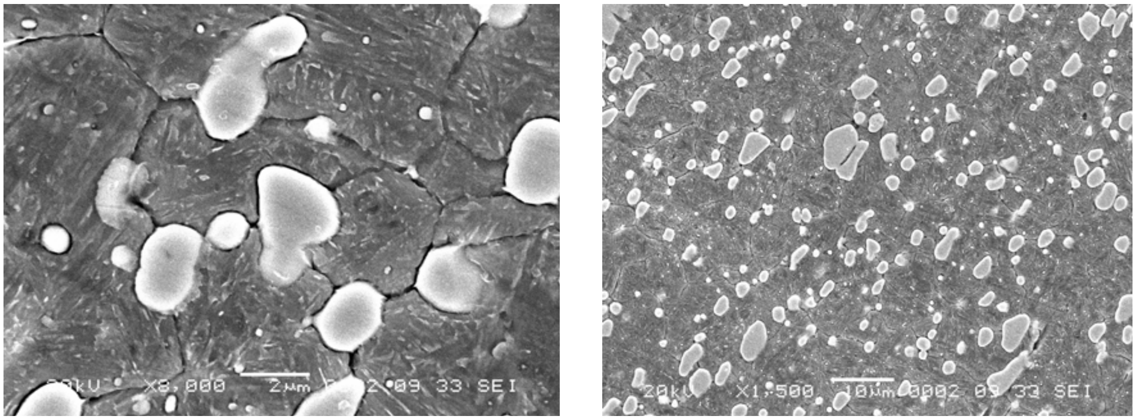


Figure 3.5: SEM micrographs of as-cast samples

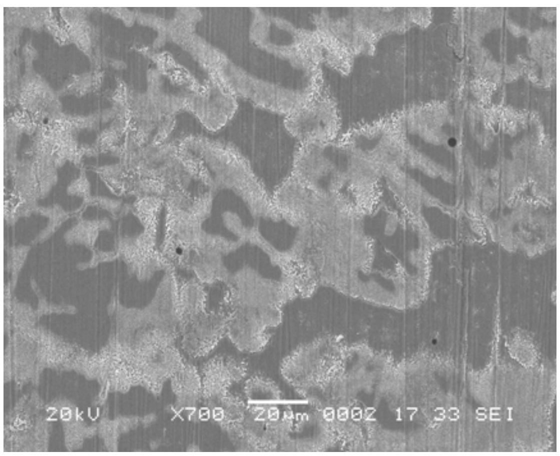


Figure 3.6: SEM micrograph of 200 rpm cast sample

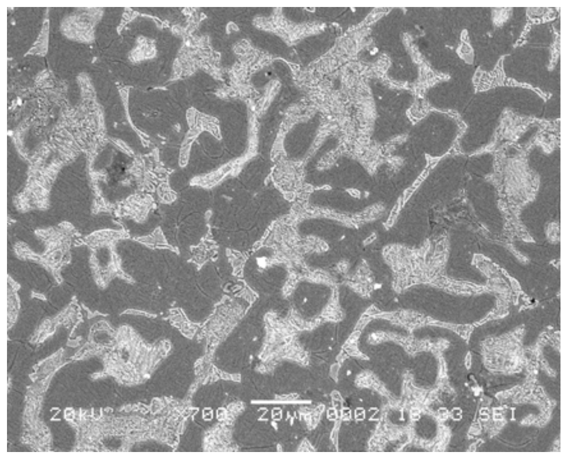


Figure 3.7: SEM micrograph of 250 rpm cast sample

Tables

sr. no.	Distance from the centre (mm)	Rockwell Hardness (HRC)
1	0	54
2	5	56
3	10	56
4	15	56.5
5	20	57

Table 3.1: Hardness values at different distances from the centre of the casting obtained with 200 rpm speed of rotation of the mould

sr. no.	Distance from the centre (mm)	Rockwell Hardness (HRC)
1	0	54
2	5	54.5
3	10	55
4	15	55.5
5	20	56

Table 3.2: Hardness values at different distances from the centre of the casting obtained with 250 rpm speed of rotation of the mould

speed (rpm)	initial length (mm)	final length (mm)	Difference (mm)
0	0.84	0.81	0.03
200	1.11	1.082	0.028
250	0.89	0.865	0.025

Table 3.3: Machinability test readings showing decrease in length of the samples prepared from the castings obtained with different speed of rotation of the mould