Effects of heat treatment on the mechanical engineering essay

Steel can be considered as a cheap material and have been used almost in every engineering application. It is very versatile material with a wide range of attractive properties which can be produced at a very competitive production cost (Sinha, 1989, Bello, K. A. et. al, 2007). Applications of steels for engineering components require a complete understanding of material properties and design requirement. Iron carbon alloys containing carbon from 0 to 1. 4% are quite often referred as plain carbon steel. The steel is divided into different categories based in its carbon content. They are classified as low carbon steel, medium carbon steel and high carbon steel. Low carbon steel has carbon content of 0. 10 – 0. 25%. While medium carbon has carbon content up to 0. 55% and high carbon steel has carbon content up to 1. 4% (R. S. Khurmi, 1987).

However, these types of steels need to be treated in order to meet some engineering specifications. The heat treatment process is carried out by heating the steel and then cooling it off. This process consists of heating the steel to a specific temperature, then holding the steel at increased temperature at specific period and lastly cooling the steel according to the specific process. The main transformation in the properties of the steel takes place in the cooling process of the steel. It depends mostly on the cooling rate of the heated steel. It is also depends on the quenching medias that have been used when cooling process takes place.

There a few heat treatments which were commonly used to treat steels. There are three basic types of heat treatment of steels: annealing, quenching, and tempering. Annealing is the heat treatment used to make steel softer and more ductile. It is also used to remove stresses in the material and reduce the grain size. Quenching refers to the process of rapidly cooling metal parts. Quenching process is used to increase the hardness of the steel so that it can resist wear. Hardened steel also used to make a cutting tool. Tempering is used to reduce the brittleness of the hardened steels and thus to increase its ductility. The process of tempering consists of reheating the hardened steel to some temperature below the lower critical temperature, followed by any desired rate of cooling.

All heat-treatment processes which are performed at high cooling rates require a suitable quenching medium. In metallurgy, it is most commonly used to harden steel by introducing martensite, in which case the steel must be rapidly cooled through its eutectoid point, the temperature at which austenite becomes unstable.

To provide a required cooling rate during quenching, various cooling media and methods are employed. Water, oil, or air can serve as the cooling medium. Many alloyed steels, which are characterized by a high stability of austenite, are subjected to step quenching. With thismethod of quenching, the temperature drop is less than in the case of direct cooling to roomtemperature and consequently quenching stresses are less.

A certain amount of austenite is retained during quenching even in steels with a relatively small content of carbon. For this reason it is impossible to impart the maximum hardness to a product. Since austenite is stable at room temperature and passes to martensite at lower temperatures, steels undergo a subzero treatment. Under this treatment quenching is continued and steels with a high content of retained austenite are immersed in liquid air or quenching mixtures whose temperature is below room temperature.

There are three equilibrium phases in the phase diagram which can be obtained by very slow cooling rates to allow equilibrium conditions to prevail. Each phase has particular characteristics, some of which are listed in Table 1.

Fig 1. 1: Iron Carbon Phase Diagram

Phase

Crystal structure

Composition

strength

ductility

Austenite( )

Solid solution of C in FCC Fe

0 to 2. 1 wt% C

Low

High

Ferrite(¡)

Solid solution of C in BCC Fe

0 to 0. 02 wt%C

Intermediate

Intermediate

Cementite

(Fe3C)

Orthorhombic compound

6. 7 wt% C

Extremely Hard

Extremely brittle

Table 1. 1 : Characteristics of the Equilibrium Phases in Steel

The amount of equilibrium phase changes that take place upon slow cooling from the austenite region in the Fe-C phase diagram into the ferrite + cementite phase field strongly depends on the carbon content. Depending on the carbon content, carbon steels can be divided into three categories: eutectoid steels (contain exactly 0. 76%C), hypoeutectoid steels (%C < 0. 76), and hypereutectoid steels (%C> 0. 76). The microstructure that develops when a eutectoid steel (0. 76% C) is slowly cooled from the austenite region to below 727 °C consists of alternating layers of Î± and cementite. This structure is called pearlite. For hypoeutectoid steels (%C < 0.

76) the microstructure consists of pearlite surrounded by pro-eutectoid Î± while hypereutectoid steels (%C> 0. 76) are composed of pearlite surrounded by cementite, as illustrated in Figure 1. 1. The hardness of carbon steels increases with increasing the carbon content due to increases in the hard phase, cementite.

1. 1Problem Statement:

Mould or dies are the tooling used to produce plastic parts in injection moulding. Since moulds have been expensive to manufacture, they were usually only used in mass production where thousands of parts were being produced. Typical moulds are constructed from hardened steel, pre-hardened steel, aluminium, and/or beryllium-copper alloy. The choice of material to build a mould from is primarily one of economics; in general, steel moulds cost more to construct, but their longer lifespan will offset the higher initial cost over a higher number of parts made before wearing out. Pre-hardened steel moulds are less wear-resistant and are used for lower volume requirements or larger components. The typical steel hardness is 38-45 on the Rockwell-C scale. Hardened steel moulds are heat treated after machining. As mild steel hardness is proven to be increased after heat treated, it should be considered as a material used in mould manufacturing.

Therefore, this research is trying to proof that by applying suitable heat treatments to mild steel, its hardenability could be increased and made it suitable for its usage as a mould steel especially in injection moulding process.

1. 2 Research Objectives

To study the effects of heat treatment on mild steel

To observe the changes of microstructure after annealing, quenching and tempering.

To determine the hardness, mechanical properties, strength and ductility of the heat treated mild steel

1. 3 Scopes

The scopes of this research are:

The specimen used in this research is A36 steel.

The mechanical properties that will be investigated are the tensile strength, microstructure and hardness

Equipment will be used are Rockwell Hardness Test, Universal Testing Machine (UTM) and SEM microscope.

1. 4 The Importance of The Study

1. To give information about the mechanical properties of the heat treated mild steel

2. To explore thepossibility of mild steel to become a suitable material for mould

1. 5 Expected Outcomes

Based on the microstructure test, the expected outcomes from the experiment will be as follows:

Pearlite – annealing process

Martensite – quenching process

Spherodite – tempering process

CHAPTER 2

LITERATURE REVIEW

2. 1Background of Steel

Pure iron is a relatively soft material and is hardly of any commercial use in that state. Alloys of iron with carbon are however very widely used. The following table indicates the names given to general group of such alloys.

Material

Percentage Carbon

WroughtIron

0 to 0. 05

Steel

005 to 2

Cast Iron

2 to 4. 3

Table 2. 1 : Carbon percentage in steel

The percentage of carbon alloyed with iron has a profound effect on the properties of the alloy. Table below shows the application of steels in the industry.

Types of Steels

Uses

1

2

3

Low Carbon Steels or mild steels

Medium carbon steels

High Carbon Steels

Chain links, nails, rivet, ship hulls, car bodies, bridges, cams, light duty gears etc

Axles, connecting rods, gears, wheels for trains and rails etc

Clutch plates, razor blades scissors, knives, punches, dies etc

Table 2. 2: Types of steels and its usage

2. 1. 1 Carbon Steel

Steel is an alloy of iron containing a small but definite percentage of carbon ranges from 0. 15 – 1. 5% (John, 1980). The term carbon steel is used for those steels in which essentially just iron and carbon are present. Most carbon steels contain less than 1. 5% carbon. According to . S. Khurmi and R. S. Sedha(1987), the alloys of iron-carbon system containing from 0 to 2. 0% carbon are called steels and those containing from 2. 0% to 6. 7% are called cast irons. However in practice, the steels are manufactured with carbon content up to 1. 4%. It is due to the fact that steels with carbon content more than 1. 4% are brittle and hence are not useful.

2. 1. 2 Mild Steel

Mild steel are those containing 0. 1 – 0. 25% carbon, they are soft, malleable and ductile (Alawode, 2002). Mild steel are used for general engineering purposes. It can be machined and worked into complex shapes, has a low lost and good mechanical properties. The typical applications of low carbon steels include automobile component, structural shapes/sections and sheets which are used in pipe lines, buildings, bridges, tin cans etc(Sidney H Avener, 1969) .

The usage of mild steel as mould in asmall injection moulding machine for forming small plastic articles in small-scale industries was studied by Oyetunji, A (2010). The mild steel is used for the construction of supporting plates, hopper, mainframe, mould, and platens, handle, and tie bars. The design, construction and testing of the small injection moulding machine had been successfully accomplished. It was observed and concluded that the practicability and efficiency of the machine depends on strict compliance with the operational procedures of the machine. He also recommended the design for small-scale investors that are willing to produce small plastic articles such as key holders, clothes pegs, flat rulers, bottle covers/caps and tally

Heat Treatment

Heat treatment can be defined as the controlled heating and cooling of metals in the solid state for the purpose of altering their properties according to requirements (W. Bolton, 1981). Heat treatment can be applied to steels to alter their properties by changing grain size and the form of the constituents present.

Oyeleke and Ade (1998) found that heat treatment improves yield strength, ultimate strength, hardness of the low carbon steel but the ductility of the low carbon steel decreases (Adeyemi, 1994). A. Adebayo et al, (2008) found that the mechanical properties of mild steel can be altered through various heat treatments.

2. 2. 1 Annealing

Annealing is the heat treatment used to make a steel softer, and more ductile, remove stresses in the material and reduce the grain size.

Full annealing for low carbon steel had been proven as the best combination in mechanical properties such as high tensile strength, hardness and ductility(M. H Jokhio, 2000). This treatment is recommended for further manufacturing process and also to be considered as final heat treatment after manufacturing process.

2. 2. 2 Quenching

The 0. 2% C low carbon steels which were heat treated showed a reasonable increase in both hardness and strength during oil and water quenching (M. B. Ndaliman(2006). Water quenching of low carbon steel has the highest tensile strength and hardness However this treatment gives the lowest ductility compared to other treatments, it is recommended when the strength and hardness is the prime factor in design. The microstructure of steel consists of the matrix of ferrite and small amount of pearlite. The fine of pearlite increases by increasing the rate of cooling (M. H. Jokhio, 2000). Quick water quenching to 600°C followed by air cooling after deformation creates tempered and softened bainite phase. Quick water quenching to room temperature after deformation develops fine ferrite-bainitetexture. Water quenching to 600°C followed by air cooling is the best regime after deformation, where it results in accepted values of ultimateas well as yield strengths with reasonable elongation (A. I. Zaky, A et al, 2008)

A study on the effect of quenching temperature and heating time on the quenched structure of a plain carbon steel by Takashi and Yoshio of Yamaguchi University(1967) proved that the longer heating time is, the lower quenching hardness for low carbon steels are. Until heating time is 2 hours, the quenching hardness has not an effect on heating time at appropriate quenching temperature for high carbon steels.

2. 2. 3 Tempering

The main purpose of tempering is to provide a disperse structure at a preset degree of cooling. In the case of low-carbon steels, quenching serves as tempering; even if not subjected to high temperature tempering, the steel has a high viscosity and a relatively great strength. A study on mechanical properties of medium carbon steel found that tempering of both oil and water quench specimen resulted in a decrease in both hardness and strength in the entire range of tempering temperatures (T. Kanwal et al, 2009). When certain steels are quenched in oil, a structure is formed even during transformation in the bainite range that is more disperse than the one formed after cooling in air. But the most disperse distribution of carbides and the most favourable properties are obtained after martensite tempering. The structure dispersion has the greatest effect on the yield stress.

An improvement of the fracture stress and yield stress and an increase in the fracture stress-yield stress ratio may be taken as a measure of the tempering efficiency. The tempering efficiency depends on the cross-sectional area and on the content of carbon and alloying elements in the steels. Although to achieve a thorough quenching the critical quenching rate has to be exceeded over the entire cross section, full tempering does not require this procedure. For example, in a quenched steel that has martensite in the surface zone and pearlite in the core, the hardness of the core sometimes may be higher than that of the surface zone after tempering. This is especially the case during a short tempering when precipitation of carbides from martensite proceeds faster than the coagulation of pearlite plates.

Bello K. A et al (2007) in their study on effect of tempering on the microstructure and mechanical properties of low carbon, low alloy martensitic steel found that the tempered dual phase (ferrite&martensite) steels have higher strength, ductility and toughness than the quenched and tempered samples. The 0. 22% C micro alloyed steels were austenized and quenched to produce lath martensite followed by annealing in intercritical region (🚺 ¡ + 🚺 ¬) and subsequently quenched to produce a dual phase of ferrite – martensite microstructure.

2. 3 Microstrucure

After being heat treated, the microstructural of the steel will be changed. The microstructural of carbon steels are often known as cementite, ferrite, pearlite, austenite and martensite. When a steel part is hardened, it is heated to a high temperature in order to convert the entire structure to the austenite phase. Austenite is a single-phase structure ofiron and carbon stable at high temperatures. If the steel were cooled slowly, the austenite wouldtransform to pearlite, which is the equilibrium phase at room temperature. Apearlitic structureis an annealed structure and is relatively soft with low physical properties. If the steel is cooledvery rapidly, a very hard and strong structure called martensite forms that is a metastablephase of carbon dissolved in iron. It may be tempered to produce lower hardness structuresthat are less brittle. Intermediate cooling rates will produce other structures referred to asbainites, although this type of structure is only produced in quantity in an alloy steel. Eutectoidcarbon steels produce predominantly martensite or pearlite, depending on the cooling rate(Totten. G. E, 2006).

CHAPTER 3

MATERIALS AND METHODS/METHODOLOGY

EXPERIMENTAL PROCEDURE

The experimental procedure for the project can be listed as:

Specimen preparation

Heat Treatment

Hardness Measurement

Mechanical Properties study

Microstructure study

Specimen preparation

Heat Treatment

Tempering

Annealing

Quenching

Test

Microstructure

Hardness

Tensile

Analysis

Fig 3. 1: Flow of methodology process

The type of material will be used in this project is mild steel (to be named later). The table below showed the composition of mild steel (ASM Handbook).

Specimen preparation

Sample of mild steel will be obtained from local supplier. The composition of mild steel A36 is showed in the Table 3. 1.

Composition

Carbon Percentage (%)

Carbon

0. 29

Iron

98

Phosphorus

0. 04

Manganese

1. 0

Silicon

0. 28

Sulphur

0. 05 max

Table 3. 1 : Composition of mild steel A36 (ASM Handbook, 2000)

Carbon

0. 26% max

Yield point

248 MPa (36 ksi) min

Tensile strength

400-552 MPa (58-80 ksi)

Total elongation

(in 50 mm, or 2 in.) 21% min

Table 3. 2 ASTM requirements for A36 steel

The dimensions of the specimen will be are as follows.

Test

Quantity

Specimen Dimension

Hardness and microstructural

29 pcs

Cylinder with diameter of 25 mm and 50 mm height

Tensile

29 pcs

Rectangular bar with:

Width = 40 mm

Length = 320 mm

Thickness = 3mm

Heat treatment

Annealing

The specimen will be heated to a temperature of 900° C. At 900°C, the specimen will be held for 2 hours. Then the furnace will be switched off so that the specimen temperature will decrease with the same rate of the furnace. The objective of keeping the specimen at 900°C for 2 hours is to homogenized the specimen. The temperature 900°C lies above critical temperature so that the specimen will get sufficient time to get properly homogenized. The specimen will be taken out after two days when the furnace temperature had already reached the room temperature.

Quenching

The specimens will be heated to a temperature of 900 degcelcius for 2 hours. After that, the specimen will be quenched into the two different mediums, palm oil and tap water. After around half an hour, the specimen will be taken out and cleaned.

Tempering

Firstly, 4 specimens will be heated to 900 degcelcius for 2 hours and then quenched in the oil bath maintained at room temperature. Among the 4 specimens, 2 will be heated to 250 degcelcius with different time interval of 1 hour, 1 and half hour and 2 hours respectively. 3 more specimens will be heated to 450 °C for the time interval of 1 hour, 1 and half hour and 2 hours respectively. Another 3 specimens will be heated to 650 °C for the same time interval. After each time interval ends, the specimens will be taken out from the furnace and will be allowed to cool in the room temperature.

Hardness Testing

The heat treated specimens hardness will be measured by Rockwell Hardness tester. The Rockwell's hardness test is generally performed when quick and direct reading is desirable. In this test a standard indentor either of 1. 58 mm diameter loaded with 100kN or a cone indentor with 120° cone and 150kN is employed. The test has nine scales of hardness (A to H and K). But B and C scales are widely used. The ball indentors are generally made of hardened tool steel or tungsten carbide. During the test, the specimen will be placed on the anvil and is raised till it comes in contact with the indentor.

Tabulation for hardness testing

Specimen Specification

Time

Hardness

Quenched in oil

Quenched in water

Quenched from 900°C and tempered at 250°C

1 hour

1 ½ hour

2 hour

Quenched from 900°C and tempered at 450°C

1 hour

1 ½ hour

2 hour

Quenched from 900°C and tempered at 650°C

1 hour

1 ½ hour

2 hour

Annealed at 900°C (taken out after 2 days) n/a

As received

n/a

Table 3. 2: Tabulation table for hardness testing

Ultimate Tensile Strength Testing

The heat treated specimens will be tested in UTS machine for obtaining the % of elongation, ultimate tensile strength, yield strength.

3. 4. 1 Tabulation for Ultimate Tensile Strength Testing

Specimen Specification

Time

UTS (in Mpa)

Quenched in oil

Quenched in water

Quenched from 900°C and tempered at 250°C

1 hour

1 ½ hour

2 hour

Quenched from 900°C and tempered at 450°C

1 hour

1 ½ hour

2 hour

Quenched from 900°C and tempered at 650°C

1 hour

1 ½ hour

2 hour

Annealed at 900°C (taken out after 2 days)

n/a

As received

n/a

Table 3. 3: Tabulation table for tensile strength

Specimen Specification

Time

Yield Strength in (Mpa)

Quenched in oil

Quenched in water

Quenched from 900°C and tempered at 250°C

1 hour

1 ½ hour

2 hour

Quenched from 900°C and tempered at 450°C

1 hour

1 ½ hour

2 hour

Quenched from 900°Cand tempered at 650°C

1 hour

1 ½ hour

2 hour

Annealed at 900°C (taken out after 2 days)

n/a

As received

n/a

Table 3. 4: Tabulation table for yield strength

Specimen Specification

Time

% Elongation

Quenched in oil

Quenched in water

Quenched from 900°C and tempered at 250°C

1 hour

1 ½ hour

2 hour

Quenched from 900°C and tempered at 450°C

1 hour

1 ½ hour

2 hour

Quenched from 900°C and tempered at 650°C

1 hour

1 ½ hour

2 hour

Annealed at 900°C (taken out after 2 days) n/a

As received

n/a

Table 3. 5: Tabulation table for % elongation

SEM for Microstructure

A more recent and extremely useful investigative tool is the scanning electron microscope (SEM). This instrument aids in investigations of the micro-structural features of all material types. The surface of a specimen to be examined will be scanned with an electron beam, and the reflected (or back-scattered) beam of electrons will be collected, then it will be displayed at the same scanning rate on a cathode ray tube (similar to a TV screen). The image on the screen, which may be photographed, represents the surface features of the specimen. The surface may or may not be polished and etched, but it must be electrically conductive; a very thin metallic surface coating must be applied to nonconductive materials. Magnification ranging from 10 to 50, 000 times ispossible, as are also very great depths-of field. Accessory equipment permits qualitative and semi-quantitative analysis of the elemental composition of verylocalized surface areas.

NO

ACTIVITIES

TIME (month)

1

2

3

4

5

6

7

8

9

10

11

12

1

Confirmation Project Title

2

Literature Search and Review

3

Research Methodology

4

Proposalpresentation

5

Data gathering

6

Data analysis

7

Summarizing and Writing

8

Project Presentation

SCHEDULE FOR MASTER PROJECT (JAN 2011 – DIS 2011)

Note : Planning Activities

Actual Planning