INVESTIGATION ON MECHANICAL PROPERTIES OF HEAT TREATED LOW CARBON STEEL.

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ABSTRACT

The heat treatment method was used in early 1000 B.C when the artifact of crude iron was found. Heat treatment is a method used to alter the physical, and sometimes chemical, properties of a material usually ductility, hardness, yield strength, and impact resistance. Heat treatment involves the use of heating or chilling, normally to extreme temperatures, to achieve a desired result such as hardening or softening of a material.. There are many types of furnace are used for heat treating but the basic types of furnace are batch furnace and continuous furnace. Selection of a material for specific application required a full understanding of its mechanical properties including tensile properties, elastic and plastic behavior, brittle fracture, strength and hardness. The purpose of this study is to obtain the most optimum value of UTS (ultimate tensile strength), Y (yield strength) and strain by using suitable heat treatment method such as quenching, hardening and tempering. After heat treatment process, these metals were test using tensile test machine to investigate the mechanical properties. Evaluation was based on the value of UTS (ultimate tensile strength), Y (yield strength) and strain. It was found out that the annealing process was the best method of heat treatment to produce the most optimum value of UTS (ultimate tensile strength), Y (yield strength) and strain. The finding suggest that there are should used other method of heat-treatment such as case hardening, carbon nitriding and so on to understand more about mechanical properties of low carbon steel or mild steel and how to change the microstructures in metal or to improve the mechanical properties of mild steel.

ABSTRAK

Kaedah rawatan pemanasan ke atas logam telah lama digunakan sejak dari 1000 tahun dahulu di mana satu artifak logam yang di sadur telah di temui. Kaedah ini adalah untuk mengubah sifat bahan seperti fizikal ataupun kimia dan antara sifat-sifat bahan itu termasuklah kekenyalan, kekerasan dan ketahanan dari pelanggaran. Rawatan ini merangkumi cara pemanasan atau penyejukan yang dilakukan dalam suhu yang sangat tinggi untuk menghasilkan keputusan yang di ingini seperti kelembutan dan kekerasan bahan tersebut. Terdapat banyak jenis relau untuk kaedah rawatan ini tetapi jenis yang utama adalah relau berkumpulan dan relau yang berterusan. Pemahaman yang mendalam tentang sifat bahan seperti daya regangan, kelakuan semasa elastik dan plastik, kadar kerapuhan, daya kekuatan dan daya kekerasan sangat-sangat di perlukan untun memilih bahan. Tujuan utama projek ini di jalankan adalah untuk mencari nilai daya regangan dan daya pemanjangan yang paling tinggi dengan menggunakan kaedah rawatan pemanasan yang paling sesuai. Selepas rawatan pemanasan, logam tersebut di uji menggunakan mesin daya regangan untuk menyiasat ciri-ciri atau sifat-sifat logam tersebut. Penilaian ciri- ciri bahan ini adalah berdasarkan nilai daya regangang dan nilai daya pemanjangan. Daripada kajian ini mendapati bahawa kaedah yang paling sesuai untuk menghasil nilai daya regangan dan nilai daya pemanjangan yang paling tinggi adalah menggunakan kaedah annealing. Untuk mendalami dan memahami lagi tentang sifat-sifat bahan atau cara-cara untuk mengubah struktur dalaman logam adalah di syorkan supaya menggunakan kaedah pemanasan logam yang selain daripada kajian ini.

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LIST OF SYMBOLS

%	-	Percentages
cm^3	-	Centimeters Cube
mm	-	Millimeter
x	-	Times
+	-	Positive
-	-	Negative
Mpa	-	Mega Pascal
^0C	-	Celsius Degree
^0F	-	Fahrenheit Degree
ρ	-	Load
s	-	Displacement
A_O	-	Sectional Area
Lo	-	Original Length
δ	-	Stress
ε	-	Strain @ Elongation
E	-	Young Modulus

LIST OF ABBREVIATION

ASTM	-	America Standard Measurement
UTS	-	Ultimate Tensile Strength
Y	-	Yield Stress

CHAPTER 1

INTRODUCTION

1.1 Introduction

Artifact from early civilization indicate that crude iron was hardened by heat treatment as early as 1000 B.C, but an understanding of the composition and structural factors controlling hardening of the iron or steel was that archived until the eighteen century [7]. Steel's ability to become strong and hard when heat treated is produced by alloying iron with carbon. The changes in the percents of carbon on iron with temperature are used to advantages in many type of heat treatment. This topic involves a lot of experimental activities to investigate the suitable heat treatment method to improve and ensure the mechanical properties achieve optimum values of low carbon steel properties which is suitable to be used as a tool for shearing machine.

Generally, steels are iron-based metals to which other chemical elements have been added. The addition of these elements can create new constituents in the metal, affecting its mechanical properties (hardness, tensile and yield strength, ductility) and machinability [7].Mechanical properties are the fore most importance in selecting material for the machine's tool and part. Think of any tool, or any part of device, or any wear member and list of the properties needed to serviceability. This list would probably include these mechanical properties factors which are strength, formability, rigidity, toughness and durability. There are many test to measure mechanical properties such as tensile test, impact test and hardness test [5].

1.2 Problem Statement

Generally low carbon steel is used for common industrial product such as nuts, plate, and sheet and for component that not required high strength. So by using heat-treatment method, the uses of low carbon steel can be wilder. Furthermore this material is lower cost than any other metal.

1.3 Project Aim & Objective

a) Aim

To find the optimum value of the low carbon steel which is suitable to be used as a tool for machines by using the suitable heat treatment method.

b) Objective

i. To obtain the optimum value of UTS (ultimate tensile strength), Y(yield strength) and strain.
ii. To propose solution by using suitable heat treatment method such as quenching, hardening and tempering.

1.4 Project Scope

The scope of the project is to find the best value of the low carbon steel to use in machines. This material will come in T or dog bone shape. The heat treatment that will be done is quenching hardening and tempering. These materials will be test using tensile test machine. After that this material will be compared according their mechanical properties focus on UTS (ultimate tensile strength), Y (yield stress) and strain.

CHAPTER 2

LITERATURE REVIEW

2.1 Low Carbon Steel

According to the Serope Kalpakjian low carbon steel also called mild steel and had less than 0.13 percents of carbon. He also said it's generally used for common industrial product such as bolt, nuts, sheet, plate and tubes and also for the machines that do not required high strength [5]. This kind of low carbon steel has many advantages which are;

a) Posses good formability
b) Posses' good weldability: best of all metals:
c) Lowest cost and should be considered first
d) Rated at 55-60% machinability
e) Tensile strength, 365 Mpa
f) Yield strength, 305 Mpa
g) Elongation, 16-20%

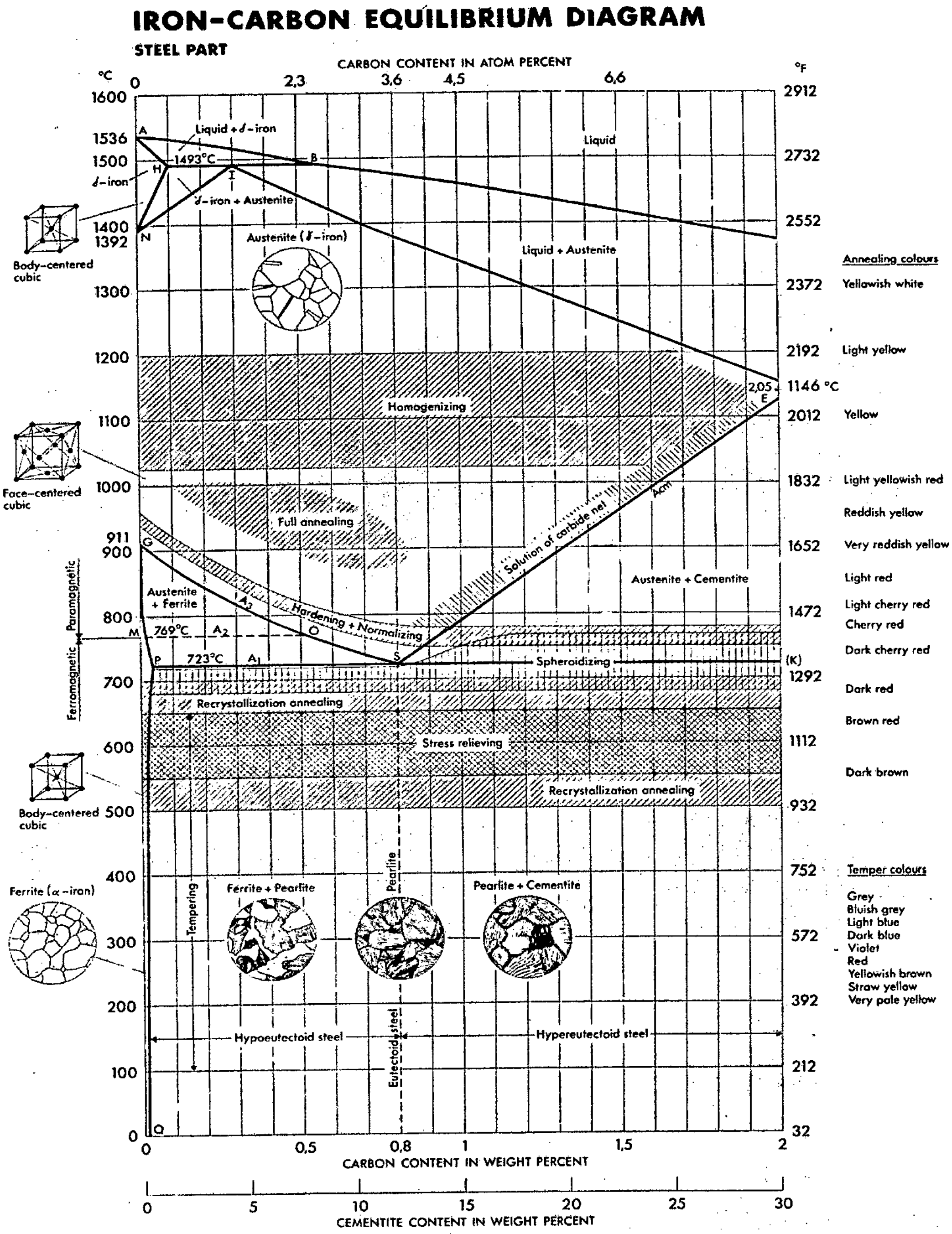

Figure 1: Iron-Carbon Equilibrium Diagram [6]

2.2 Heat treatment

The amount of carbon present in plain carbon steel has a pronounced effect on the properties of steel and on the selection of suitable heat treatments to attain certain desired properties. The purpose of heat treating plain-carbon steel is to change the mechanical properties of steel, usually ductility, hardness, yield strength, and impact resistance [6]. Note that the electrical and thermal conductivity are slightly altered. As with most strengthening techniques for steel, the modulus of elasticity (Young's modulus) is never affected. Steel has a higher solid solubility for carbon in the austenite phase, therefore all heat treatments, except spheroidizing and process annealing, start by heating to an austenitic phase. The rate at which the steel is cooled through the eutectoid reaction affects the rate at which carbon diffuses out of austenite. Generally speaking, cooling quickly will give a finer pearlite (until the martensite critical temperature is reached) and cooling slowly will give a coarser pearlite. Cooling a hypoeutectic (less than 0.8 % C) steel results in a pearlite structure with α-ferrite at the grain boundaries. If it is hypereutectoid (more than 0.8 wt% C) steel then the structure is full pearlite with small grains of cementite scattered throughout [6]. The relative amounts of constituents are found using the lever rule.

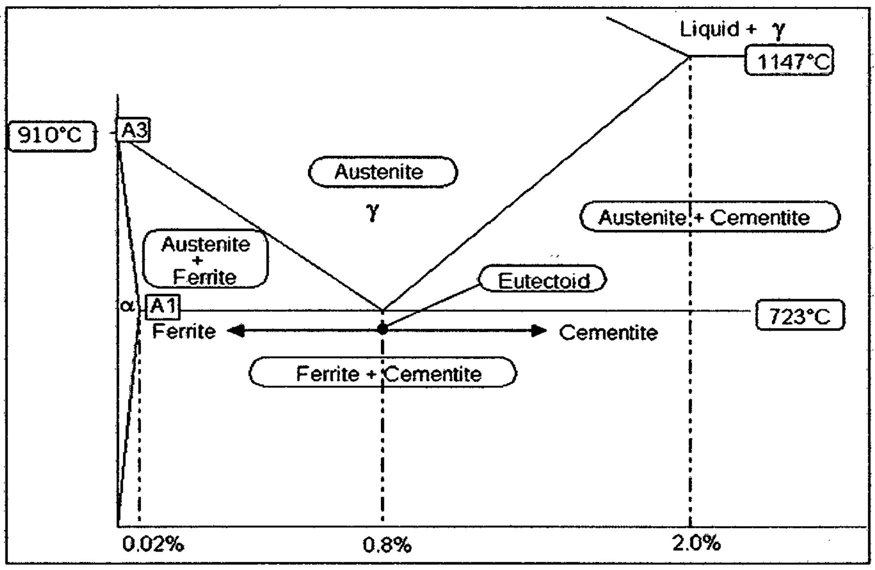

Figure 2: Iron-carbon phase diagrams [5]

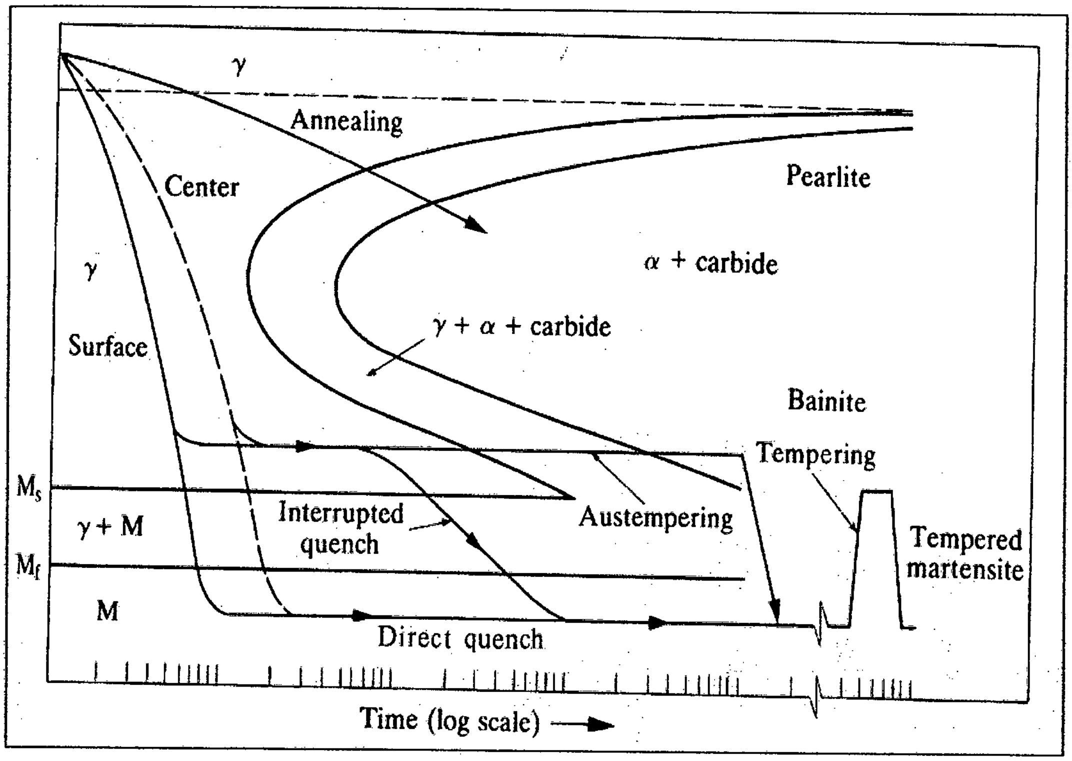

Figure 3: Transformation process [7]

2.2.1 Quenching

Quenching is a rapid cooling after solution of heat treatment. After heating to a high enough temperature to cause recrystallisation, the heated carbon steel is cooled very rapidly, for example by being dropped into cold water, there is no time for the austenite to loose its excess carbon atoms and they become trapped in the structure. The result is a new structure called martensite. [10]

The cooling rate must be rapid enough to prevent the formation of other transformation product such as pearlite, bainite, ferrite, or cementite. The choice of cooling medium is dependent on the desired cooling rate, which is determine by the composite (hardenability) of the steel, and the size and shape of the section being quenched. [6]

As a consequence, martensite is very hard and brittle and the steel become harder and more brittle. The hardness and strength increases quite significantly with an increase in carbon content. [10] Quenching set up high thermal and transformation stresses that can cause distortion or cracking of the part. There for is usually desirable to keep those stresses at a minimum by cooling at a rate that is just slightly faster than the critical cooling rate as determine by the hardenability of the steel and the size and the shape of the part being quenching. The most commonly use as a medium for quenching is water, mineral oil and a forced air. [6]

2.2.2 Annealing

Steel is annealed to reduce the hardness, improve machinability, facilitate cold-working, and produce a desired microstructure. Full annealing is the process of softening steel by a heating and cooling cycle, so that it may be bent or cut easily. In annealing, steel is heated above the transformation temperature to form austenite, and cooled very slowly, usually in the furnace. [6]

There are several types of annealing like black annealing, blue annealing, box annealing, bright annealing, flame annealing, intermediate annealing, isothermal annealing, process annealing, recrystallisation annealing, soft annealing, finish annealing and spheroidizing. These are practiced according to their different final product properties in the industry.

The two-stage heat treating process of quenching and tempering is designed to produce high strength steel capable of resisting shock and deformation without breaking. On the other hand, the annealing process is intended to make steel easier to deform or machine. In manufacturing steel products, machining and severe bending operations are often employed. Even tempered steel may not cut or bend very easily and annealing is often necessary. Process annealing consists of heating steel to a temperature just below the A_1 for a short time. This makes the steel easier to form.

This heat treatment is commonly applied in the sheet and wire industries, and the temperatures generally used are from 1020 to 1200 ^{0}F (550 to 650 ^{0}C). Full annealing, where steel is heated 50 to 100 ^{0}F (90 to 180 ^{0}C) above the A_3 for hypoeutectoid steels, and above the A_1 for hypereutectoid steels, and slow cooled, makes the steel much easier to cut, as well as bend. In full annealing, cooling must take place very slowly so that a coarse pearlite is formed. Slow cooling is not essential for process annealing, since any cooling rate from temperatures below A_1 will result in the same microstructure and hardness.

2.2.3 Tempering

Tempering (formerly called drawing), consists of reheating a quenched steel to a temperature below the transformation temperature for an appropriate time and cooling back to room temperature. Freshly quenched martensite is hard but not ductile. Tempering is needed to impart ductility to martensite usually at a small sacrifice in strength. [6]

The effect of tempering may be illustrated as follows. If the head of a hammer were quenched to a fully martensitic structure, it probably would crack after the first few blows. Tempering during manufacture of the hammer imparts shock resistance with only a slight decrease in hardness. Tempering is accomplished by heating a quenched part to some point below the transformation temperature, and holding it at this temperature for an hour or more, depending on its size. The microstructure changes accompanying tempering include loss of acicular martensite pattern and the precipitation of tiny carbide particles. This microstructure is referred to as tempered martensite.

2.2.4 Heat Treating Furnace and Equipment

There are many types of furnace are used for heat treating but the basic types of furnace are batch furnace and continuous furnace. Because they consume a lot of energy, their insulation and efficiency is important for the design consideration as much as their initial cost, the personal needed for their operation and maintenance and their safe use. [2]

Uniform temperature and accurate control of temperature or time cycle are importance, so in modern furnace are equip with the various electronic control devices. New development of treating furnace includes computer-controlled system which is programmed to run through a complete heat treatment cycle repeatedly and with reproduces accuracy. Heating-system fuels are usually gas,oil,or electricity. [2]

The fuels usually affect the furnace's atmosphere and introduced the product of combustion into the furnace. However electrical heating has a slower startup time and it's more difficult to handle and adjustment.

a) Batch Furnaces

In a batch furnace the parts to be heat treated are loaded and unloaded into the in individual batches. The furnaces usually consist of an insulated chamber, a heating system and access door. The basic types of batch furnaces are:

i. A 'box furnace' is a horizontal rectangular chamber with one or two access doors through which parts are loaded. This types are versatile simple to handle and to use, and available in several sizes. A variation of this type is the car-bottom furnaces. The parts to be heat treated, usually long or large are loaded onto a flatcar which then moves on rails into the furnaces. [5]

ii. A 'pit furnace' is a vertical pit bellow ground level into which the parts are lowered. These types of furnaces is particularly suitable for long parts because they can be suspended by one end and consequently are less likely to warp during processing than if positioned horizontally within a box furnace. [5]

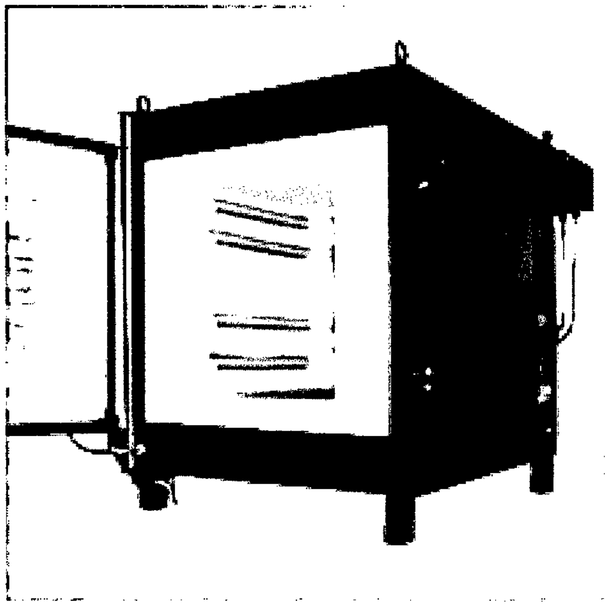

Figure 4: Sample of batch furnace

2.3 Mechanical properties

In manufacturing operation, many parts are formed into various shapes by applying external forces to the work piece by mean of tool and dies. Because deformation in these processes is carried out by mechanical means, an understanding of the behavior of the behavior of the material in response to externally applied forces is important. The behavior of manufactured part during its expected service life is an important consideration. [5]

This statement was agreed by Woodrow Chapman. He said that selection of a material for specific application required a full understanding of its mechanical properties including tensile properties, elastic and plastic behavior, brittle fracture strength and hardness. Woodrow also said, that the selection of material commonly based of either or both of the following reason.1) the part or structure made from the material will satisfy, as completely as possible all of the essential requirement of the application.2) the part or structure made from the material can be produce and maintained for a lower cost then is possible with any other material. [6]

However according to Norman E.Dowling to assure performance, safety, and durability, it is necessary to avoid access deformation that is bending, twisting or stretching of the components of the machine, vehicle or structure. In addition cracking in component must be avoided entirely or strictly limited so that it does not progress to the point of the complete fracture. The study of deformation and fracture in material is called mechanical behavior and properties of materials. [2]

2.3.1 Ductility

Serope Kalpakjian said that ductility is the extent of plastic deformation that the material undergoes before fracture. [5] This statement also agreed by Norman E.Dowling. in the tension case, this mean the ability to stretch by plastics strain but with the creep strain also sometimes contributing. [2]

Engineering fracture strain Or elongation

$$\varepsilon = \frac{(l_f - l_i)}{l_i} \times 100$$

Reduction of area, %RA

$$= \frac{(A_o - A_f)}{A_o} \times 100$$

According to the ASTM Standards, for metal is usually to measure the elongation on the specimen after broken, using marks placed a know distance apart prior to the test (Chapman, 2004). Since the elastic strain is recovered when the stress return to zero immediately after fracture, an elongation measurement made after fracture corresponds to the plastic component of e and e elongation. The different between this parameter is too small for ductile material, so that the distinction is often not important.

2.3.2 Stress-Strain

According to tensile test, when the first load is applied, the specimen elongates in proportion to the load and this effect called 'linear elastic' behavior. If the load is removed the specimen returns to in original shape and length, in an elastic process. The engineering stress or nominal stress is defined as the ratio of the applied load P to the original cross section area A_0 of the specimen. [5]

$$\text{Engineering stress, } \sigma = \frac{P}{A_0}$$

$$\text{Engineering strain, } e = \frac{(l - l_0)}{l_0}$$

Where l_0 is instantaneous length of the specimen

Metals including steel have a linear stress-strain relationship up to the 'yield point', as shown in the figure. Some steels show an unusual behavior where the stress falls after the yield point. This is due to the interaction of carbon atoms and dislocations in the stressed steel. Below the yield strength all deformation is recoverable, and the material will return to its initial shape when the load is removed. The ratio of the stress to strain in elastic region is known as 'modulus of elasticity', E, or 'young modulus'. [2]

$$\text{Modulus of elasticity, } E = \frac{\sigma}{e}$$

For stresses above the yield point the deformation is not recoverable, and the material will not return to its initial shape. This unrecoverable deformation is known as 'plastic deformation' [3]

After the yield point, steel and many other ductile metals will undergo a period of 'strain hardening', in which the stress increases again with increasing strain up to the 'ultimate strength'. If the material is unloaded at this point, the stress-strain curve will be parallel to that portion of the curve between the origin and the yield point. If it is re-loaded it will follow the unloading curve up again to the ultimate strength, which has become the new yield strength.

After a metal has been loaded to its yield strength it begins to "neck" as the cross-sectional area of the specimen decreases due to plastic flow. When 'necking' becomes substantial, it may cause a reversal of the engineering stress-strain curve, where decreasing stress correlates to increasing strain because of geometric effects. This is because the engineering stress and engineering strain are calculated assuming the original cross-sectional area before necking. The peak stress on the engineering stress-strain curve is known the 'ultimate tensile strength'. As the progresses, the engineering stress drop further and the specimen finally fracture at the necked region. This phenomenon called 'breaking' or 'fracture stresses'. [2]

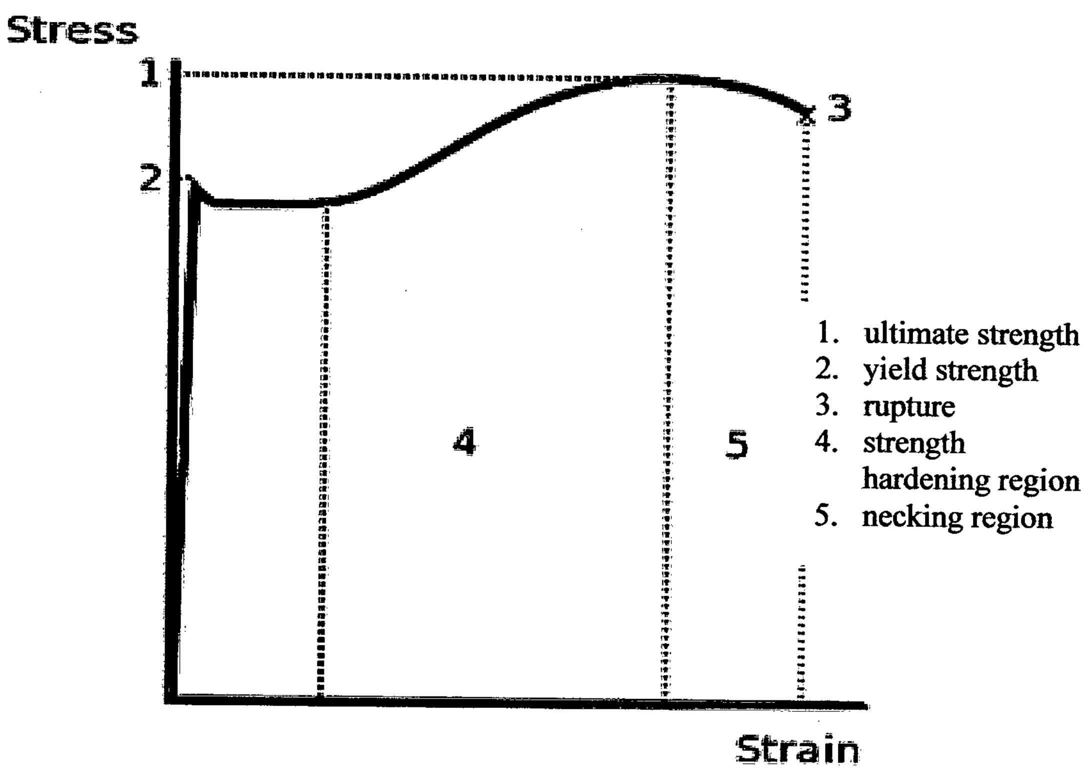

Figure 5: Stress and strain of low carbon steel [12]

2.3.3 Fatigue

According to A.Jacob-2005 the first article that published about fatigue was in 1837 by Wilhelm Albert and he also devised a test machine for conveyor chains used in the Clausthal mines. A.Jacob also said that the failure called fatigue (endurance) occurred under condition when the stress develops were well below the ultimate stress and frequently below the yield strength and fatigue also causes over 75% of failure of the mechanical parts and component in service. [1]

In materials science, fatigue is the progressive, localized, and permanent structural damage that occurs when a material is subjected to cyclic or fluctuating strains at nominal stresses that have maximum values less than (often much less than) the static yield strength of the material. A practical example of low-cycle fatigue would be the bending of a paperclip. A metal paperclip can be bent past its yield point, bent so it will stay bent) without breaking, but repeated bending in the same section of wire will cause the material to fail. [4]The following characteristics are common to fatigue in all materials:

a) The process starts with a microscopic crack, called the initiation site, which then widens with each subsequent movement, a phenomenon analyzed in the topic of fracture mechanics.
b) Failure is essentially probabilistic. The number of cycles required for failure varies between homogeneous material samples. Analysis demands the techniques of survival analysis.
c) The greater the applied stress, the shorter the life.
d) Damage is cumulative. Materials do not recover when rested.
e) Fatigue life is influenced by a variety of factors, such as temperature and surface finish, in complicated ways.
f) Some materials (e.g., some steel and titanium alloys) exhibit an *endurance* limit or fatigue limit, a limit below which repeated stress does not induce failure, theoretically, for an infinite number of cycles of load. Most other non-ferrous metals (e.g., aluminum and copper alloys) exhibit no such limit and even small stresses will eventually cause failure.
g) As a means to gauge fatigue characteristics of non-ferrous and other alloys that do not exhibit an endurance limit, a fatigue strength is frequently determined, and this is typically the stress level at which a component will survive 10^7 loading cycles.

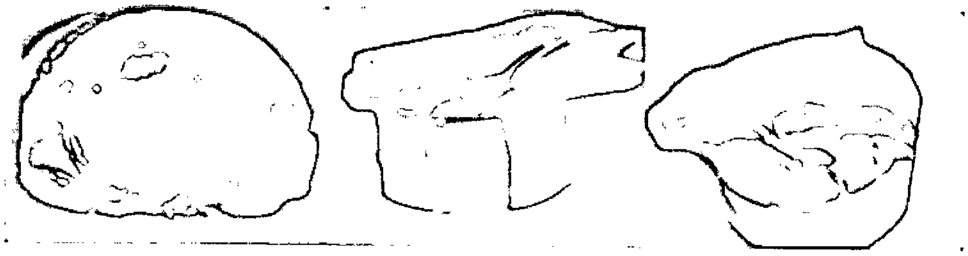

Figure 6: Sample of the fatigue failure

2.3.4 Creep

Creep is a major concern in engineering, since it can cause materials to fail well below their yield stress. According to A.Jacob creep is a slow process of plastic deformation that takes places when a material is subject to a constant of loading stress below its normal yield strength. [1] But according to www.answer.com Creep is the term used to describe the tendency of a material to move or to deform permanently to relieve stresses. [3]

Material deformation occurs as a result of long term exposure to levels of stress that are below the yield or ultimate strength of the material. Creep is more severe in materials that are subjected to heat for long periods and near melting point. The rate of this damage is a function of the material properties and the exposure time, exposure temperature and the applied load (stress). Depending on the magnitude of the applied stress and its duration, the deformation may become so large that a component can no longer perform its function - for example creep of a turbine blade will cause the blade to contact the casing, resulting in the failure of the blade. Creep is usually a concern to engineers and metallurgists when evaluating components that operate under high stresses and/or temperatures. Creep is not necessarily a failure mode, but is instead a damage mechanism. Moderate creep in concrete is sometimes welcomed because it relieves tensile stresses that may otherwise have led to cracking.