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Engineering of St 60 Steel for Industrial Use with Tensile Test at PTKI Material Lab

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ABSTRACT

Steel is an indispensable material in building an industry. In this research one of the engineered steels is St 60 steel; when it is not heated, the hardness is HRc 15.65 at a temperature of 800°C, 900°C, and 1000°C for 0.5 hours The steel is quenched with water (H_2O) as a cooling medium and, the hardness is 77.75 HRc, 94.00 HRc and 112.73 HRc. When salt water (NaCl) is used as a cooling medium, the hardness is 45.6 HRc, 65.00 HRc and 88.50 HRc; while the media is oil cooling, the hardness is 32.25 HRc, 49.50 HRc and 75.24 HRc. When tempered at a temperature of 300ºC, then dipped with H_2O the hardness is 68.36 HRc, 80.11 HRc and 98.75 HRc. When dipped in NaCL the hardness is 40.60 HRc, 55.50 HRc and 79.90 HRc. Being cooled in the oil the hardness is 29.73 HRc, 43.36 HRc and 67.18 HRc. When tempered at 300°C there is a decrease in hardness of 8% to 20% as well as being tempered at 400°C. All this results in hardness decrease. Cooling with water can reach the hardness of 61.40 HRc, 75.13 HRc and 87.40 HRc and being cooled in NaCl the hardness becomes 41.60 HRc, 50.39 HRc, 68.60 HRc and with oil is 32.27 HRc, 45.36 HRc and 58.93 HRc. There is a decrease in hardness of 18% to 25%. Being tempered at 500°C, the hardness decreases, being cooled with water the hardness becomes 59.36 HRc, 65.22 HRc, 72.57 HRc. Being tempered with salt water the hardness is 55.60 HRc, 59.20 HRc, 63.90 HRc and being cooled with oil the hardness is 36.60 HRc, 40.36 HRc, 52.18 HRc. In case of price before and after tempering, a decrease in hardness is about 24%-30%. Annealing at a temperature of 800°C the hardness is 15.65 HRc.

Keywords: Hardening, Normalizing, Tempering, Annealing, Hardness, Microstructure.

INTRODUCTION

The outstanding importance of steel in engineering is based on their ability to change mechanical properties over a wide range when subjected to controlled heat treatment.[1] In various manufacturing processes of steel components, heat treatment is the most sensitive and least controllable operation because it involves unexpected and uncontrollable distortion.[2] In the automotive industry as well as in factories, determining the right material is basically a compromise in various properties, the environment, the working process, how to use it and the extent to which the properties of the material can meet the specified requirements. There are several technical properties that must be considered when selecting the materials used, namely, mechanical properties (hardness, microstructure, treatment process, modulus of elasticity, creep limit, tensile strength, fatigue properties, ductility, impact, wear resistance and strength ratio (weight) as well as the properties of resistance to, bending, torsion and shear); properties during the forming process, machinability, weldability, hot and cold working characteristics and malleability; and properties to environmental influences, resistance to corrosion, heat, wear and weathering.

Material selection is ultimately determined by various things mentioned above, including the methods of manufacturing and formation. Therefore, it can be said that the selection of the right material is a continuous process and needs to be reviewed technically, economically and objectively. Iron or steel is very widely used in the field of engineering, or we could say that almost most technological developments are always dealing with iron or steel, both for transportation, building structures, agricultural equipment, machinery and so on, if iron or steel cannot be used for other purposes. Certain other materials can be selected, namely alloy steel that has been combined with other elements so that its properties are close to the required properties.

The general objective of this research is to analyze the heat treatment of St 60 and its specific objectives are to determine the properties of the carbon steel after heat treatment, after tempering, and after annealing, and after normalizing. The research benefit is help engineers in designing tools used in relation to heat treatment or heat transfer. The main problem is: what appropriate processing process is required in order to meet the aspects of the specifications? what certain specifications are required for a component of machines or a construction? and how to process metal without changing the chemical elements it contains?

LITERATURE REVIEW

Steel Heat Treatment

Sinha has ever argued that all binary Fe-C alloys containing less than about 2.11 wt% carbon are classified as steels and all those containing higher carbon content are termed cast iron. Steels are the most complex and widely used engineering materials because of (1) the abundance of iron in the Earth's crust, (2) the high melting temperature of iron (1534^oC), (3) a range of mechanical properties, such as moderate (200-300 MPa) yield strength with excellent ductility to in excess of 1400 MPa m^{-2}, (4) associated microstructures produced by solid-state phase transformations by varying the cooling rate from the austenitic condition.[3] Digges stated that heat treatment may be defined as an operation or combination of operations that involves the heating and cooling of a solid metal or alloy for the purpose of obtaining certain desirable conditions or properties.[4] Heat treatment of metals and alloys is one of the many wonderful processes discovered by man to mould materials to desired properties for making implements is his ascent to modern civilization. Heat treatment of steels alone covers a very wide range of processes.[5]

Heat treatment operations require a direct or an indirect supply of energy into the treated workpieces and its subsequent removal to affect the heating and the cooling, respectively, of these pieces.[6] He added that, in heat treatment operations, when heating or cooling the treated workpieces, non-stationary temperature fields develop in which the temperature distribution changes with time. Through the surface *F* of the plate of the thickness *s*, the heat flux Q is supplied (during heating) or extracted (during cooling).[6] There are four basic types of heat treatment of steels including annealing normalizing, hardening, and tempering.[4],[7] Heat treatment of components is to date mostly accomplished in gaseous atmospheres, the more so if plasma and vacuum are regarded as special cases of gaseous atmospheres. In comparison, heat treatment in solid or liquid media is negligible in numbers. Heat treatment in gaseous atmospheres falls into two categories: (1) process with the aim of avoiding a mass transfer between the gaseous atmosphere and the material, and (2) process with the aim of achieving just such a transfer.[8] Parts for heat treatment should have not only correct dimensions but also a consistent residual stress pattern. Ideally, the part should be absolutely stress-free so that movement due to stress-relief can be disregarded, but in practice some final machining passes are necessary before het treatment.[2]

Annealing

Annealing is a process involving heating and cooling, usually applied to produce softening. Annealing can be classified into full annealing, process annealing, and spheroidizing.[4] Annealing is carried out to improve machinability and cold formability, to restore ductility, to reduce or eliminate structural non-homogeneity, to refine the grain size, to relieve internal stresses and to prepare the structure of the steel for subsequent heat treatment [5]. Annealing has the following forms: (a) diffusion annealing, (b) softening, (c) phase-recrystallization annealing or full annealing (normalization, high-temperature or coarse-grain annealing, pearlitization), and (d) stress relief annealing and recrystallization annealing.[9] Stress-relief annealing is an annealing process below the transformation temperature A_{c1}, with subsequent slow cooling, the aim of which is to reduce the internal residual stresses in a workpiece without intentionally changing its structure and mechanical properties.[11] Residual stresses in a workpiece may be caused by: (1) thermal factors (e.g., thermal stresses caused by temperature gradients within the workpiece during heating or cooling), (2) mechanical factors (e.g., cold-working), and (3) metallurgical factors (e.g., transformation of the microstructure). [11]

Normalizing

Normalizing is a process in which a steel is heated to a temperature above the Ac_3 of the A_{cm} and then cooled in still air. [4] Normalizing is one of the most widely used heat treatment processes applied on almost all castings over-heated forgings, very large forgings, etc. Normalizing is done to refine the grain structure, improve machinability, relieve internal stresses, and to improve mechanical properties of structural carbon and low-alloy steels, etc. [5] With reference to normalizing. Normalizing or normalizing annealing is a heat treatment process consisting of austenitizing at temperatures of 30-80^{o}C above the A_{c3} transformation temperature (for hypoeutectoid steels) followed by slow cooling (usually in air), the aim of which is to obtain a fine-grained, uniformly distributed, ferrite-pearlite structure. [11] He added that normalizing is applied mainly to unalloyed and low alloy hypoeutectoid steels. For hypoeutectoid steels normalizing is performed only in special cases, and for these steels the austenitizing temperature is 30-80^{o}C (86-176^{o}F) above the A_{c1} transformation temperature.[11] Normalizing always involves transforming the steel to the austenitic condition by heating to about 50^{o}C (100^{o}F) above the A_{C3} temperature as defined in the iron-carbon phase diagram.[2] This treatment (normalizing) have three main purposes: (1) to control hardness for machinability purposes, (2) to control structure, and (3) to remove residual stresses on heating.[2]

Hardening

In case of hardening, steels can be hardened by the simple expedient of heating to above the Ac_3 transformation, holding long enough to ensure the attainment of uniform temperature and solution of carbon in the austenite, and then cooling rapidly (quenching). [4]. Hardenability refers to the property of steel which determines the depth of the hardened zone induced by quenching from the austenitizing temperature. Hardenability required for a particular part depends on many factors such as size, design, and survive conditions [5]. Hardening is a heat-treating operation necessary to impart hardness to any component. [5] The depth of the hardened zone is termed hardenability; hardenability of steel is also characterized by transformation time-temperature curves (IT curves.[9]

The ability of a steel to increase in hardness during quenching is called its hardenability or hardening capacity. Steel with 1.9% C quenched from a temperature higher than A_{st} has the same hardness as quenched steel with 0.1% C. [10] Hardenability, in general, is defined as the ability of a ferrous material to acquire hardness after austenitization and quenching. The ability to reach a certain hardness level is associated with the highest attainable hardness. As a consequence of the austenite-to-martensite transformation, the depth of hardening depends on the following factors: (1) shape and size of the cross section, (2) hardenability of the material, and (3) quenching conditions. [6] A steel has high yield strength but low ductility, and a small area below the stress-strain curve indicates low toughness.[11] Hardening, which is the first operation of the hardening and the tempering process, will yield a martensitic structure (provided a correct austenitization and quenching with a cooling rate greater than the critical rate for the steel in question have been realized), the hardness of which depends on the dissolved carbon content.[11]

Tempering

Tempering (sometimes called drawings) is the process of reheating hardened (martensitic) or normalized steels to some temperature below the lower critical (Ac_1).[4]. By tempering, ductility can be increased, and hardness and strength decreased. In the majority of structural steels, the purpose is to obtain a combination of high strength, ductility, and toughness. [5]. In case of tempering procedure, tempering furnaces should be equipped with automatic temperature control within ±5°C. [5]. There are four stages of tempering: (1) first stage tempering, in which in this first stage of tempering (100-200°C), ε-carbide forms from martensite; the composition of this carbide is close to $Fe_{2.4}C$, (2) second stage of tempering, in which, in the temperature range of 200-35°C, the retained austenite in the steel decomposes into ferrite and cementite, (3) third stage of tempering, in which, in the temperature range of 250-750°C, cementite precipitates within the martensite; the composition of the cementite is Fe_3C, and (4) fourth stage of tempering, in which tempering at higher temperature (>700°C) leads to the precipitation of more equilibrium alloy carbides such as M_7C_3 and $M_{23}C_6$. [12].

The main processes that take place during tempering are precipitation and recrystallization of martensite; quenched steel has a metastable structure. [9] The basic process that takes place during tempering is martensite precipitation. The first structural change during tempering is carbon segregation at dislocations. The second stage of tempering is precipitation of intermediate ε-carbides with a hexagonal lattice, which forms under heating above 100°C (212°F). During the third stage, cementite precipitates above ~250°C (~480°F). At the final stage of tempering above 350°C (660°F), cementite particles coagulate and spheroidize. [10]

Steel has higher yield strength than in its normalized condition but also much higher ductility than in its hardened condition.[11] He also added that tempering temperature and tempering time are consequently interchangeable with respect to resulting hardness; however, very short or very long tempering times do not yield optimum toughness. To obtain the optimum toughness for chromium steel, the tempering times should between 1 dan 5 h. Tempering of steel increases ductility and toughness of quench-hardened steel, relieves quench stresses, and ensures dimensional stability.[2] They added that the tempering process is divided into four stages: (1) tempering of martensite structure, (2) transformation of retained austenite to martensite, (3) tempering of the decomposition products of martensite, and (4) decomposition of retained austenite to martensite.[2]

MATERIALS AND METHODS

Place and Time

This research was conducted at the PTKI materials laboratory in Medan in March 2017. The tests carried out included hardening at temperatures of 800°C, 900°C and 1000°C, tempering 300°C, 400°C and 500°C, annealing and normalizing.

Materials and Equipment

The materials were St 60 carbon steel, salted water, pure water, and oil; while the equipments included furnace, dryer, tweezers, vernier calipers, polish, dryer machine, hardness tester machine, wiper, jar, tissue, grinding machine, and miser

Testing Methods

Testing methods covered the following: hardening, tempering, annealing, and normalizing. In hardening, the procedures were: St 60 carbon steel was turned into 18 specimens with a diameter of 14 mm and a height of 20 mm, cleaned the steel with fine sand paper until it was shiny and clean, tested the hardness of each specimen and recorded it, heated the specimen in a heating furnace at temperatures of 800°C, 900°C, and 1000°C and hold each for 0.5 hours, dipped the specimen into aqua water, salted water and oil, tested the hardness and record, and did microstructure test and took photos and printed them. During tempering, reheated the hardened specimen in the heating furnace of each specimen at a temperature of 300°C, 400°C and 500°C, cooled with water for hardness test and recorded them, did microstructure test and took photos and printed them.

The annealing included to reheat the specimen in the heating furnace at a temperature of 800°C, hold for 1 hour and cool for 20 hours in the heating furnace after turning it off or off, to take the specimen after cooling and clean the steel again from all impurities and measure its hardness and record it, and to do microstructure test and take photos and print them. Lastly, the normalizing was carried out by reheating the specimen in an 800°C heating furnace for 1 hour and cooling it with ambient air, by cleaning the heated steel again from all impurities and measuring its hardness and recording it, doing microstructural testing and taking photos and printing them.

Data Processing

After obtaining the hardness value of each specimen, it is then tabled, making it easier to record and analyze it. To complete it is done by using excel. Data processing with excel is easier to graph the relationship between heating temperature and hardness that occurs in each cooling process with water, salt water and oil media. This graph will be able to show the change in hardness, with a change in the position of the process points on the graph will show the occurrence of differences in hardness between materials with different treatment methods that have been given. The data provided will be given a conclusion which will be described later.

Conceptual Framework

This research is structured in a conceptual framework starting from the preparation of tools and materials to testing until the results and conclusions are obtained in the order: problem (changing the properties of steel without changing the chemical elements), preparations (create specimen with diameter 14 cm, height 20 mm, clean and measure hardness), hardening implementation (eat the specimens to temperatures of 800°C, 900°C and 1000°C, immerse them in water, salt water and oil, respectively), tampering execution (heat the specimen at temperatures, 300°C, 400°C and 500°C, cooled with water), annealing (heated the specimen at a temperature of 800°C, and cooled in a heating furnace), normalizing implementation (heat the specimen to 800°C, and cool it with ambient air), data collection (record the hardening, tempering, annealing, normalizing hardness numbers and take a micro photo of the specimen), data processing (the data is processed with excel into the form of temperature vs hardness curve), data analysis and conclusion.

RESULTA AND DISCUSSION

Steel with No Heat Treating

The material used is St 60 steel, the mechanical properties of the hardness are HRc 15.65. While the composition is 0.44%C, 0.30%Si, 0.70%Mn, the microstructure with the matrix is Ferrite with white color and Pearlite with black color stacked in the form of palms with microstructure photos as shown in Figure 1.

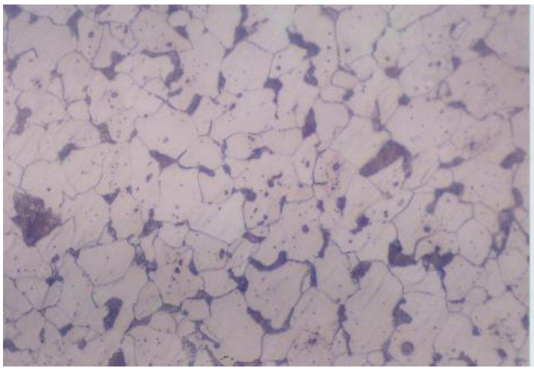

Figure 1. Microstructure of St 60 steel before heating

Heat Treating

After heating the St 60 steel at a temperature of 800°C, 900°C and 1000°C respectively, it was then immersed in the cooling media, respectively, water (H2O), salt water (NaCl) and oil. From the results of the heating, hardness testing was carried out, heated at 800°C, 900°C and 1000°C and immersed in water cooling medium (H2O) the hardness was 77.75 HRc, 94.00 HRc and 112.73 HRc, the hardness of the salt water (NaCl) cooling medium was respectively 45.6 HRc, 65.00 HRc and 88.50 HRc, while the hardness of the oil cooling medium was 32.25 HRc, 49.50 HRc and 75.24 HRc, respectively. After heating and dipping into the cooling medium, testing the microstructure using a microscope is carried out.

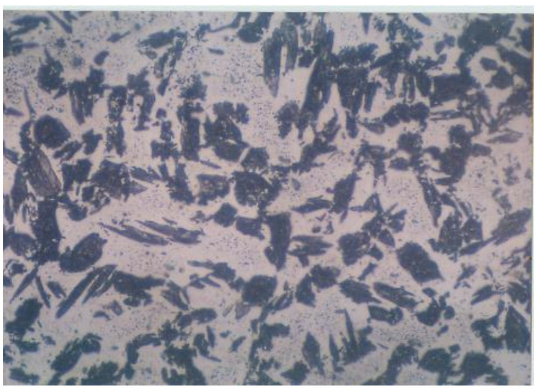

Figure 2. Microstructure of water-cooled steel (H2O)

From Figure 2, the relationship between the heat treatment and the cooling medium given to steel heated above the critical temperature, the matrix form that occurs is martensite (black) and alternating ferrite (white) hoses that are piled up like palms. Steel like this is very hard but brittle or brittle, and always has residual stresses when heating, so it is not good to use it directly. For this reason, it is necessary to eliminate residual stresses that occur with the tempering process, namely heating below the critical temperature, 300°C, 400°C and 500°C.

Tempering

a. Tempered at 300°C

Tempering is reheating steel that has been quenched, then reheating each at a temperature of 300°C and cooling with water, which aims to eliminate the residual stress that occurs in the steel after being immersed in water, salt water and oil cooling media. The relationship between steel heated at a temperature of 800°C, 900°C and 1000°C and tempered at a temperature of 300°C is clear, then re-dipped with water (H2O) the hardness is 68.36 HRc, 80.11 HRc and 98.75 HRc, respectively. Dipped in salt water (NaCL) the hardness was 40.60 HRc, 55.50 HRc and 79.90 HRc, respectively. Cooling with oil the hardness is 29.73 HRc, 43.36 HRc and 67.18 HRc, respectively. In this case tempering with 300°C from the overall tempering test there is a decrease in hardness of 8% to 20%.

b. Tempered at 400°C

Steel that has been heated at temperatures of 800°C, 900°C and 1000°C is immersed in water (H2O), salt water (NaCL) and oil cooling media, because it is very brittle and contains residual stresses, so in this research it was carried out to eliminate these residual stresses by tempering at 400°C. As a result, there is a decrease in hardness. Cooling with water has a hardness of 61.40 HRc, 75.13 HRc and 87.40 HRc, Cooling with salt water (NaCl) has a hardness of 41.60 HRc, 50.79 HRc, 68.80 HRc, cooling with oil the hardness is 32.27 HRc, 45.36 HRc and 58.93 HRc. It turns out that there is a decrease in hardness of 18% to 25%. There is a difference in the increase in the curve between cooling with oil, salt water and water, but when compared to without tempering there is a decrease in hardness as described above.

c. Tempered at 500^oC

In this research, tempering was also carried out at 500^oC, there was also a decrease in hardness, the relationship between hardness and heating of steel is then tempered at 500^oC. After tempering at 500^oC, the hardness decreases, cooling with water has a hardness of 59.36, 65.22 HRc, 72.57 HRc, hardness of salt water 55.60 HRc, 59.20 HRc, 63.90 HRc and cooling with hardness oil it becomes 36.60 HRc, 40.36 HRc, 52.18 HRc. When compared to the hardness value before tempering and after tempering, there is a decrease in hardness of 24% to 30%. Microstructure testing using a microscope is carried out, the microstructure image is as shown in Figure 3. The microstructure consists of cementite with alternating ferrites with an orientation to form a spherical structure.

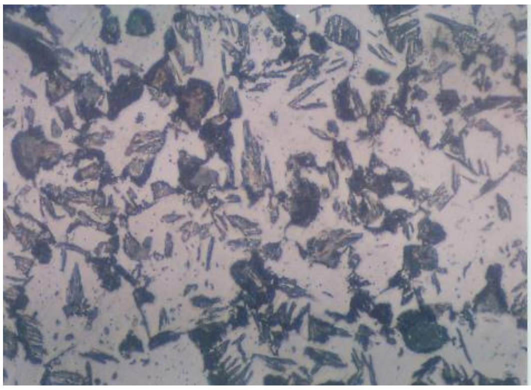

Figure 3. Tempered steel microstructure

Annealing

Annealing is the process of softening steel by heating it to a temperature above the critical temperature and then cooling it slowly enough in the heating furnace itself or in a place that has good heat insulation. Obtaining large fine crystal grains can improve machining properties. The size of the crystal grains is very fine, because the carbon can spread evenly into the metal, pearlite crystal grains are transformed into several fine and homogeneous ferrite and pearlite crystals. The hardness is close to the original hardness value of 15.65 HRc.

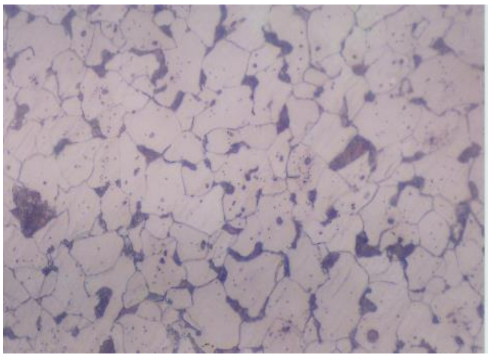

Figure 4. Steel annealing

Normalizing

Normalizing refers the process of heating steel at a temperature of 50^oC above the critical temperature and cooling is carried out with air because it is rather slow, and the opportunity for the formation of proeutectoid ferrite (in hypoeutectoid steel) or proeutectoid cementite (in hypereutectoid steel) will be more and pearlite become less. Ferrite (white) is more abundant than cementite (black). In other words, normalizing is to change the position of the eutectoid point to be more to the left in the hypoutectoid steel and more to the right in the hypereutectoid steel so, the eutectoid is no longer 0.8% C. The structure in the normalizing process is smoother and more homogeneous, thus providing a better response to the hardening process; its hardness is 14.9 HRc

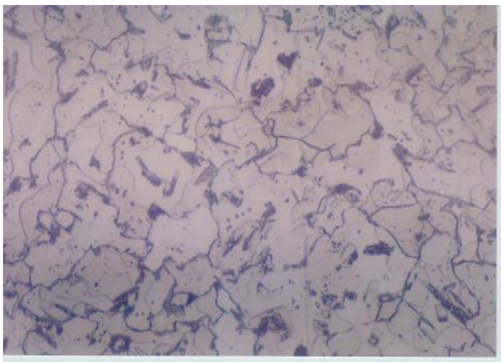

Figure 5. Steel normalizing

CONCLUSION

By analyzing after testing the hardness and observing the size of the metal crystal grains, the following conclusions are drawn:

1. After hardening treatment and cooling with water, salt water and oil cooling media, the highest hardness is when heating reaches temperature of 1000°C with water cooling medium (H2O) of 112.73 HRc, while with salt water at a temperature of 1000°C with hardness in 88.50 HRc; while with oil the hardness occurs at 1000°C heating with a hardness of 75.24 HRc. It turns out that the hardness increases because carbon build-up occurs on the outer shell of the metal, because it is retained during quenching, but becomes brittle.
2. After tempering the hardness decreases compared to hardening, because the heating occurs below the critical temperature, below 723°C, so that the carbon has no chance to get out of the metal into the metal shell at that tempering temperature, where martensite is a metastable structure in the form of a solid solution. supersaturated where the carbon trapped in the body center tetragonal structure will begin to emit carbon which precipitates as iron carbide, while the body center tetragonal will gradually become body center cubic structure, alpha iron, and ferrite. With the release of the carbon, the stress in the tetragonal body center structure will decrease while reducing the hardness as well.
3. By annealing or softening the metal crystal grains will become finer, the metal becomes softer, meaning that the metal carbon atoms are re-spread throughout the metal or starting from the metal shell to the metal core, making it easier for the machining process, the internal stress will be lost, more ferrite than cementite, the hardness is lower than heat treatment.

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