The Effects of Shielded Metal Arc Welding (Smaw) Welding On The Mechanical Characteristics With Heating Treatment in S45C Steel

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Abstract. Steel material has been used mainly for making tooling, automotive components, other household needs, power generators to frame buildings and bridges. This study aimed (1) to analyze the mechanical Characteristics of S45C steel with and without heating treatments, and (2) to analyze the temperature of heating treatment which could result in the maximal strength of S45C steel after the welding process. The research was conducted in the laboratory of mechanical engineering study program, Departement of mechanical Engineering, Christian university of indonesian paulus, makassar. The method used materials, instruments, and the dimensions determination of specimen based on the proposed testing standard, Next, was to determine the mechanical characteristics of the S45C steel which had been welded and heated. The tensile specimens, the hardness specimen, the impact specimen, and microstructures of which, each of the 3 specimens was the specimen without treatment, the specimen with the welding without heating, and the specimen of 150°C, 250°C, 300°C. The research results indicated that the treatment process of 150°C, 250°C and 300°C produced the changes of mechanical characteristics with the tensile strength of 42 kgf/mm² when the temperature had reached 300°C, but at the temperature 300°C, the its toughness would decrease to Hi = 0.836 J/m² and its hardness would increase to 40.83 at the temperature of 300°C. The value of the maximum strengs was reached at the heating temperature of 300°C for the tensile strength and the hardness, while at the temperature of 300°C its impact value would decrease.

Keywords: Steel S45C, SMAW, Heating treatment

1. Background
Steel material has been widely used for the manufacture of tools, automotive components, other household needs, generator power plants to the framework of buildings and bridges. In the application, the steel must have a strong structure, because all its structures will be affected by the frictional effect resulting in deformation or deformation. The effort to keep the metal more friction resistant is to do
the heat, it plays an important role in efforts to increase steel hardness as needed. In addition, the selection of material types also needs to be considered in accordance with its function [1].

Hardening is a working heat process that is applied to produce hard workpieces. This treatment consists of heating the steel to its hardening temperature (austenitization temperature) and holding it at that temperature (holding time) for a certain period of time and then cooled to a very high quench rate to obtain the desired [2].

The process is hot up to temperature and temperatures. The heating is carried out at the required temperature, usually between 200°-600°C depending on the need. The higher the heating temperature, the greater the decrease in the hardness of the elasticity increases. Hardened steel due to its heat and less suitable to be used with heat treatment, hardness and brittleness can be lowered to meet the use of the condition, which is being heated or hardened at temperatures below the critical temperature by cooling. This process is similar to an annealing process because here its properties can be carefully controlled, since there is no stability [3].

The electrode consists of two types of coated (flux) and non-coated parts which are the base for clamping the welding pliers. The function of the flux or electrode layer in the weld is to protect the liquid metal from the air environment to produce protective gas, stabilize the arc, the source of the alloying element. In welded steel wire, electrode wire is divided into electrodes for soft steel, high carbon steel, alloy steel, cast iron, and non-ferrous metals. The electrode material must have the same metallic properties [9].

Arifin [4] describes welding using electric arc welding requires a welding wire (electrode) consisting of coated metal lining of a chemical mixture. The function of the electrode as a generator and as an added material. Electric arc welding is the process of grafting metal by utilizing electric power as a heat source. Las arc welding is one type of electric weld where the heat source or the material pipe that is connected or welded comes from the electric arc.

Sonawan [7], explaining in the field of welding required an ideal relationship of open V connections and closed camp V connections. Connection V open to connect plate with thickness 6-15 mm with the angle between 60°-80°, root distance 2 mm, root height 1-2 mm.

Suharno [8], explaining about SMAW welding is a heat shielded arc welding generated from an electric arc between the end of the electrode and the metal to be welded. And another researcher [5] proposed a process of thermal cooling of mechanical properties and microstructure that is increased hardness, tensile strength and microstructure differences compared to non-heat treatments specimens and tempered specimens, the influence of oil quenching the formation of martensite and bainite structures so that the specimen becomes hard.

The S45C steel is of medium carbon steel, medium carbon steels containing carbon (C) between 0.3% to 0.6% and their carbon content allow the steel to be hardened by a suitable heating treatment [5].

Based on the above background, the important problem to be studied is how the difference of mechanical properties of Steel S45C with heating treatment and without heating effect and on mechanical condition of Steel S45C after welding. The purpose of this study was to analyze the mechanical properties of S45C Steel with heating and non-heating treatment and to analyze the temperature that can provide maximum power in S45C Steel after welding.

2. Materials and Methods
This research was conducted for six months at the Mechanical Technology Laboratory of Mechanical Engineering Program of the Christian University of Indonesia Paul Makassar. The equipment used in the research is Tensile Test Machine, Hardness Testing Equipment, Impact Test Equipment, Microscope, Polish Machine, Digital Camera. The materials used in this research are Steel S45C, Sulfuric Acid (H2SO4), Sandpaper.
The method used in this study was conducted using materials, tools, and the determination of the specimen dimensions based on the recommended testing standard then to determine the mechanical properties of S45C steel that have been welded and subjected to heating treatment. Preparation of specimens consisting of tensile specimens, hardness specimens, impact test specimens and microstructures in which each of the three specimens was based on unheated specimens, specimens with non-heating welding and specimens with welding with heating 150º, 250º, and 300º celsius.

Statistical analysis was performed using ANOVA variance analysis on tensile and hardness test data. Varian Analysis (Analysis of variance, Anova) is a technique used to compare two or more population parameters, this technique is often used for research, especially in experimental research design [10].

3. Results

Calculation of Pull Test

Based on the tensile test on one of the normal specimens or without the welding process and the heating process, it is known that the material strength is based on the following data: Dimension of the specimen (Based on ASTM E8 test standard) is Length (Lo): 50 mm, 144 mm². Data on tensile test results (Based on the maximum conditions) are yielding (Py) Expenses: 4952 kg, Added length in Pmax (ΔLmax): 20.8 mm. From the available equations, we can determine some components as information based on tensile test results as follows: Maximum Stress (σmax): 56.16 kgf / mm², Strain (εmax): 0.4%, and Material elasticity (Emax): 136.97 kgf / mm². Based on the results of calculations that have been done known that the material on the heating process the higher the heating process (0ºC-300ºC) the average tensile load until the maximum conditions increased. While the result between heating temperature to a tensile strength of material known as in Figure 1.

![Figure 1](image)

**Figure 1.** Graph of the relationship between heating temperature to strength Drag the material.

Calculation of impact test

From the calculation result, it is known that every increase of heat treatment temperature resulted in decreasing effort to break the specimen, as shown in Figure 2 graph. With the constant cross section for each test specimen, the decreasing of material price decreases as shown in Figure 3. The decline in the value of the effort to break the specimen and its impacted price is due to an increase
in the brittle or brittle properties of the material. The condition can also be known by the easier the pendulum as a pounder load to break the specimen as shown in the graph of figure 4.

![Figure 2](image2.png)

**Figure 2.** The relationship between the heating temperature of the business To break the specimen.

![Figure 3](image3.png)

**Figure 3.** The relationship between the temperature of the heat treatment to Material impact value.

![Figure 4](image4.png)

**Figure 4.** The Relationship of warming temperature relation to height of pendulum After breaking the specimen.
Calculation of hardness test

From the hardness test data, it is known that with the temperature change of heating, resulting in the change of hardness value of the material, the higher the given temperature, the higher the hardness value of the material. From a number of points of emphasis on the parent metal also experienced an increase in hardness but not significant where the minimum hardness value in the specimen without heating treatment can be seen in Table 1.

Table 1. Test result data and impact test calculation

| No | Material                  | Specimen Specification | Angle | h | h | h | U | Hi |
|----|---------------------------|------------------------|-------|---|---|---|---|----|
| 1  | Raw Material              | 10 10 2 80             | 67    | 0.531 | 0.898 | 92.529 | 1.157 |
| 2  | without heating treatment | 10 10 2 80             | 67    | 0.531 | 0.898 | 92.529 | 1.157 |
| 3  | Raw Material              | 10 10 2 80             | 67    | 0.531 | 0.898 | 92.529 | 1.157 |
| 4  | Heat Treatment 150°C       | 10 10 2 20             | 68    | 0.545 | 0.884 | 91.096 | 1.139 |
| 5  | Heat Treatment 250°C       | 10 10 2 20             | 71    | 0.587 | 0.842 | 86.704 | 1.009 |
| 6  | Heat Treatment 300°C       | 10 10 2 20             | 66    | 0.517 | 0.912 | 93.863 | 1.009 |
| 7  | Average                   |                        | 66.33 | 0.580 | 0.846 | 87.451 | 1.093 |
| 8  | Average                   |                        | 68.33 | 0.550 | 0.879 | 90.588 | 1.052 |
| 9  | Average                   |                        | 72.667| 0.612 | 0.817 | 84.165 | 1.052 |
| 10 | Average                   |                        | 79.00 | 0.705 | 0.724 | 74.607 | 0.933 |
| 11 | Average                   |                        | 84.00 | 0.780 | 0.649 | 66.87  | 0.836 |

Observation of Micro Structures

Microstructure testing was performed to determine the difference of metal structure in the specimen without heating treatment and a specimen of heating process 150°C, 250°C, and 300°C Celsius. The microstructure was observed in the order of sand, polishing, etching with 5% H2SO4 solution for 3 sec, then examining micro structure with optical microscope Nikon Japan type 251565 and equipped with webcam camera with 50 to 500 times magnification.

Statistical Analysis

Statistical analysis was performed using annova variance analysis on tensile test and hardness test data. Based on the data of tensile test results known F smaller than the F crit (F < F crit) with 8.2699 difference. The analysis of hardness test is known to be smaller than F crit (F < F crit) by the difference of 8.235453 while the F test toughness is smaller than F crit (F < F crit) by the difference of 8.2699.
4. Discussion
This study shows that the effect of SMAW (Shielded Metal Arc Welding) welding effect on mechanical properties with heating treatment on S45C steel. The higher the heating temperature increases the strength of the material. The tensile test calculation is known that in the heating material in the heat treatment process the higher the heating temperature (0°C - 300°C) the average tensile load until the maximum condition increases, on the welding material without heating process Pmax = 3661.3 kgf. The temperature of 150°C average maximum tensile load of Pmax = 4777.0 kgf, subsequently increased and at a temperature of 300°C the tensile load was at 6051.2 kgf. The condition also affects the tensile strength properties of material expressed by the maximum voltage, in the graph of figure 4.2. Based on the graph it is known at the temperature 0°C σmax = 25.4kgf mm², at 150°C σmax = 32.3 kgf / mm², 250°C σmax = 40.1 kgf / mm² and at 300°C σmax = 42.0kgf / mm².

Impact Testing With a constant cross-sectional area for each test specimen, with the decreasing of the effort, the material impact price decreases. Due to the increase in heating temperature, there is a decrease of material impact price (Hi), on a unobserved specimen, Hi = 1,132 J / m², and so on decreased to heating temperature 300°C Hi = 0,836 J / m². The impact price is due to increased brittle or brittle properties. The condition can also be known by the easier pendulum as a pounder load to break the specimen. The average of these changes is seen in the increasing angular degree of the impact test arm after breaking the specimen (β). Where on the specimen without heat treatment process h2 = 0,550 m and increased up to 300°C heating temperature with h2 = 0,780 m.

Violence testing from a number of pressure points, on the parent metal also experienced an increase in hardness but not significant where the minimum hardness value in the specimen without heating treatment was 35.01 and the highest at 300°C heating temperature of 35.52. In the weld metal part (Filler) also experienced an increase in hardness due to changes in warming temperature. In the material without heating treatment process, it is known that maximum hardness value is 37.25, at temperature 150°C = 38,80, at temperature 250°C = 40,49 and at temperature 300°C = 40,83. The increase shows the ductile value of the material decreases and the hard properties increases.

Observation of microstructure based on microstructure photograph is known to start the process without heating treatment and process heating treatment 150°C, 250°C and 300°C in microstructure there is a change of structure where the main composition of a micro structure consisting of ferrite, martensite and pearlite change either a percentage of amount or distribution. The change in the microstructure resulted in a change of strength of both tensile, impact and hardness. In specimens without heating treatment, the percentage of ferrite composition is more dominant than that of heat treatment up to 300°C. This condition results in a material decrease in hardness and toughness (impact) and increased tensile strength at each heating temperature increase.

5. Testing And Advice
From the result of research and data analysis, it can be concluded that the heating process of 150°C, 250°C and 300°C resulted in the change of mechanical properties where tensile strength will continue to increase until 300°C at 42 kgf / mm², while at temperature 300°C its toughness will decrease with Hi = 0,836 J / M2 and its hardness increased to 300°C = 40.83. The value of its strength at a heating temperature of 3000C for its attraction and its hardness at 300°Ct temperatures has a declining effect. Very highly recommended for a heating process with higher temperature.

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