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# Analysis of GMAW Welding Connections on A36 Material with a Heat Treatment and Rapid Cooling Process

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***Abstract-*** *Fires are caused by a variety of causes. Fires in steel construction, especially in welding joints, can damage the material, alter its crystal structure, and alter its mechanical properties. Due to the extinguishing process, the material undergoes rapid cooling as well. The purpose of this study is to analyze the characteristics of the mechanical properties of ASTM A36 steel with rapid cooling after heat treatment. GMAW welding was conducted on A36 steel material at 400 °C to 700 °C, followed by rapid cooling with water. Study results include crystal structure, hardness level, and ultimate tensile strength of the material. As observed from the crystal structure, ferrite changed into coarse ferrite, fine ferrite, and a mix of martensite bainite. In the weld zone, the highest hardness value is 169.3 HV at the coupon temperature of 550 to 700 °C; 166.3 HV on the comparison coupon; and 141.3 HV at a coupon temperature of 400 to 550 °C. The ultimate tensile strength coupon value of 550 °C to 700 °C is 622.5 N/mm2, the comparison coupon value is 669 N/mm2, and the 400°C to 550 °C coupon value is 588 N/mm2 for metal welds. The material is ductile.*

***Keywords-*** *GMAW, Hardness Test, ASTM A36 Material, Micro Test, Tensile Test.*

## I. Introduction

Fires often occur with a variety of causes in forests, buildings, transportation, and industry. The fire resulted in increasing heat, especially the welding connection area and rapid cooling of the extinguishing efforts. A welded joint is a combination of two or more metals by means of partially melting the parent metal and with or without a filler metal that utilizes thermal energy [1]. Fires result in changes in the quality of mechanical properties in the form of microstructure, hardness level, and tensile strength of materials after experiencing fire and cooling [2]. The effect of *PWHT* carbon steel ST 42 with *SMAW* welding obtained the result of the material experiencing a decrease in tensile strength and hardness when the microstructure is getting rougher and vice versa [3]. The welded connection of SA 387 *Grade* 11 *Class* 1 material due to *PWHT* obtained results the higher the temperature and *holding time* , the lower the level of hardness of the material [4]. Combustion above austenite temperature against SA 36 material by *SMAW* welding method where the higher the combustion temperature, the lower the tensile strength and hardness [5]. Post-burning material has tensile stress and melt increases with combustion temperature, while strain value tends to decrease [2].

Based on the literature review, several studies have examined the effect of metal combustion with temperature variations with *the SMAW* welding method but lacked research with *the GMAW* welding method. The use of *GMAW* (*Gas Metal Arc Welding*) welding because it is widely used in the industrial world [6]. Heat treatment using *a furnace*, no combustion process was found with direct exposure to fire with *blanders*. This study will be conducted experiments related to the characteristics of the *GMAW* welding joint that burns with a temperature of 400 °C to 700 °C with rapid cooling in *ASTM* A36 material. The purpose of the study was to analyze the characteristics of mechanical properties based on *micro tests, hardness vickers tests,* and *tensile tests.*

## II. Material and Method

The research method uses experimental methods, the welding process is carried out at the PT INKA workshop. The test was carried out in the laboratory of the Madiun State Polytechnic and Brawijaya University to obtain data on the effect of heat treatment with rapid cooling. Heat treatment refers to ISO 834 standard temperature variations ranging from 200 °C to 1000 °C [2]. Variable studies with heat treatment at temperatures of 400 °C to 550 °C and temperatures of 400 °C to 550 °C.

### *A. ASTM A36 Steel*

ASTM A36 Steel is a low carbon steel that has the property of being able to weld well, used in various fields such as industry, automotive, design and transportation [7]. *ASTM* A36 steel has various elements can be seen in table 1 [8].

TABLE 1. Elements of ASTM A36 Steel

| Elements | Percentage Rate (%) |
|---|---|
| Carbon (C) | 0,14 |
| Silicone (Si) | 0,244 |
| Manganese (Mn) | 0,64 |
| Phosphorus (P) | 0,012 |
| Sulfur (S) | 0,0066 |
| Copper (Cu) | 0,01 |

### *B. Coupon Preparation*

Cutting *coupons* using *CNC plasma cutting* as per Figure Fig. 1 with the addition of 3 mm dimensions to avoid the effect of cutting heat.



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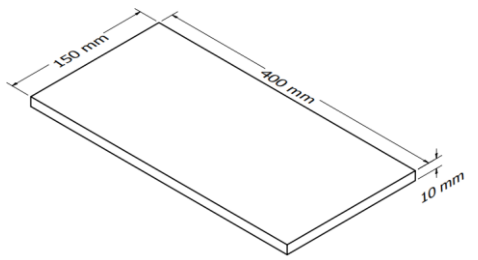


Fig. 1. Dimensi Coupon

The *bevel* angle is 30 and °*the root face is* 1 mm as per Figure **Error! Reference source not found.**.

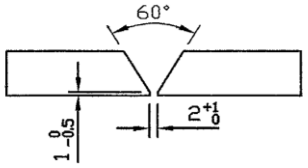


Fig. 2. Bevel Coupon

## C. Welding

Pengelasan using *GMAW* is carried out by a certified *welder* at PT INKA (Persero). The type of connection is the V *groove butt joint*, 1G position with a root gap of 2 to 3 mm and with other welding parameters adjusted to the Welding Procedure Specification (WPS) such as table 2 parameters.

TABLE 2. Welding Parameters

| Parameter | Description |
|---|---|
| Gas | Argon Balance (Ar 82 % + CO2 18 %) |
| Voltage | (Root = 21 until 23 V) dan (Filler/Cap = 26 until 28 V) |
| Current | (Root = 120 until 140 A) dan (Filler/Cap = 235 until 255 A) |
| Wire | ER70S-6 (1.2 mm) |
| Gas Flow | 17 liter/minute |

## D. Heat Treatment

The heating of the coupon aims to simulate the occurrence of a fire. The heat treatment rate is 400 °C to 550 °C and 550 °C to 700 °C. Heating carried out in the weld zone area using a drilling machine with LPG (liquefied petroleum gas)[9], holding time 13 until 15 minute [10]. After reaching the desired time and temperature, cooling with running water is carried out until the coupon temperature is less than 100 °C [10]. **Error! Reference source not found.** is the measurement point of heat treatment temperature.

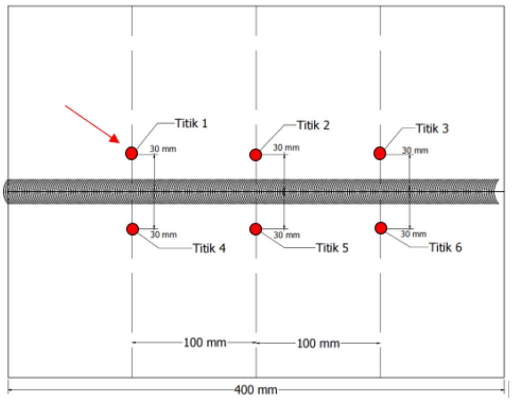


Fig. 3. Heat Treatment Measurement Point

## E. Micro Test

Micro test using machine *Polisher Shapir 330* for the creation of testing coupons and *Mikroskop Olympus DP 22* to make observations on the test coupon with reference to the ASTM E407 standard [11]. The dimensions of the micro test coupon are according to Figure Fig. 4.

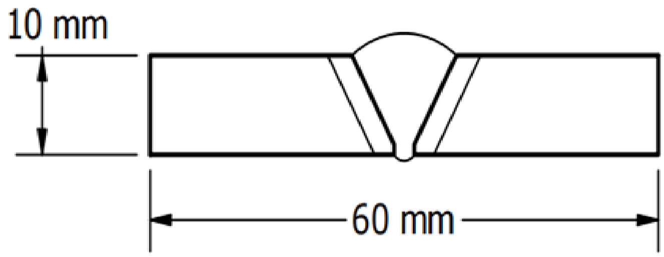


Fig. 4. Micro Test Coupon

## F. Hardness Vickers Test

Hardness testing by the hardness vickers method refers to the ASTM E92 standard [12]. The machine used is the *Mitutoyo Hardness Tester*. The coupon dimensions of the vickers test hardness correspond to Figure Fig. 5.

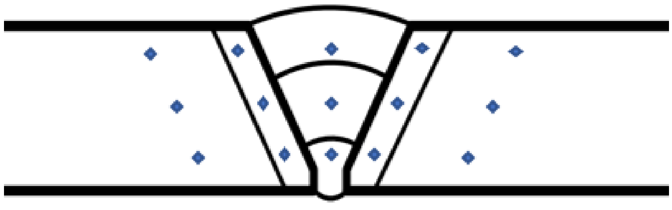

Fig. 5. Hardness Vickers Test Identation Point

## G. Tensile Test

Tensile testing to determine the strength of the melt, elastic area, plasticity, and properties of the material. Tensile test standard refers to ASTM E8 [13]. The dimensions of the coupon tensile test correspond to Figure Fig. 6.

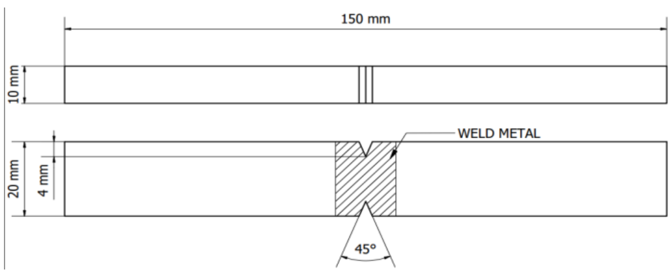


Fig. 6. Tensile Test Coupon

# III. Results and Discussion

## A. Micro Test Result

The results of the micro test can be seen on the Figure Fig. 7 to Figure Fig. 12. Here are the observed structures.

P = Perlite
F = Ferrite
S = Spheroid
MB = Martensite bainite
BT = Transition limits
BG = Gain boundary



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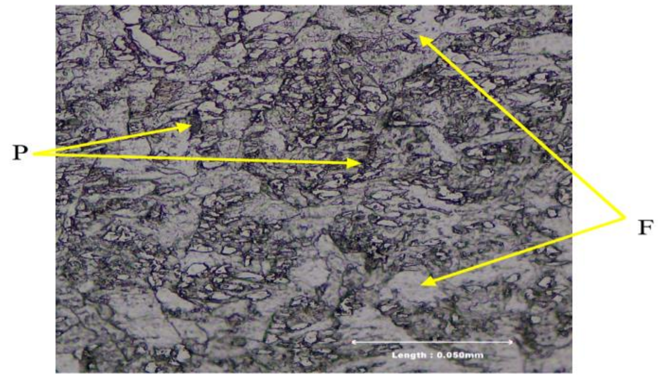


Fig. 7. Base Metal Coupon Comparator

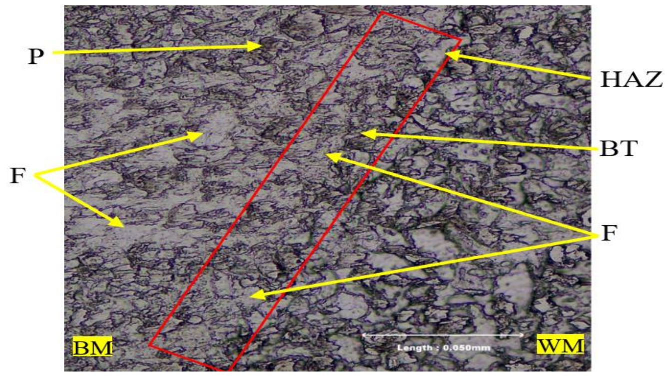


Fig. 8. HAZ Coupon Comparator

The result of the microstructure *of the metal coupon weld* without heat treatment is perlite and ferrite based on Fig. 8 due to welding. Perlite is blackish and ferrite is white [10]. Ferit bersifat lunak memiliki tingkat kekerasan antara 140 hingga 180 HV [10]. The structure of the HAZ fits the box of red color. The boundary between the metal weld and HAZ is predominantly black color perlite phase. The HAZ phase is dominated by ferrite structures. In base metal, it can be seen that the difference in the black structure of perlite and ferrite is getting tighter, indicating that the base metal area has a hardness level below *HAZ* [10].

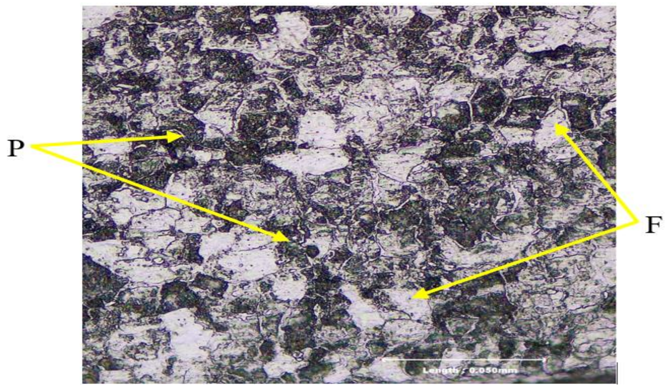


Fig. 9. Base Metal Coupon 400°C to 550°C

The metal weld phase is dominated by black and white colors with grain boundary borders that are clearly different from the results without heat treatment. The ferrite phase is formed more coarsely. The rougher the ferrite phase, the hardness level decreases [3]. The HAZ on Fig. 10 is quite clearly visible the boundary between the blacker weld metal while the base metal has a blackish and white arrangement with a clear grain boundary. The phase on the predominantly white HAZ has a smoother structure than the base metal. In the red box, HAZ looks to have a larger structure than base metal. The structure of the base metal is rougher than the HAZ so that the hardness level of the base metal is below the HAZ [10].

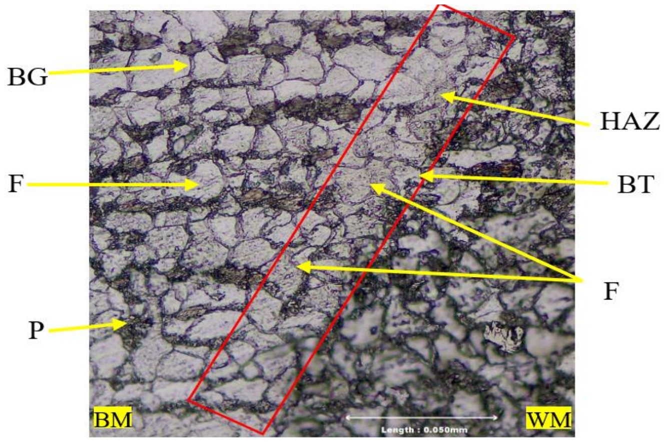


Fig. 10. HAZ Coupon 400 °C to 550 °C

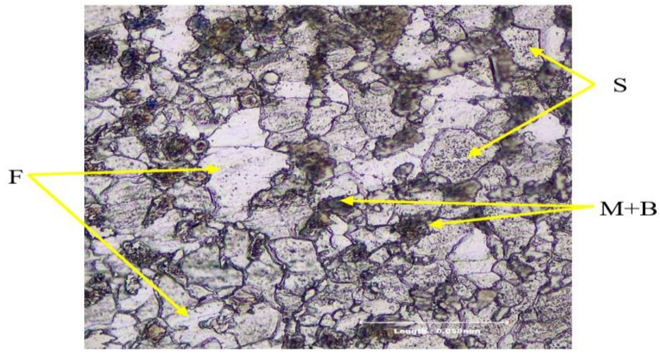


Fig. 11. Base Metal Coupon 550 °C to 700 °C

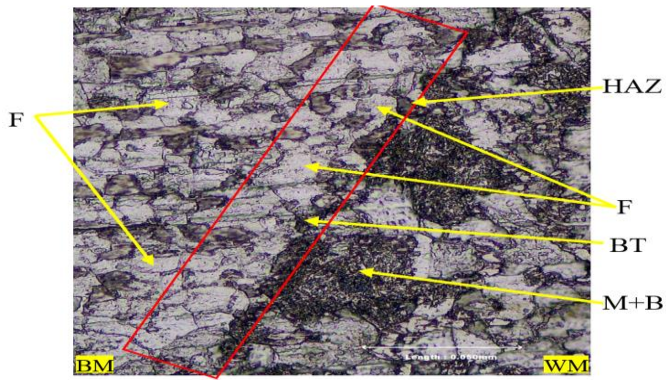


Fig. 12. HAZ Coupon 550 °C to 700 °C

Heat treatment metal welds of 550 to 700 °C are predominantly gray and blackish in color. The perlite structure is clearly visible consisting of cementite and layered flattened ferrite. Perlite has a hardness level ± 180 to 250 HV [10]. The structure of ferrite formed because of heat treatment undergoes a change to fine ferrite with a wide shape. Based on the CCT diagram , the results of heat treatment of 550 to 700 °C with a holding time of 840 s and cooling for 100 s to a temperature of < 100 °C resulted in the formation of a ferrite structure into a mixture of martensite bainite [8]. Spheroid is a light-colored round-shaped cementite structure formed from heat treatment below the A1 point of the eutectoid [14]. Phase changes result in an increased level of hardness of metal welds with heat treatment of 550 to 700 °C. HAZ in the red part of the structure observed ferrite is white [10]. The structure of the base metal is tighter in contrast to the finer HAZ area, resulting in a higher level of hardness of the HAZ than the base metal. It can be seen that the BT (HAZ transition boundary with metal weld) is black with the shape of a short needle that is not aligned, which is a mixed structure of bainite and martensite. Horizontal longitudinal arrangement shows the base metal area with the formation of material by rolling process[10].

*B. Hardness Vickers Test Result*

The hardness test of vickers is carried out at 15 points to determine the level of hardness on each welding layer. Each layer consists of 5 test points of 2 points on the base metal, 2 points on the HAZ part, and one point on the weld zone.

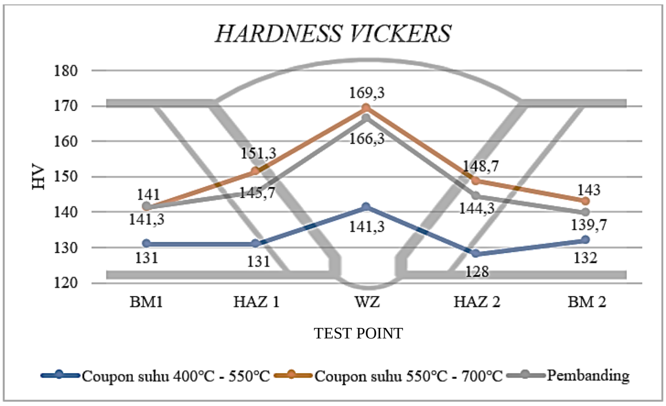


Fig. 13. Comparison Graph of Heat Treatment Hardness to Test Point

The testing of coupon hardness temperatures of 400 to 550 °C of hardness in all three regions decreased compared to coupons without heat treatment. Based on the phase structure in Fig. 10, there is a change in the structure from ferrite to coarse ferrite resulting in a decrease in the level of hardness of the material. When the microstructure gets rougher, the level of hardness of the material will decrease because the large grain size results in the density of dislocation density [15]. Coupon testing temperatures of 550 to 700 °C an average hardness value resembling coupon results without heat treatment. The highest value in the weld zone is above the coupon hardness value without heat treatment, because the microstructure is getting smoother, the hardness level of the material will increase because the small grain size results in a higher dislocation density [15]. The phenomenon from the test resultsFig. 13 resembles a triangle, the hardness value is higher than the base metal, HAZ, and weld zone and returns to the base metal. There is a deviation in the value at the HAZ point 2 with a temperature of 400 to 550 °C because the heat treatment applied unevenly results in different phases resulting in a decreased level of hardness [10].

*C. Tensile Test Result*

The results of the coupon fault tensile test are on the metal weld according to Fig. 14. Because the shape of the tensile test coupon uses V notch to find out the maximum strength in the weld zone.

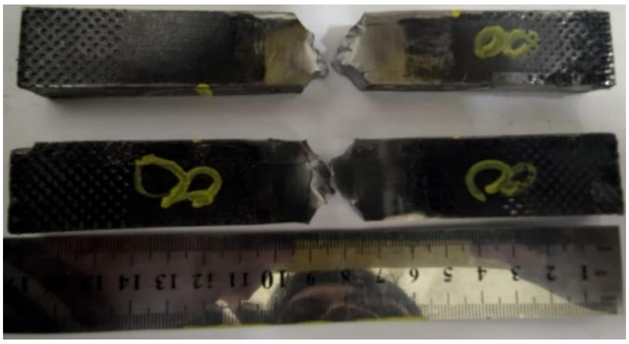

Fig. 14. Tensile Test Result

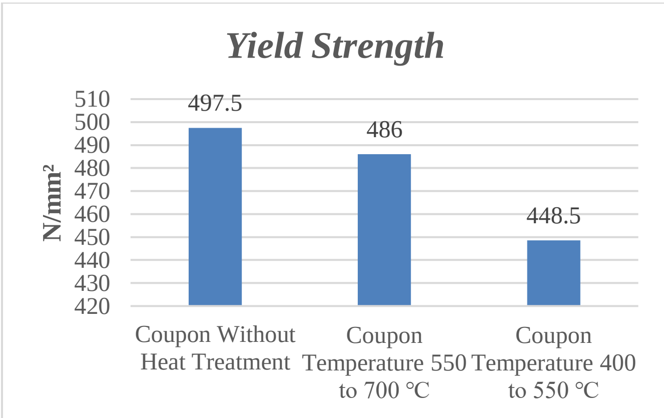


Fig. 15. Graph of Comparison of Yield Strength Values Against Heat Treatment

Yield strength is the limit of the point of elasticity of the material. The material will experience a permanent increase in length after exceeding the yield strength limit [16]. The yield strength chart shows the phenomenon of heat treatment coupons decreasing below the yield strength value of coupons without heat treatment which is 497.5 N/mm$^2$. Heat treatment materials of 400 to 550 °C undergo a phase change of ferrite to coarse ferrite resulting in a decreased level of elasticity. The material quickly undergoes a length increase and necking until it breaks. The yield strength value affects the elongation and ultimate yield strength results [10].

An elongation graph is an increase in the length of the material until it breaks. The elongation of the third coupon variable under the elongation value of the ASTM A36 data sheet is 23 %. The highest decrease in heat treatment coupon temperature is 400 to 550 °C. Material length gain is influenced by yield strength, the smaller the yield strength value of small material length gain because the material is necking and fracture faster [2]. Elongation coupon temperatures of 400 to 550 °C decrease as the yield strength value drops according to



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Fig. 15. The value of elongation affects the outcome of ultimate tensile strength [3].

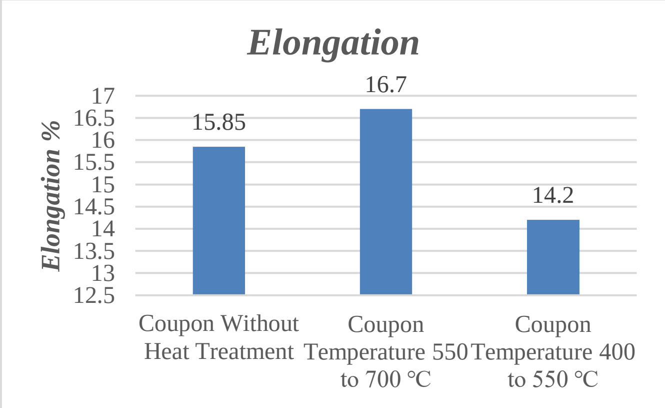


Fig. 16. Comparative Graph of Elongation Values Against Heat Treatment

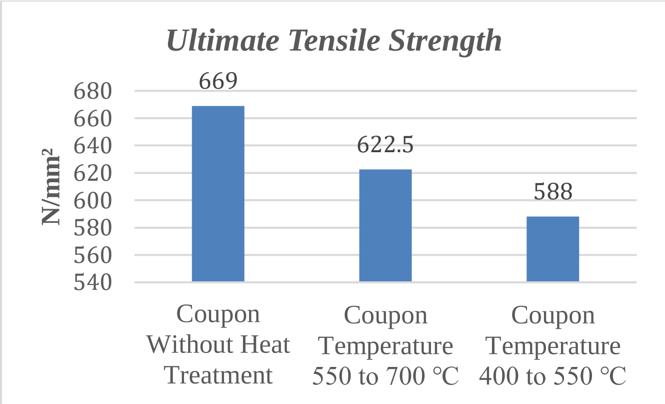


Fig. 17. Graph Comparison of The Ultimate Values of Tensile Strength Against Heat Treatment

The ultimate tensile strength (UTS) graph shows different values on each variable. The UTS value of the three variables is above the UTS value of the ASTM A36 material, which is 449 N/mm$^2$. UTS on the smallest 400 to 550 °C heat treatment coupon, the value is linear with yield strength and Fig elongation valuesFig. 15 Figure 16 and Figure 17 The lowest heat treatment coupon hardness value of 400 to 550 °C, the value is linear with the ultimate tensile strength value.

### *D. Discussion*

The heat treatment coupon of 400 to 550°C of ferrite microstructures transform into coarse ferrite. Rough microstructure then the level of hardness of the material decreases because the large grain size results in the density of dislocation of the stretch [15]. The hardness value decreases below the coupon without heat treatment. When the size of the structure is rough, the tensile strength decreases because it cannot maintain the movement of the dislocation due to the narrower grain boundary area [17]. Heat treatment coupons of 550 to 700°C ferrite microstructure transforms into harder fine ferrite [3]. A mixed structure of martensitic bainite and spheroid *is* formed. The finer the microstructure, the more the hardness of the material will increase because the small grain size results in a higher dislocation density [15]. The yield strength value is higher than the heat treatment coupon of 400 to 550 °C**.** When the size of the structure is smooth, the tensile strength will be greater because it can maintain dislocation movement better because the grain boundary area is wider [17]. The ultimate tensile strength value of the three variables above the material value of ASTM A36, the coupon experienced a decrease in strength after undergoing heat treatment. Elongation value above 5 % of the material is still ductile after welding and heat treatment [18].

## IV. Conclusion

Based on the research that has been carried out and the description of the discussion, it can be concluded that the heat treatment coupon of 550 to 700 °C has an increase in the hardness value and a decrease in tensile strength [14]. Inversely proportional to heat treatment coupons temperatures of 400 to 550 °C which experienced a decrease in hardness and tensile strength compared to coupons without heat treatment [4]. Changes are caused by chemical composition, heat treatment, and cooling rate so that microstructure changes occur and have an impact on the mechanical properties of the material [10].

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