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The Effect of Heat Input on Welding Combination of GTAW and SMAW SA537 Material on Mechanical Properties and Microstructure

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Abstract

The combination of GTAW (Gas Tungsten Arc Welding) and SMAW (Shield Metal Arc Welding) processes on SA537 Class 2 carbon steel using variations of heat input is the main choice to get the best quality welded joints. This research aims to joint SA537 Class 2 material using the GTAW and SMAW process with heat input variations to get the best joint and determine the joint results mechanical properties and microstructure analysis. The experimental method uses a combination of GTAW and SMAW processes with a single V butt joint design, groove angle of 60o, root face 2 mm and root gap of 4 mm as many as 7 passes, and variations in heat input of 2.5 kJ/mm, 2.8 kJ/mm and 3.2 kJ/mm. According to ASME section IX, the mechanical testing results showed that the specimen with a heat input of 2.8 kJ/mm gave optimum results with the highest tensile strength of 480 MPa compared to the other two specimens, and there were no cracks when tested for bending The higher the heat input, the greater the decrease in the percentage of ferrite. Using a heat input of 2.8 kJ/mm in this study provides a weld result with better mechanical properties and microstructure than the use of heat input of 2.5 kJ/mm and 3.2 kJ/mm.

1. Introduction

The technology of metalworking has long been known in human civilization. All of this shows how important metals are in human life from ancient times to modern times like today. Humans continue to develop metal processing technology over time, including the metal joining technologies such as welding [1]. Various welding processes are available in the field, so welding is widely used in fabrication and manufacturing to joint materials in various compositions, shapes, and sizes. These days, welding is used in the production of most of the steel structures in the engineering industry and is one of the most significant processes used in some industries, including an oil refinery, automotive, shipping, aircraft, train, bridge construction, pressure vessels, oil and gas pipelines, manufacturing and nuclear. New installation, improvements, adding, and joining structures use welding processes. Welding is an efficient, reliable, and economical process that offers various advantages such as simple setup, low production costs, and high efficiency of welded joints [2,3,4,5,6,7,8].

Welding is joining materials in the weld zone using heat and/or force, with or without filler metal [9]. Some of the most commonly used welding techniques are the SMAW and GTAW processes. Shielded Metal Arc Welding (SMAW) is a process that melts and joins metal by heating them with an arc created between cover electrodes such as a stick and metal [10]. Shielded metal arc welding is considered the simplest arc welding process because the equipment used can be easily moved from one place to another. The cost of the whole setup is relatively cheaper. This process uses different types of electrodes, so there are many applications to joining various metals and their alloys. Depending on the need, SMAW can be carried out with alternating and direct current resources efficiently [11]. Shielded metal arc welding is most widely used in small-scale industries and still occupies a leading position in domestic, maintenance, fabrication, and offshore applications [12].

The shielded arc welding (SMAW) process is widely used to join armored steel plates in manufacturing turrets and hulls, landing gear, grounding ships, mining equipment, mortar casings, and armored vehicles, vehicles, patrol vehicles, etc.

Many welding processes are available to manufacture high-strength armor steel structures; however, SMAW is often used to join thick steel sections due to its lower cost and easy equipment availability [13]. TIG welding is an electric arc welding process that uses non-consumable electrodes. In TIG welding, the electrode or tungsten only functions as an electric arc generator when it comes into contact with the workpiece, while filler metal is the filler rod [14]. The shielding gases commonly used to protect the tungsten electrodes in the GTAW process are argon, helium, nitrogen, hydrogen, or a mixture [15].

Several studies on carbon steel welding have been done by several researchers, such as that of Nurul Syahida et al. showing that there is a difference in the amount of pearlite between low and high carbon steel due to the increase in heat input during the GMAW process. For low carbon steel, the amount of pearlite continues to decrease as the heat input increases. In contrast, the amount of pearlite continued to increase as the heat input increased for high carbon steel [16]. Research results of Abdul Hamid et al. It is concluded that PWHT after SMAW process of S275J2 carbon steel can improve the physical and mechanical properties of the material. The hardness decreases and the Charpy impact energy increases. Based on the microstructure analysis, the grain size increased after PWHT process [17]. Bambang Teguh Baroto's research results, 2017 show that the higher current used in welding, the higher penetration and the speed of melting. A large electric current can also reduce grain spatter and increase bead gain as a result, the high current of electricity will widen the HAZ area [7]. While decreasing the heat input will minimize the longitudinal distortion and transverse direction distortion in the A36 steel GTAW process [4]. In addition, the study shows that welding current is the most important parameter of welding process (7.71%), followed by welding speed (30.0%) and welding speed (19.5%), respectively [18].

High process heat input is known to affect the macroscopic and microscopic effects of the HAZ and weld metal, thereby affecting the mechanical properties of the joint [19]. Another study by Manas Kumar Saha confirms that a higher heat input results in a wider weld bead with low reinforcement and low penetration [20].

Abdullah Mohd Tahir's research on AISI 1020 steel indicates that filler metal and current characteristics significantly influence the mechanical properties of welding [21]. Didit Sumardiyanto's experiments on API 5L Grade X52 also showed that as the amount of heat input (expressed as current) increased, mechanical properties such as tensile strength, hardness and impact decreased [8]. On the other hand, the increase in weld tensile strength is greater when using a negative direct current electrode (DCEN) than with a positive direct current electrode (DCEP) with increasing welding amperage [11].

In addition, the selection of input parameters to obtain the best welding quality is higher welding current and lower welding speed [22]. This indicates that travel speed and heat input contribute to undercut formation. In addition, the overall hardness decreases with increasing heat input [23].

Naima Ouali's research on stainless steel indicates that increasing the heat input reduces the hardness of the weld metal, possibly due to the difference in the ferrite/austenitic ratio [24]. Heat input has a greater influence on tensile strength and it is found that tensile strength decreases with increasing heat input. There is an increase in weld toughness with an increase in heat input due to an increase in the ferrite delta content [25].

As the arc voltage and welding current increase, the hardness value increases and the yield strength, tensile strength and impact strength decrease. This behavior is related to the fact that an increase in current and voltage means an increase in heat input can create space for the formation of defects so that the observed mechanical properties are reduced. The increase in hardness can be attributed to the alloy coating of the electrode being added to the weld deposit [6]. Another result of SMAW process low carbon steel is concluded that as the current increases, the hardness and strength increase but the impact strength decreases, while the hardness and strength continue to decrease but the impact strength increases as the normalization temperature increased [26].

Prasad's study of HSLA with the SAW process showed that the average hardness of the weld metal and the HAZ decreased with increasing heat input and the maximum hardness was found in the HAZ. And the increased heat input makes the grains coarse and produces columnar dendrites on welding. At low heat input the failure mode is mostly brittle, while at high heat input it is mostly ductile. [27].

Asibeluo and Emifonye explain that an increase in welding current leads to an increase in welding temperature and decreases toughness and hardness since increasing cooling time leads to rapid grain growth [28]. This was also conveyed by Kumar, Anja, and Saxena with a higher heat input, slower cooling rate, and vice versa. Whereas the microstructure and micro hardness depend on the cooling rate, the faster the cooling rate of fine grains is formed and the hardness increases, and with the slower cooling rate coarse grains are formed and the hardness decreases [13].

Based on the above study, there has been no research on the joint of SA537 Class 2 using the GTAW and SMAW processes and the need to study the mechanical properties and microstructure of structural steel SA537 Class 2 due to the welding process. In addition, heat input also acts as the main parameter in welding that affects the mechanical properties of welded joints. Therefore, the main focus of this study is to identify the effect of weld heat input parameters (low, medium, and high) on the mechanical properties and microstructure of low carbon steels. This research aims to the joint SA537 Class 2 using the GTAW and SMAW process with heat input variations to get the best joint and determine the joint results mechanical properties, microstructure analysis of the welding process results, and the exact heat input on the welding of SA537 Class 2. The metal joint is SA537 Class 2 with a thickness of 16 mm using a current variation of 100A, 120A, and 140A.

SA-537 Class 2 steel is a type of low carbon steel standard pressure vessel from ASME which is made of a mixture of carbon, manganese, silicon, and heat-treated by quenched and tempered methods. These plates are commonly used to design pressure vessels, boilers, and heat exchangers on ships and in oil and gas companies[29].

2. Methods

The process of welding SA 537 class 2 steel measuring 300 x 180 mm and 16 mm thick uses GTAW and SMAW machines. Root welding using the GTAW process with 99.9% Argon protection gas, 20 Volt voltage, and 50 mm/min welding speed. Welding current 90 A with DCEN polarity. Meanwhile, hot pass, filler, and capping welding uses the SMAW process with a voltage of 25 volts, welding speed of 60 mm / min, and currents varying 100, 120, and 140 A with DCEP polarity. The filler metal used in the GTAW process is ER80S-Ni2 and the SMAW process uses E8018-C1 H4R with a diameter of 3.2 mm. Welding of SA 537 class 2 steel with a single V butt joint design, groove angle of 60o, root face 2 mm, and root gap of 4 mm was performed with 7 passes. After the visual test, a metallographic test is carried out, starting with cutting the specimen, mounting it, then sanding it until it is smooth using sandpaper and polishing before dipping it in a 2% Nital etching solution to see the area of the weld and its surroundings at a macro and micro level using an optical microscope. Hardness measurements were carried out at 2 points in each area and experiments using the Vickers method with HV10 loads. Sampling for the tensile test refers to the ASME section IX standard [30] with two test specimens for each variation of current strength. The test results obtained are then processed for analysis and conclusions are obtained following the objectives of this study. The distribution of test samples according to the ASME sect IX: 2019 standard is shown in Figure 1 and the schematic of the bending test method is shown in Figure 2.

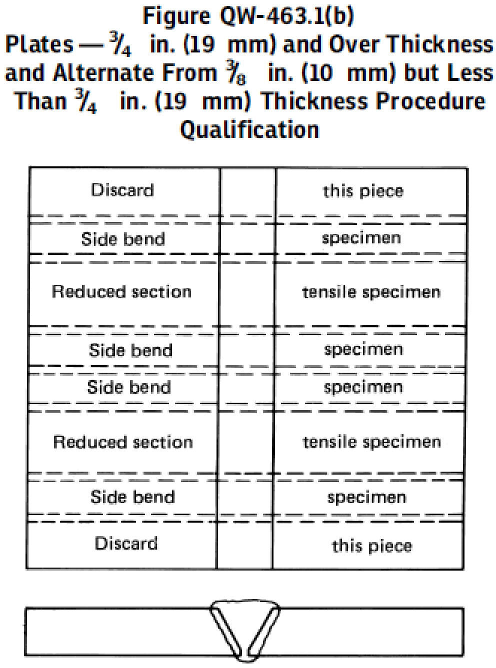

Figure 1. Distribution of test specimens [30]

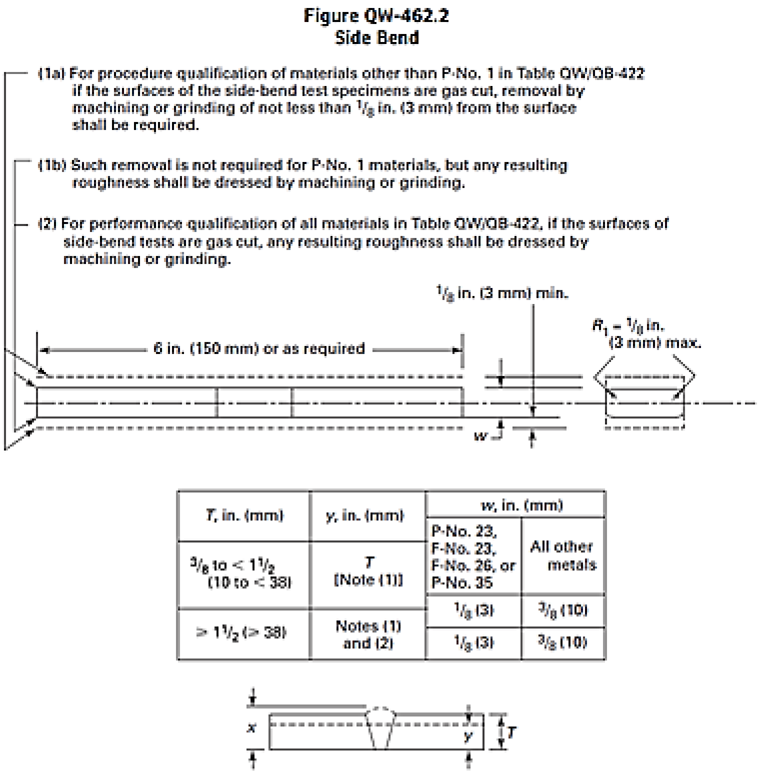

Figure 2. Schematic of bending test method

3. Results and Discussion

3.1. Visual Analysis of Welding Results

Visual testing in figure 3 shows that the welding steel SA 537 class 2 used GTAW and SMAW process is well jointed. The face sides look unified and are well connected for variations in currents of 100 A, 120 A, and 140 A. The overall experimental result looks good. The visual examination of the cross-section of the weld metal and heat-affected zone show complete fusion and freedom from cracks and can be accepted refer to the ASME section IX standard [30] and to be continued with other tests.

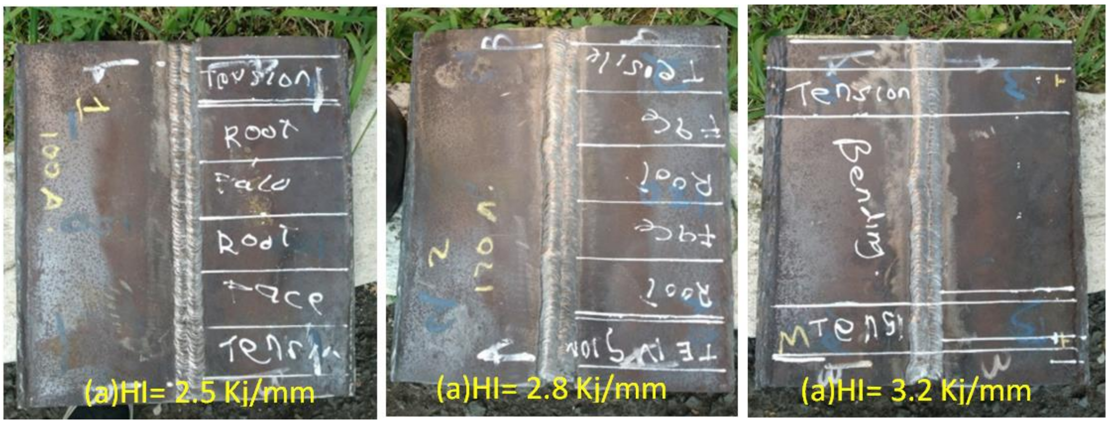

Figure 3. Results of the GTAW and SMAW Process Visually with Heat Input (kJ/mm) : (a) HI =2,5 kJ/mm, (b) HI=2,8 kJ/mm, (c) HI = 3,2 kJ/mm.

3.2. Analysis of Tensile Test

The results of the tensile test of a weld joint using a different heat input to find out how the resistance of the material to static loads is given slowly until the material is broken are shown in Figure 4. Fractures in the material can occur in the Weld Metal, HAZ, or Base Metal sections. The fault area will determine the suitability of the material for use.

Figure 4. Fracture of Tensile Test Specimens with Heat Input (kJ/mm): (a) HI =2,5 kJ/mm, (b) HI=2,8 kJ/mm, (c) HI = 3,2 kJ/mm.

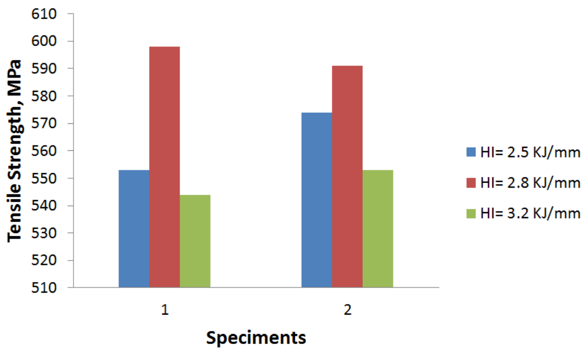

Figure 5. Tensile Test Results

Figure 5 shows that the increase in heat input to a certain point will increase the tensile strength and then decrease with the higher the heat input. The results of the tensile test of specimens with a heat input of 2.8 kJ/mm experienced a fracture on the weld metal but the tensile strength value of 594 MPa was higher than the tensile strength of the base metal 550 MPa. While the tensile strength of the specimen with a heat input of 3.2 kJ/mm, the tensile strength value of 548 is lower than that of the base metal. According to ASME Section IX, the test specimen with a heat input of 3.2 kJ/mm cannot be used because it has a tensile strength below the minimum tensile strength of the base metal.

3.3. Analysis of Hardness Test

The results of the test specimen hardness are shown in Figure 6.

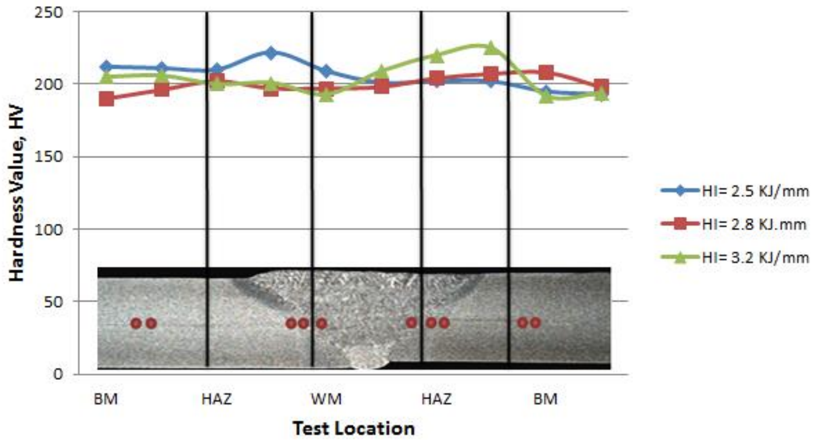

Figure 6. Distribution of Hardness

The hardness test of the SA537 Class 2 material welding specimens has different hardness levels in the weld metal, HAZ, and base metal areas, depending on the grain size of the microstructure and the cooling rate of the material. Overall, the hardness value in HAZ is higher than base metal and weld metal with the highest value of 220 HV. However, the hardness of the parent metal, HAZ, and weld metal with variations in heat input showed no significant difference. The difference in Heat Input does not significantly affect the hardness results in the HAZ and weld metal area of the SA537 Class 2 material welded with E8018 electrodes and ER 80S-Ni2 filler. Hardness will increase if the resulting grain is small. This can occur because in smaller grains the movement of the dislocation will be more difficult. Meanwhile, if the cooling rate is fast, then the grains do not have time to change to become large so small grains have a higher hardness value than large grain sizes. The higher the heat input, the slower the cooling rate so that it can affect its lower hardness. The low hardness of the weld in the welding process using filler ER 80S-Ni2 is also influenced by the high level of nickel which has the property of increasing the ductility of the filler. Then in the HAZ area, the hardness is higher than the base metal area because the HAZ area is a part of the metal that is affected by direct heating from the welding process and experiences a fast cooling rate so that the distorted atoms increase the hardness value in the HAZ area. Then in the HAZ area, the hardness is higher than the base metal area also because of the dominance of the pearlite phase which is formed due to the influence of heat input [31].

3.4. Analysis of Bending Test

The bending test specimen uses the Side Bend method because the material has a thickness above 10 mm and it is feared that it will not be able to withstand loads according to ASME SECT. IX standards. The results of the SA537 Class 2 bending material test results from the SMAW and GTAW processes are shown in Figure 7.

Bending Type	HI = 2.5 KJ/mm	HI = 2.8 KJ/mm	HI = 3.2 KJ/mm
Side	 *No Discontinuity*	 *No Discontinuity*	 *No Discontinuity*
Side	 *No Discontinuity*	 *No Discontinuity*	 *No Discontinuity*
Side	 *No Discontinuity*	 *No Discontinuity*	 *No Discontinuity*
Side	 *No Discontinuity*	 *No Discontinuity*	 *Discontinuity 0.73mm*

Figure 7. Bending Test Results

The results of the bending test using a heat input of 3.2 kJ/mm in one of the specimens, there is a discontinuity of 0.73 mm in length, and the crack occurs right in the middle of the weld metal. This occurs due to a large amount of heat input during the welding process [32]. The 0.73 mm long crack is a discontinuity which is allowed because according to the criteria determined by ASME IX the discontinuity includes defects if it is more than 3.2 mm so that specimens with a heat input of 3.2 kJ/mm can be accepted according to these standards. The test results of all specimens are acceptable according to ASME IX standards.

3.5. Analysis of Microstructure Examination

The results of the micro photo of metallographic testing using a 200x magnification show the phases formed in the welding area and the parent metal with differences in heat input during the welding process shown in Figure 8. We can see that the phase in the specimen consists of ferrite and pearlite. Ferrite is light in color and tends to be resilient, while perlite is dark and tends to be hard [33]. All specimens experienced changes in the size and amount of ferrite and pearlite in the base metal area and on the weld metal. The higher the heat input given to the welding process will result in a decrease in the percentage of the amount of ferrite and the size of the microstructure will tend to be uniform [34]. The percentage of the amount of ferrite in the weld metal area is almost the same for all variations of heat input and specimens with a heat input of 3.2 kJ/mm experienced the largest decrease in the amount of ferrite from 66.67% at base metal to 52.78% for weld metal around 13%. In the HAZ area, there are fine and slightly coarse grains but in the weld metal, the grains obtained tend to be coarse which makes the mechanical properties of the material decrease. The microstructure will increase in size (coarse) as the temperature increases during the welding process. High heat input causes microstructure coarsening in the HAZ, therefore steel which has high heat input has a rugged microstructure [16].

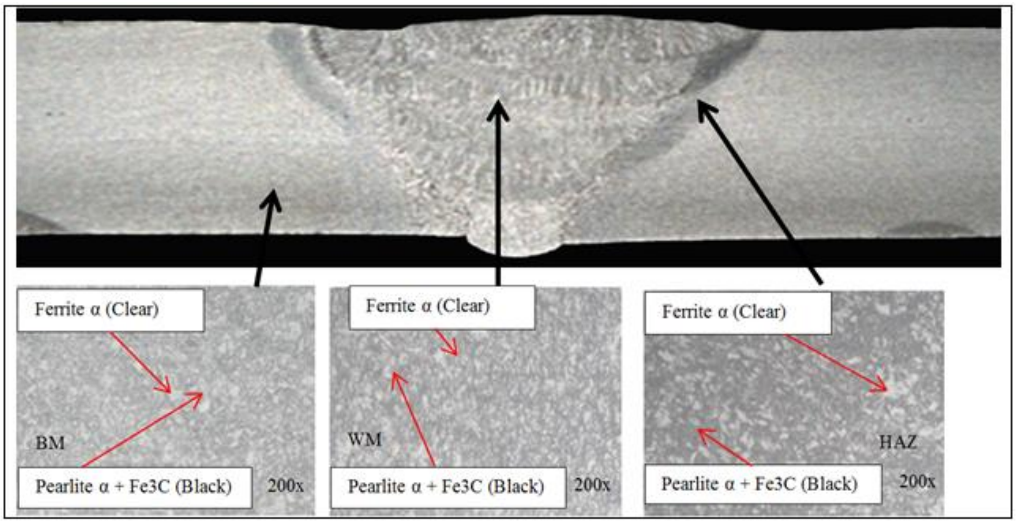

Figure 8. Microstructure Examination

4. Conclusion

The metal connection process SA A537 Class 2 size 300 x 180 mm and 16 mm thick using the GTAW and SMAW process with a single V butt joint design, groove angle 60º, root face 2 mm and root gap 4 mm as many as 7 passes have been successfully carried out. The test results show that the use of heat input 2.8 kJ/mm gives better results than the other two heat input variations with a tensile strength of 598 MPa and a weld metal hardness of 198 HV. The bending test results showed no cracks in the specimen and a decrease in the percentage of the ferrite phase. Appropriate heat input using a combination of the GTAW and SMAW processes will provide welds with good mechanical properties and microstructure. This research can be used as a reference in preparing specifications for welding procedures for boilers, pressure vessels, and heat exchangers on ships and so on. Further research can be done by testing the material's resistance to corrosion in the field.

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