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Analysis of Quenching Temperature Variations in the Heat Straightening Processfor Multiple Repair FCAW Welding HSLA SM490YA Material

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Abstract

In the steel structure fabrication industry, girders play a crucial role as supporting beams during construction. The girder's components include end plates and beams, with the end plate serving as a critical connection point for the beam to the column. Welding at this juncture demands careful consideration. This analytical research focuses on the impact of multiple repair welding and quenching temperatures during the heat straightening process on the toughness and microstructure of HSLA SM490YA material, utilizing FCAW welding. To assess the effects of multiple repair welding, the study compares different repair scenarios—welding without repair, two repairs, and three repairs, all performed at a 50% depth. Subsequently, the heat straightening process occurs at a temperature of 650ºC on the repaired material. Post-heat straightening, quenching is carried out with temperature variations of 650ºC, 475ºC, and 300ºC. The findings indicate that the repair process during welding and subsequent quenching after the heat straightening process leads to a decrease in toughness values. This results in a finer grain size, with the material phase predominantly composed of pearlite. These research outcomes should be carefully considered by industry professionals, particularly in critical connections, when determining quenching temperatures after the heat straightening process in repair procedures.

1. Introduction

Industrial development has increased significantly in both manufacturing and construction services. In industry, the demand for metal construction using a welding process is very high because welding is the most effective form of metal joining in terms of strength. Steel structure companies must carry out welding according to the standards and procedures used. The contract requires the production process to follow standartAmerican Welding Society D1.1[1].

In the pipe rack construction fabrication process, the connections used on the girders use CJP groove weld, where the end plate on the girder item is a critical part because it supports the dynamic load distributed throughout the steel structure. The risk of failure in the welding process has the potential to cause stress concentrations, which will later cause failure in the structure due to welding angle errors and the welder's concentration starting to decrease, resulting in defects. Therefore, after the item has finished the welding process, a weld inspection must be carried out to see whether the material has any defects caused by the welding process.

In several cases, there were several findings on girder items indicating that the results of the NDE (NonDestructive Examination) ultrasonic testing contained indications of discontinuity in the weld joints, so repairs were needed to eliminate these indications. In this case, repair treatment plays an important role in supporting the quality of the weld results. Apart from that, repair treatment also has a big influence on the HAZ (Heat Affected Zone) area and welded joints, so it needs to be something that needs to be paid attention to. The impact of high heat input causes deformation of the material, especially in the area around the weld joint.[2].

As deformation occurs in the component, a heat straightening action is applied to the end plate to restore parallel geometry. Determining the heat straightening temperature has significant implications for the mechanical characteristics of the end plate. Gradually increasing the heat straightening temperature will result in an increase in tensile strength and a decrease in material toughness[3]. During the joint inspection, the repair process was carried out using the heat straightening method, which involved an initial stage in the form of two cold working stages, followed by a heating process and sudden cooling using water (quenching). It is important to note that this method has the potential to change the microstructure of the deformed material [4], and these changes can affect its mechanical properties [5]. In addition, special attention needs to be paid to the suitability of the temperature and cooling media used in the deformation repair process, in line with the requirements described in Clause 7 Fabrication, C7.25. Heat straightening[1].

Therefore, based on the explanation of the problems above, further research was carried out by varying the multiple repair and quenching temperatures to determine the results of the impact test values in the HAZ(Heat Affected Zone) area and the results of the microstructure in the heat straightening process resulting from FCAW welding of HSLA SM490YA material.

2. Research Method

In this research, the material used was SM490YA steel plate with a thickness of 16 mm for 7 test coupons. Welding was carried out using an FCAW welding machine and using filler metal E71T-1C with a diameter of 1.2 mm. The shielding gas used is 99% CO2.

The welding process used is Flux Core Arc Welding (FCAW) with a single bevel butt joint and a welding position of 1G. The welding process uses CO2 shielding gas with a flowrate of 10–24 L/min. The welding parameters used can be seen in Table 1.

Table 1. Welding Parameters

Layer	Voltage (V)	Current (A)	Travel Speed (mm/min)	Heat Input (kJ/mm)
Root	26-28	189-231	40-65	0,1193
Fill	22-28	149-220	50-105	0,1031
Cap	23-25	151-185	55-110	0,0674

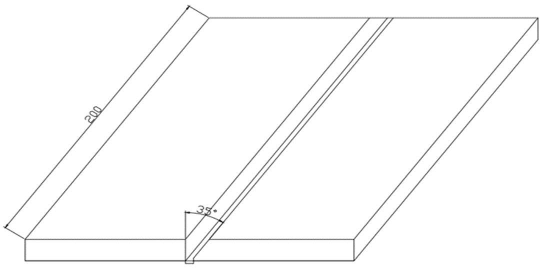


Fig. 1. Test piece

The welding parameters used are based on Welding procedure specifications from companies operating in the field of structures, where the standard referred to is the American Welding Society D1.1/D1.1M 2020 concerning Structural Welding Code—Steel.

After the welding process is complete, the next step is the repair process. In this study, variations in the number of repairs were carried out, namely non-repair, 2 repairs, and 3 repairs. The repair process uses a hand grinder to a depth of 50% of the thickness of the base metal in the weld metal and welding again using the parameters in Table 1.

The repair depth requirement is 50% of the thickness to accommodate defects that often occur in the field, namely a depth range of between 30% - 70% of the material thickness. so we take the 50% Fig. from the middle of what happens in the field.

On the test specimen, a heat straightening process was then carried out using an OAW torch. The heat distribution scheme uses a line pattern. When applying heat to the material for the second and third times, wait for the temperature to be below 120°C [6]. First, the deformation size is measured before the heat straightening process is carried out. Then measure the long dimensions of the material that will undergo the heat straightening process. The heat straightening process is carried out with a neutral flame. The torch tip distance when carrying out the heat straightening process is a maximum of 10mm from the material. When carrying out the heat straightening process, calculate the time it takes to reach a maximum temperature of 650^{o}C.After that, write down the time obtained when it reaches a maximum temperature of 650^{o}C.Then the movement uses a constant-line heating pattern to maintain a stable temperature. Temperature measurements are carried out on areas exposed to heat for 2–3 seconds after the heating process. Note the time obtained from the heat-straightening process. The heat straightening process was carried out using a heating scheme for the number of specimens of six joints: 3 joint specimens are repaired twice with a heating temperature of 650°C and watercooling media, and 3 joint specimens are repaired three times with a heating temperature of 650°C and water cooling media. After the heat straightening process is carried out, the quenching process continues. The quenching process is carried out on areas exposed to heat after heating the material using water from a hose.

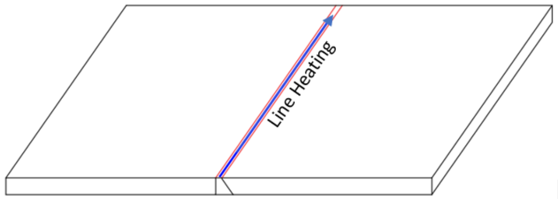


Fig. 2. Simulation of line pattern heating process

Fig. 3. Quenching Process

Table 2. Heat straightening process time

Time of heat application			
Specimen	Time (minute)	Speed (mm/s)	Temperature (°C)
Repair 2X	44,01	4,54	650
Repair 2X	45,17	4,42	
Repair 2X	44,28	4,51	475
Repair	44,02	4,54	

Time of heat application			
Specimen	Time (minute)	Speed (mm/s)	Temperature (°C)
3X			
Repair 2X	45,28	4,41	300
Repair 3X	45,57	4,38	

Impact was carried out to determine the toughness properties of the material. In this research, the method used was the charpy method, where the specimen was adjusted to the desired test temperature and then the pendulum was lifted to its initial position. After that, set zero on the needle on the impact testing machine, and then the specimen is placed on the anvil. The position of the notch is in the middle of the pendulum's trajectory, and then the pendulum swings to hit the specimen. Next, read and record the impact energy value and final angle after the pendulum hits the specimen.

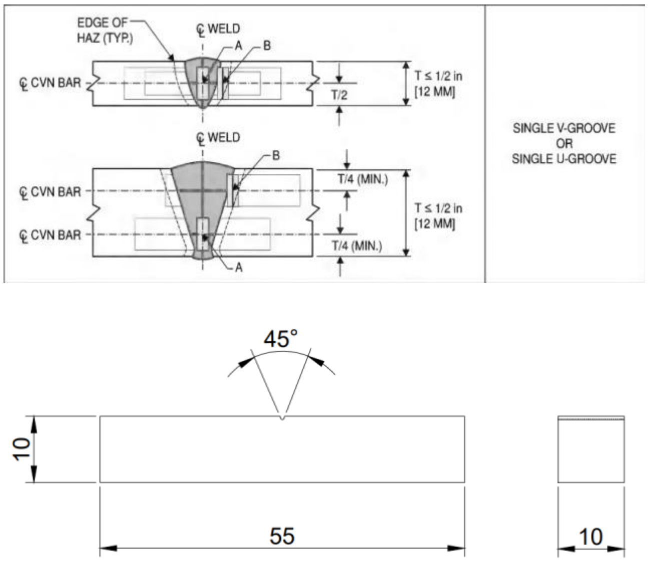


Fig. 4. Specimen Impact Test[1]

Micro-etching testing is a test of the structure of a material through magnification using a special microscope. Microtesting aims to see whether there are changes in the microstructure of the material after undergoing microtesting carried out in three observation areas, namely base metal, weld metal, and HAZ(Heat Affected Zone). First, the specimen is prepared by polishing using a machine and rubbing paper to grade 2000 until it is clean and free of stains. After polishing, etching was carried out with 2% nital solution (2 ml + 98 ml alcohol) and micro-tested using an OLYMPUS optical microscope at 500x magnification in the HAZ(Heat Affected Zone), base metal, and weld metal areas.

3. Results and Discussion

3.1 Impact Testing

This test was carried out at the HAZ(Heat Affected Zone) with the test specimen temperature at 0°C for all test specimens. The energy results (joules) obtained from the impact tests that have been carried out can be seen in Fig. 5.

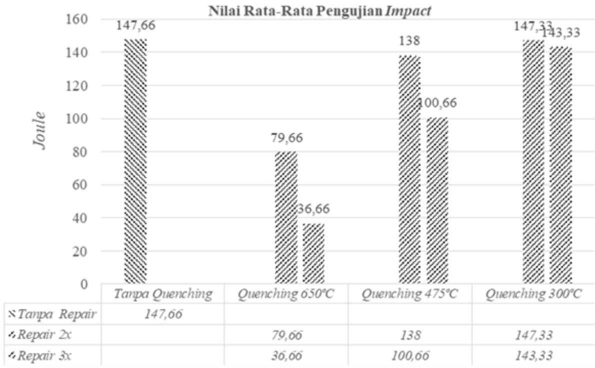


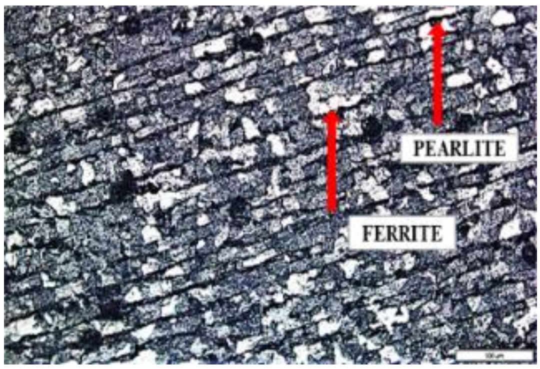
Fig.5. Average value of impact testing

From the results of the impact tests that have been carried out, the impact energy value decreases as the welding repair process and quenching temperature increase. The number of repairs will influence a significant reduction in energy absorption in impact testing [4]. Apart from that, the heat straightening process in the deformation area and then cooling quickly to the temperature after the heat straightening process also results in a decrease in the impact energy value.

For example, in the impact value of the HAZ(Heat Affected Zone), the highest impact energy value is found in the 2x repair specimen with a quenching temperature of 300°C, namely 147 joules, while the lowest impact energy value is in the 3x repair specimen with a quenching temperature of 650°C, namely 36 joules. So the 3x welding repair with quenching treatment at a temperature of 650ºC is not recommended because it does not meet the acceptance criteria for the impact test energy value at a temperature of 0 ^{0}C according to AWS D1.1:2020, namely 54 Joules[1]. But if you refer to the JIS g3106 material standard which states that the impact energy value at a temperature of 0 ^{0}C is a minimum of 27 joules[7]. so the value of 36 joules is still considered acceptable.

3.2 Microstructure Testing

In this research, microstructure testing was carried out in the base metal area to determine the microstructure of the base metal. The results of microtesting on base metal, HAZ(Heat Affected Zone), and weld metal can be seen in Fig.s 6, 7, and 8.



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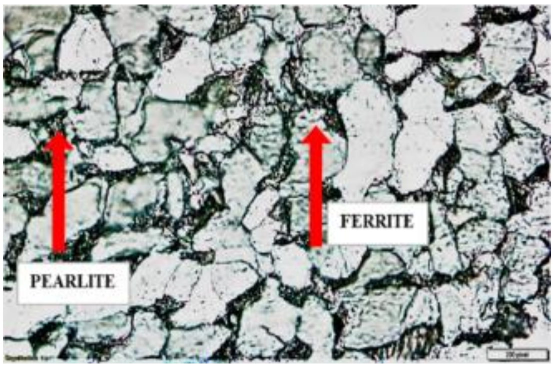

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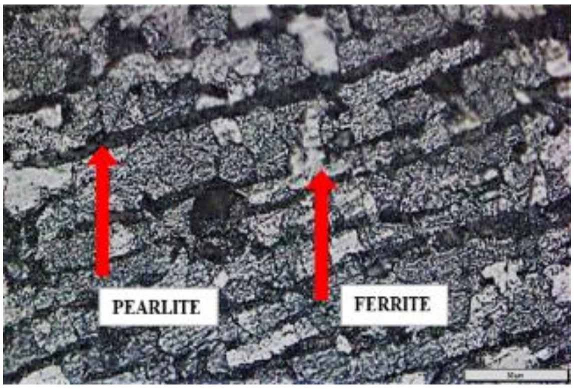

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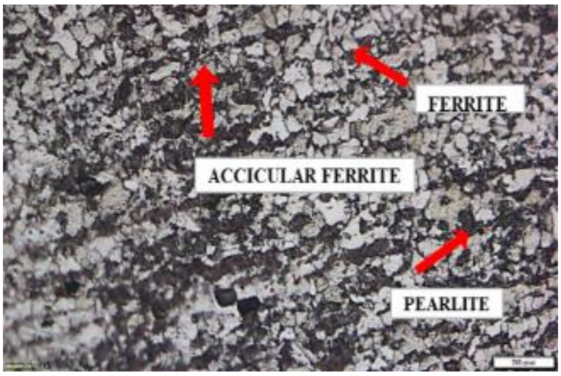
Fig. 6. Microstructure of base metal at 500x magnification at 650ºC quenching: (a) without repair; (b) 2x repairs; (c) 3x repairs

In Fig. 6, the base metal used in this research is SM490YA, as shown in the Fig. above, which underwent variations without treatment: 2x repair and quenching 650ºC, 2x repair and quenching 475ºC, 2x repair and quenching 300ºC, 3x repair and quenching 650ºC, repair 3x and quenching 475ºC, repair 2x and quenching 300ºC. Basically, this base metal is classified as HSLA carbon steel. In HSLA carbon steel, there are ferrite and pearlite phases, where the characteristics of ferrite and pearlite are shown in white for ferrite and black for pearlite [8]. It is almost the same as other carbon steels, but this base metal is dominated by ferrite with pearlite content, which has a natural, flat, elongated shape due to the rolling process of the raw material.



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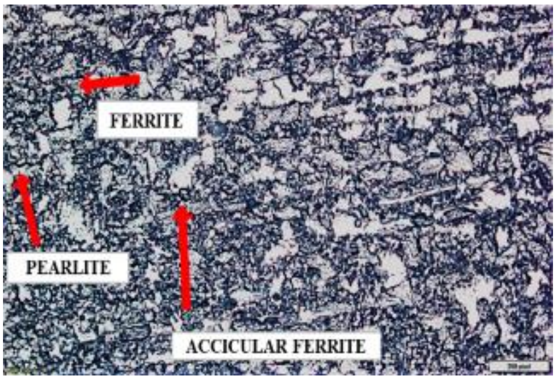

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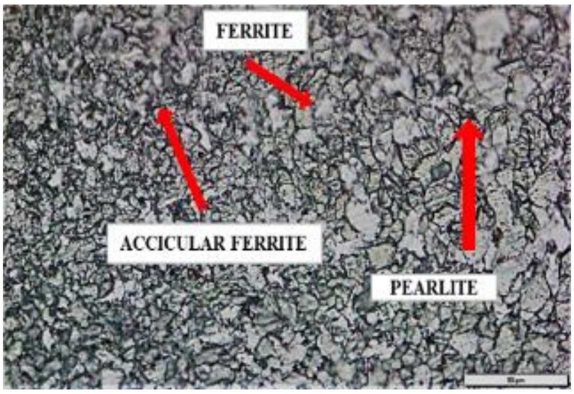

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Fig. 7. Microstructure of the HAZ(Heat Affected Zone)500x magnification at 475ºC quenching: (a) without repair; (b) 2x repairs; (c) 3x repairs

Fig. 7 shown that the HAZ (Heat Affected Zone) area above, it is found that this HAZ area has experienced a faster thermal and cooling cycle, resulting in changes in the microstructure [2]. In this HAZ(Heat Affected Zone) area, microstructural changes occur in each specimen due to variations in repair and quenching. In the HAZ(Heat Affected Zone) area, there is a change in grain size, which becomes finer than in the base metal part because the HAZ(Heat Affected Zone) area receives higher heat input compared to the base metal area.

The multiple repair processes can cause additional thermal cycles, which can significantly influence microstructural changes, deformation, and the mechanical properties of the material. The microstructures that appear in the HAZ (Heat Affected Zone) area include accicular ferrite (AF), ferrite, and pearlite. In materials, the microstructure of accicular ferrite has the characteristic of being tightly flat like needles with random orientation, which forms an interlocking structure so that it can increase the toughness of a material [9]. This is also supported by mechanical testing in the form of impact tests in the HAZ(Heat Affected Zone)area carried out in this research, which resulted in an increase in toughness values.

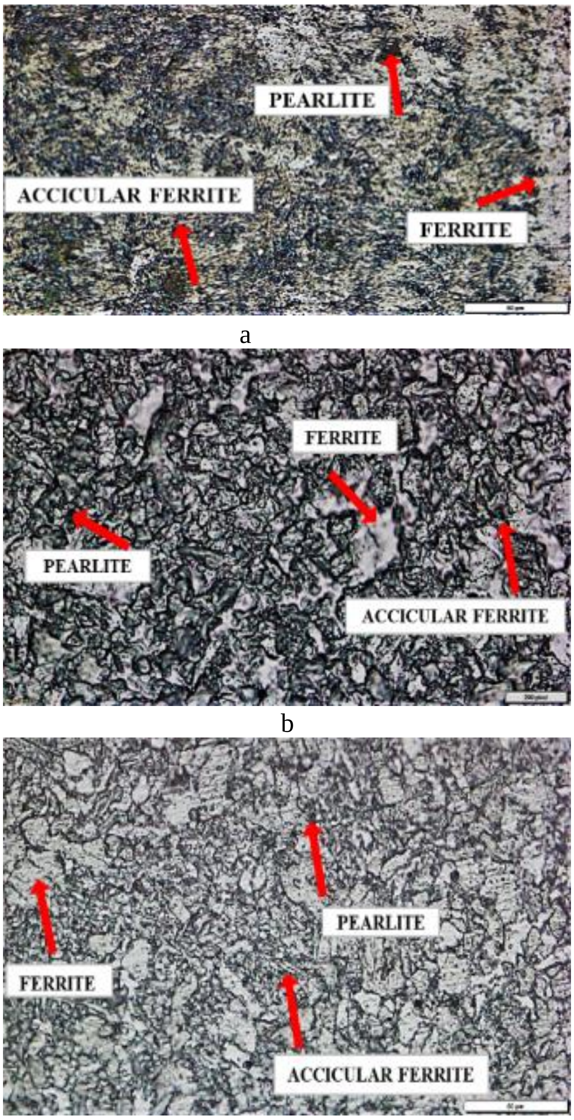

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Fig. 8. Microstructure of Weld Metal with 500x magnification at 300ºC quenching: (a) without repair; (b) 2x repairs; (c) 3x repairs

Fig. 8 shown that the microstructure appears at each repair and quenching temperature variation in the weld metal area experiencing accicular ferrite growth. As discussed in the HAZ (Heat Affected Zone) area, accicular ferrite can appear and tends to increase because it is supported by a slow cooling rate. As a result of accicular ferrite, which dominates at slow cooling rates, of course this will have an influence on the ductility and toughness of the weld metal, causing an increase in the hardness value in the weld metal area.

Too much heat results in a different microstructure compared to welding without repair. The microstructure of welding without repair has larger grains than the material that has been repaired. In the weld area, the grain size becomes smaller as the number of repairs increases, which also affects the phase percentage, with ferrite decreasing and pearlite increasing as the number of repairs increases. This final structural change also affects the mechanical properties of the material. The results of microstructure testing show that the percentage of pearlite increases as the welding repair process increases. As the percentage of pearlite in the material increases, the hardness value will also increase. From the results of the observations above, changes in the microstructure also occur due to the heating and cooling processes of water and air. It will also increase in size as the heating process increases [10].

4. Conclusion

From all the impact testing results that have been carried out in the HAZ area on each test specimen, the minimum acceptane criterion impact energy value based on AWS D1.1:2020 is 54 Joules. There is an impact energy value that does not meet the acceptance criteria for the impact test in AWS D1.1:2020, namely on the 3x repair welding specimen with a quenching temperature of 650°C, namely 36 Joules. The risk is that if it is not met, the structure will easily break if subjected to repeated loads. The impact test results show that the more repair processes there are, the tougher the toughness value decreases. This is in line with the hardness value which increases as the number of repairs carried out increases. From the overall comparison of impact test specimens it can be concluded that multiple repair treatment and temperature quenching affect the impact energy value of the HSLA SM490YA material. All the microstructure test results show that multiple repair and quenching temperatures in the heat straightening process affect the microstructure which causes the accicular ferrite structure to dominate in the HAZ(Heat Affected Zone) and Weld Metal areas. In the material, the microstructure of accicular ferrite has the characteristic of being tightly flat like a needle with random orientation which forms an interlocking structure so that it can increase the toughness of a material. In the HAZ (Heat Affected Zone)and Weld Metal areas where toughness increases. This can be seen in the mechanical test values in the form of impact tests which show that there is an increase in toughness with each welding repair treatment and a decrease in quenching temperature.

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