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A36 Material Characteristics of GMAW Welding Re-Pair Results DT & NDT

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Abstract*—Welding process is one of the joining of metals by heating the metal and adding additional materials, metal joints if not in accordance with the procedure can result in welding defects, changes in the mechanical properties of material, and changes in the structure of material. This study uses the methodof repair or re-welding on materials that have welding defects. This study aims to compare and analyze the structure of the material, the mechanical properties of the material withoutrepair with the repaired welded joint. Variations of the repair process with variations of repair 2 times, repair 3 times and repair 4 times using GMAW welding on ASTM A36 steel material. The results of the study on the mechanical properties of the material in the form of the ultimate tensile strength of thespecimen, the value of hardness, the microstructure of thespecimen containing the structure of ferrite and pearlite. The results of the highest hardness test values in the weld metal areawith repair values 2 times 170,2 HV, without repair 166 HV, repair 3 times 163.3 HV, repair 4 times 162.8 HV. The results of ultimate tensile strength variations without repair 700 N/mm^2, repair 2 times 736 N/mm^2, repair 3 times 719 N/mm^2, repair 4 times 690.5 N/mm^2 with tensile test fractures located inthe base metal area. The results of the ultimate tensile strength of the specimen without repair and repair are still within the minimum tensile requirements for ASTM A36 steel material of449 N/mm^2 (attachment 4) so that welded joints up to 4 times repair can be used.*

Keywords*— Tensile test, hardness test, microstructure, GMAW welding.*

I. Introduction

Welding serves as a connector for two components of a plateor similar metal profile, such as carbon steel, stainless steel, and aluminum materials [1][2]. ASTM A36 is a low carbon steel with good weld resistance properties and is widely used in construction, automotive, industry. Welding of ASTM A36 material can be done with the GMAW welding type [3].

GMAW Direct Current (DC) with reverse polarity (Positive Electrode Direct Current) is a type of welding that is often used in the manufacturing industry. The advantages of GMAW welding are: minimum welding sparks (arcs), do not produce slags, high current welding can be used, and high welding speed [4].

Weld characteristics, usability of construction, and welding skills are taken into account for the corresponding welding results. Re-welding (repair) aims to repair the construction of damaged metal materials so that they become the destination form and function the same as the basic metal [5]. However, materials with welding repetition increase the chances of welding defects, deformations, or changes in material metallurgy [2][3][6].

During the re-welding process the welding object causes maximum heating then followed by cooling which can affect the microstructure of the weld metal and the formation of a Heat Affected Zone (HAZ) [7]. Welded metals undergo a series of phase transformations from liquid to austenite (the forming base of other phases), perlite (a two-phase mixture formed during the time of austenite) [4][8]. So, it is necessary to study changes in the mechanical properties and material structure of the welded joint repair process [9].

Based on related research, the more repair processes are carried out, the lower the tensile strength of the material. The results of the repair show that the more the connection of the welding object undergoes repair, the more polished the mechanical properties than the material of the welding object without repair [5][10].

This study aims to analyze the comparison of the effect of repair with GMAW welding on tensile testing, hardness testing, and microstructure testing on ASTM A36 steel. The material used is in the form of a plate with a thickness of 10 mm [1]. This research is entitled "A36 Material Characteristics of GMAW Welding Re-Pair Results DT & NDT Testing".

II. Methodology

A. Parameter Research

Welding uses ASTM A36 material with a 1G position GMAW welding type [1]. The pre-welding process consists of cutting the specimen and forming a opposite bevel angle of 60^0 with a distance between the root faces of 2 to 3 mm.

TABLE 1. Welding parameters of the object of study

Parameters		
Process	GMAW	
Gas & flow gas	Argon 82% + Carbon dioxide (CO2) 18% & 15 to 17L/min	
Position	1G	
Amper	Root: 120 to 140 A	Fill/Cap: 235 to 255 A
Voltage	Root: 21 to 23 V	Fill/Cap: 26 to 28 V
Wire (Ø mm)	ER 70 S-6 (1.2 mm)	
Connection	V groove butt joint	
Root gap & face	2 to 3 mm	1 mm

B. Test Variables

1) Tensile Testing

The test is carried out by providing a continuous tensile force until the material is fractured. Material fracture is divided into three areas, namely base metal, weld metal and HAZ. Materials are divided into materials without repair, repair 2 times, repair 3 times, and repair 4 times. These variables produce a tensile test graph in the form of a comparison graph between strain and stress, then processing and analyzing the

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data. The test specimen refers to the ASTM E8M-04standard [8].

2) Surface Hardness Testing

Hardness testing is done by pressing the test specimen. Using the Vickers hardness method to determine the level of material hardness. This test uses the Vickers hardness method to determine the level of material hardness. The test results are in the form of hardness values in units (HV), then processing and analyzing the data are carried out [11].

3) Micro Testing

Micro testing is carried out by observing the structure in the welding joint area using a microscope, provided that the test specimen has been etched. The results of observations in the form of structures on the base metal, weld metal, HAZ boundaries, layers and welding results [4][10][12].

C. Tools and Materials

Supporting tools and materials for research on the effect of GMAW welding repair on tensile strength, hardness, and microstructure in ASTM A36 steel materials are used.

TABLE 2. Research Tools and Materials

Tools	Material
Welding machine GMAW 1 set	Steel plate A36
CNC Plasma Cutting Machine	Wire ER 70 S-6 (1.2 mm)
MTS Exceed E64 TestingMachine	Argon 82% & CO2 18%
Optical Microscope	Grinding eyes (cut, stone, and wire brush)
Polisher Machine	Sandpaper
Multi Vickers Hardness Tester	Nital etching liquid
Hand grinding	Alcohol
Calipers	Autosol
Welding gauge	
Work glasses	
Work gloves	
Welding helmets	
Apron/welding jacket	
Welding gloves	
Slag hammer	
Steel brush	
Combination pliers	

D. Procedure Research

1) Flowchart

2) Preparation of Research Objects

The welding process begins with the preparation of welding material with dimensions of 400 mm in length, 150 mm in width, and 10 mm in thickness. Preparation of V groove potent material is carried out because the welding process uses the 1G position [1].

Fig. 2 (a) shows the material of the V groove as it appearsto be above. Fig. 2 (b) the shows a side-view V groove with atotal angle of 60^0 with a root face of 1 mm. The process of setting root gaps and installing backing on specimens is carried out after the dimensions and angles of the bevel are appropriate.

Fig. 3 (a) shows the adjustment of the root gap to a distance of 2 mm in order for welding breakout to occur. Fig. 3 (b) demonstrate the installation of backing to reduce over-deformation during the welding process and the installation of overflow plates for the welding start and stop process so that welding is not directly performed on the bevel [1].

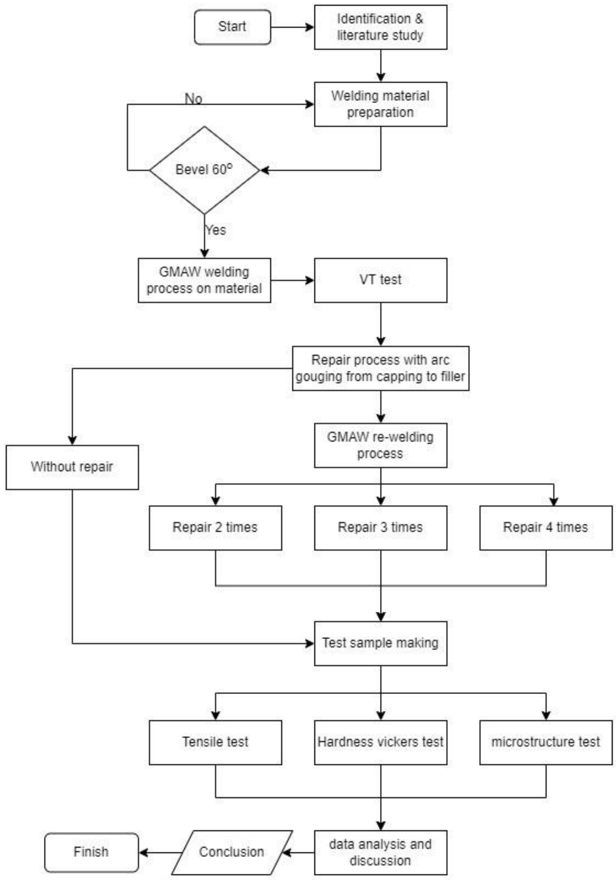
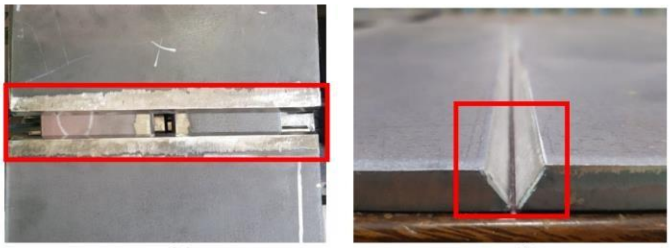
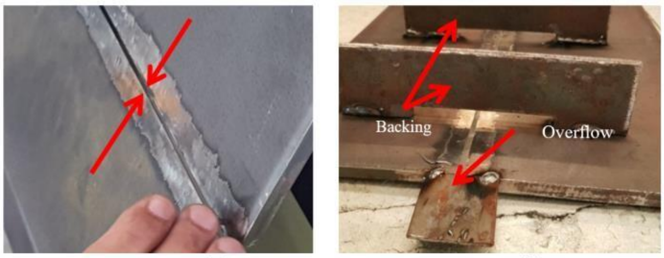


Fig. 1. Flowchart



(a) (b)

Fig. 2. Bevel V groove (a) top view, (b) side view



(a) (b)

Fig. 3. (a) Setting root gap, (b) Installation of backing and overflow

3) Specimen Welding Process

The welding process of the research object using the GMAW OTC XD500S welding machine refers to the parameters in table 1[6]. The welding process consists of 3 layers, namely: root, filler, and capping. A sample of the results of welding the object of study is show fig 4.

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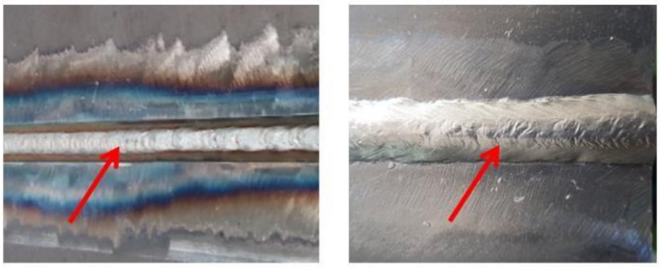
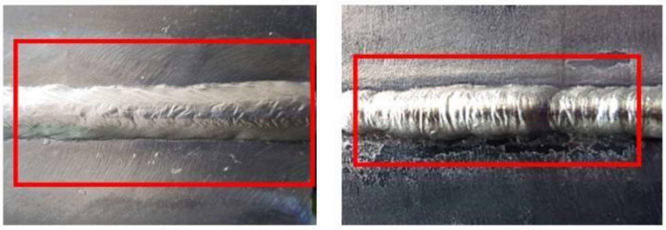


(a) (b)

Fig. 4. (a) Root welding result, (b) Capping welding result

Fig 4. shows the results of root welding until capping is carried out with a procedure according to WPS. Visual test is carried out by observing the results of welding.



(a) (b)

Fig. 5. (a) Visual test results (capping) (b) Visual test results (root)

Fig. 5 (a) is the result of visual testing on the capping part where there is a welding spatter (welding spark) and Fig. 5 (b)visual testing of the root part. Visual testing follows the standards of ASME section VIII Div 1 UW-35. After visual testing of specimens is carried out repair using the gouging process[13][14][15].

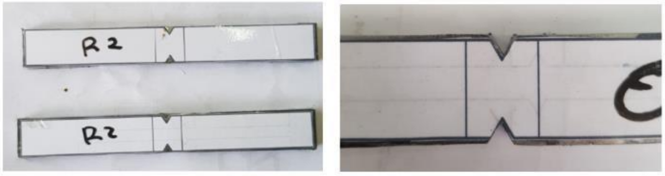
(a) (b)

Fig. 6. (a) Specimens After Gouging, (b) Boreback After Gouging

Fig. 6 (a) indicate the results of the gouging process. There are remaining gouging results that need to be cleaned by grinding until the surface is flat and clean as shown in Fig. Fig. 6 (b). So repair process is carried out by welding GMAW following the parameters in table 1. The total proses of welding correspond to the number of repair test variables, namely: without repair, repair 2 times, repair 3 times, and repair 4 times.

4) Specimen Manufacturing and Testing Process

Specimen cutting using a plasma cutting machine produces more precise cutting results. After cutting with plasma cutting is carried out the formation of the profile shown fig. 7.



(a) (b)

Fig. 7. (a) Prior to Profiling, (b) After Profiling

Fig. 7 (a) specimens after the cutting process using a plasma cutting machine are carried out dimensional measurements for tensile testing referring to the ASTM E8M-04 standard. The tensile test profile making process uses a hand grinding machine [8][16]. Fig. 7 (b) show specimens that have been cut and profiled according to tensile testing standards and are readyfor testing using the MTS Exceed E64 tensile testing machine.

Fig. 8. MTS Exceed E64 Tensile Testing Machine,

Fig. 8 shows the MTS Exceed E64 tensile testing machine of the Madiun State Polytechnic material test laboratory used to test repair specimens. The tensile testing specimen clamped on the vise with the position of the specimen vertical. The result obtained from tensile testing can be a graph of the elasticity of the material. From the graph, you can find out the ultimate tensile strength value, yield strength value, and the elongation value of the research object [3].

Fig. 9. Hardness Test Specimens

Fig. 9 Shows the process of measuring the dimensions of the test specimen. The formation of hardness testing specimens is carried out by cutting following the dimensions of the measurement results.

(a) (b)

Fig. 10. (a) Sanding of Test Specimens, (b) Sanding Results

Fig. 10 (a) is the process of sanding test specimens with the use of sandpaper roughness levels ranging from grids of 100, 150, 200, 800, 1000, 1500, and 2000. The sanding process uses a saphire 330 polishing machine in one direction until the surface is flat [17]. After the sanding process is carried out, the polishing process is continued.

(a) (b)

Fig. 11. (a) Polishing Using Autosol, (b) Polishing Results with Autosol

Fig. 11 (a) specimen polishing process using saphire polishing machine 330. The smearing of autosol and rubbing on the fabric is carried out until the surface of the specimen is glossy as shown figure fig. 11 (b). The violent test was carried out using a mitutoyo hardness tester.

Fig. 12. Etching Hardness Test Specimens

Fig. 12 is an etching process that aims to correlate the surface of the test specimen to be visible between the boundaries of the metal base, weld metal and HAZ to facilitate the determination of the indentation point. Indentation determination is carried out at 15 points to find out the level of hardness of each welding layer.

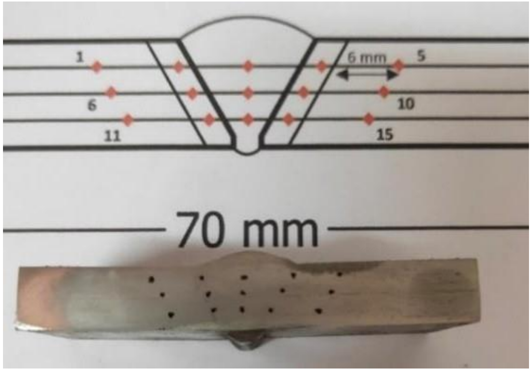


Fig. 13. Vickers Hardness Testing Point

Fig. 13 vickers hardness testing points each layer consists of5 test points, 2 on the base metal, 1 on the metal weld section and 2 on the HAZ part. The indentation distance of the first layer is 2.5 mm from the face surface, the second layer is 2.5 mm from the first layer and the third layer is 2.5 mm from the second layer. For the distance of the test point on the base metal 6 mm from the HAZ part.

Fig. 14. Mitutoyo Rockwell Hardness Tester HR 400

Fig. 14 is a rockwell mitutoyo testing machine with the replacement of an angle diamond pyramid indentator 136^0 for vickers hardness testing, a given compressive force of 60 kgf.

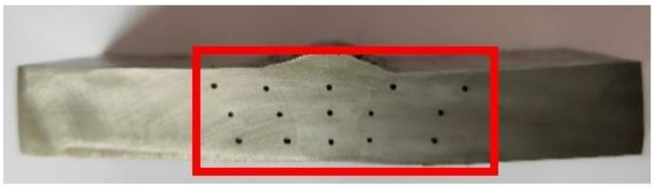


Fig.15. Vickers Hardness Testing Results

Fig. 15 is the result of testing the hardness of vickers with predetermined points. The result of the indentation carried out in addition to the basin depth of the test specimen is the hardness value with units of hardness vickers (HV)[7].

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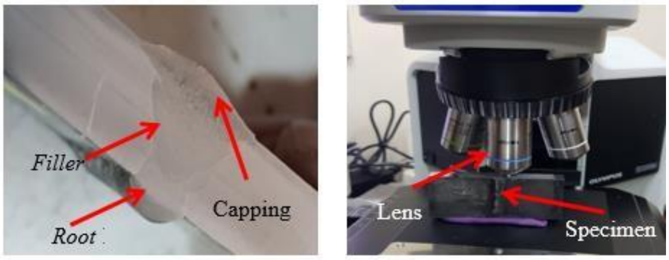
The process of making microstructure test specimens is the same as hardness testing until the etching stage. The dimensions of the microstructure test specimen are 70 mm long and 30 mm wide. The etching process is carried out by smearing nital liquid for 10 to 15 seconds. Cleaning of nital liquid using running water and dried with a clean cloth[7]. Microstructure testing is carried out using optical microscope aids.



(a) (b)

Fig.16. (a) Results After smearing Nital Liquid, (b) Observations with An Optical Microscope

Fig. 16 (a) is the result of applying nital liquid for 10 to 15 seconds. See the boundary between the root, filler and welding capping. Observation specimen of the object of study using an optical microscope with a magnification of 500 times as show fig. 16 (b). The results of this test are in the form of a representation of the microstructure of specimen constituents in each area of the study object. The results of the study are in the form of the influence of the constituent structure on the material characteristics of the research object [11].

III. Results and Analysis

Data analysis of the results of tensile testing, hardness testing, and microstructure testing was carried out. The data processing of each test is different according to the needs and purposes of the test. The data from the tensile and hardness test analysis are presented with graphs, while the data from the microtest analysis are presented with the image comparison method to facilitate understanding.

A. Tensile Test Result Analysis

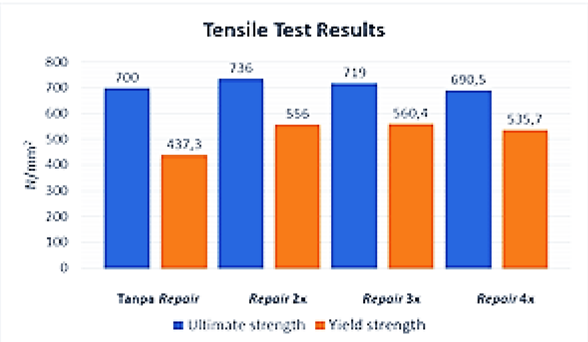


Fig.17. Graph of Tensile Strength Value of Research Objects

Fig. 17 shows the results of the yield strength and ultimate strength values of the study object. The average yield strength value of specimens without repair is 437,3 N/mm^2, repair specimens 2 times 556 N/mm^2, repair specimens 3 times 560,4 N/mm^2, repair specimens 4 times 535,7 N/mm^2.

The ultimate tensile strength value obtained in the variation without repair is 700 N/mm^2, repair 2 times 736 N/mm^2, repair 3 times 719 N/mm^2, repair 4 times 690,5 N/mm^2. It can be known in the tensile test carried out that the ultimate tensile strength value of the repair specimen is 2 times with a value of 736 N/mm^2 is higher than that of specimens without repair and there was a decrease in the value of ultimate tensile strength in the repair specimen 3 times, and repair 4 times.

The ultimate tensile strength results obtained refer to the minimum tensile material tensile provisions used in the datasheet of 449 N/mm^2 can be ascertained the range of the ultimate tensile value results the strength in the GMAW welding process without repair, repair 2 times, repair 3 times and repair 4 times is still within the minimum tensile provisions of ASTM A36 steel used. The result of elongation is an increase in the length of the material until it breaks. Variable elongation without repair is 16.7%, repair 2 times is 21.7%, repair 3 times is 20%, repair 4 times is 13.33%, specimen without welding and repair is 16.7% below the value of the elongation datasheet A36 steel material by 23%, The lowest elongation results occurred in the repair material 4 times this is because the increase in length of the material is getting smaller because the material breaks faster.

B. Analysis of Hardness Testing Results

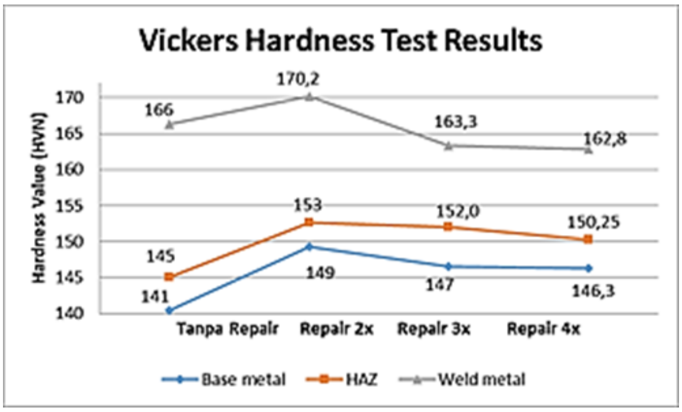


Fig.18. Graph of Average Hardness Test Value of Object Study

Fig. 18 shows hardness, the highest hardness value in the weld metal area and has a microstructure where the perlite predominates more than ferrite. In the weld metal area, the variation without repair has a hardness level of 166 HV, the repair variation 2 times has a value of 170.2 HV, the variation of 3 times the repair has a value of 163.3 HV, and the variation 4 times the repair has a value of 162.8 HV. The results of specimen repair 2 times, repair 3 times and repair 4 times by GMAW welding against ASTM A36 steel based on graph17 show on metal welds higher hardness values compared to base metal and HAZ this is because the weld metal area gets an additional metal wire material that fills between the gaps of the specimen that the welding process carries out, while the lowest level of hardness is found in the base metal area [18].

In ASTM A36 material, the hardness value obtained is 141 HV, it can be ascertained the range of hardness values in the GMAW welding process without repair, repair 2 times, repair 3 times and repair 4 times is still within the minimum hardness

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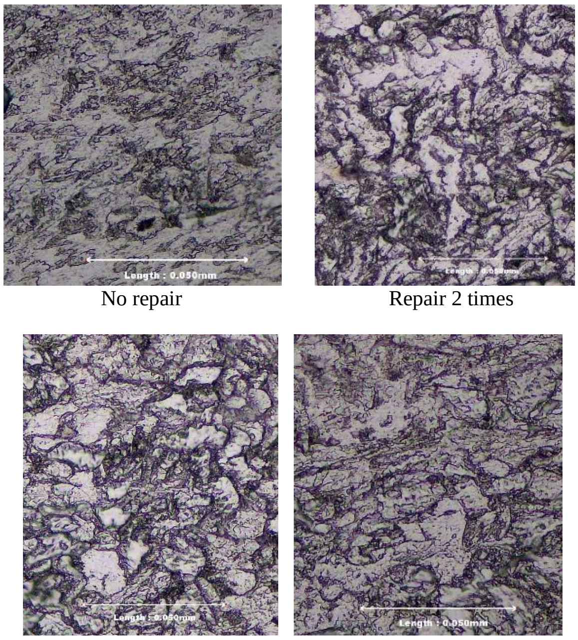
provisions of the ASTM A36 steel used.

C. Micro Test Result Analysis

TABLE 3. 3Base Metal Microstructure

Base metal

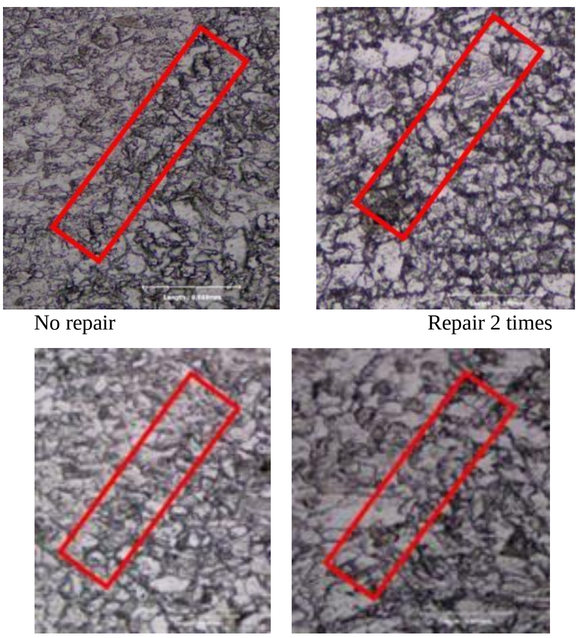


No repair | Repair 2 times | Repair 3 times | Repair 4 times

Table 3 result micro-testing with a magnification of 500 times carried out on base metal with variations without repair has more dominating and coarser ferrite with a lower level of hardness while base metal variation repair 2 times and repair 3times perlite dominates, repair 4 times ferrite dominates.

TABLE 4. Microstructure 4of HAZ

HAZ

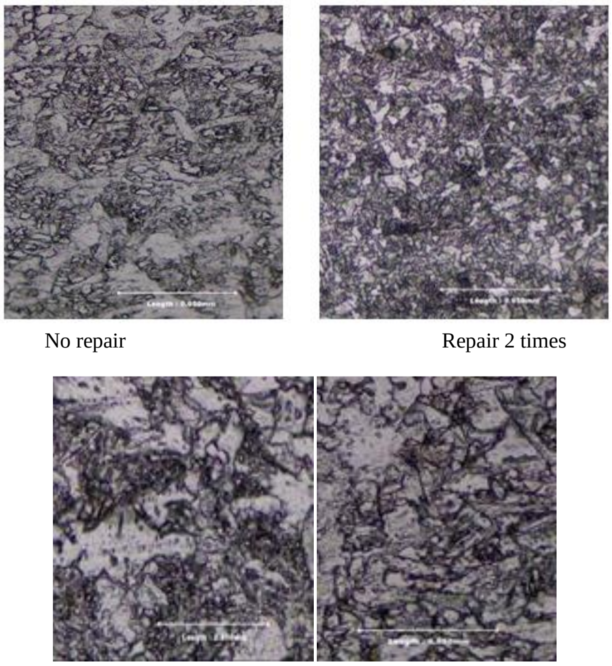


No repair | Repair 2 times | Repair 3 times | Repair 4 times

Table 4 shows the variation without repair in HAZ dominated by perlite, the variation in repair 2 times the microstructure in the HAZ perlite area dominates compared to ferrite, the structure of the HAZ area is smoother and the smoother the phase in the HAZ area, the hardness level increases. Repair 3 times the microstructure in HAZ ferrite is more dominant than perlite, the structure of the HAZ area is rougher, the rougher the phase in the HAZ area, the hardness level decreases. Repair 4 times the microstructure of HAZ ferrite predominates with a rougher HAZ area structure.

TABLE 5. Metal 5Weld Microstructure

Weld metal



No repair | Repair 2 times | Repair 3 times | Repair 4 times

Table 5 is a metal weld microstructure resulting from observations made on variations without repair, repair 2 times, repair 3 times and repair 4 times dominated by smoother plastic structures with an increased level of hardness.

IV. Conclusion

Based on the results of research that has been carried out regarding the effect of repair on A36 steel, the following conclusions were obtained:

- The resulting tensile test fault results are located on the base metal, for the average value of ultimate tensile strength in variations without repair of 700 N/mm^2, repair2 times 736 N/mm^2, repair 3 times 719 N/mm^2, and repair4 times 690,5 N/mm^2, results of ultimate tensile strength repair 2 times, repair 3 times, repair 4 times is still withinthe minimum tensile provision of ASTM A36 steel material of 449 N/mm^2 so that the welded connection carried out up to 4 times repair can be used.
- The results of vickers hardness testing have the highest level of hardness in metal weld parts, with variations without repair having a hardness level of 166 HV, repair variations

2 times having a value of 170 HV, variations of3 times repairs having a value of 163.3 HV, and variationsof 4 times repair having a value of 162.8 HV. The hardnesslevel of the material without repair, repair 2 times, repair 3 times and repair 4 times is still within the minimum hardness requirements of ASTM A36 steel of 141.6 HV

- Based on the results of microstructure observations on metal welds, it is dominated by a smoother perlite structure which has an impact on increasing the hardness value in specimens.

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