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The Effect of Electrode Type on The Tensile Strength Characteristics of Welded Joints Between SA.240 Tp.304 Stainless Steel and SA.36 Carbon Steel Alloys through SMAW Welding Process

Azwinur[1*], Syukran[1], Akhyar[2], Ferdiyansyah[3]

[1]Department of Mechanical Engineering Politeknik Negeri Lhokseumawe, Jalan Banda Aceh-Medan km. 280 Buketrata, Lhokseumawe 24301, INDONESIA

[2]Department of Mechanical and Industrial Engineering, Syiah Kuala University, Jalan Syech Abdurrauf No. 7, Darussalam, Banda Aceh 23111, INDONESIA

[3]PT. Pupuk Iskandar Muda, Krueng Geukueh, Lhokseumawe 24354, INDONESIA

*Corresponding Author

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Abstract: Practically, every construction in the industry uses a welding process as a media connecting metal alloys. The quality of the welding joint such as welding strength and defects needs to be maintained especially in dissimilar metals welding process, chemical elements and mechanical properties of the two materials are very much different. The welding strength is influenced by types of joints in welding, butt joints, arc voltages, welding currents, welding speeds, and the electrodes that used. The purpose of this study was to investigate the effect of electrode types on chemical composition, hardness, and tensile strength of dissimilar welded metals between the SA.240 Tp.304 stainless steel and SA.36 carbon steel alloys. Metals welded through a process of gas tungsten arc welding (GTAW) for the root pass, while the filler pass, and capping are welded through a process shielded metal arc welding (SMAW). The electrode used was AWS EWTh-2 or tungsten doped with 2% of tory, the argon gas used 15 lpm with a flow meter volume. Electrode type variations used E309L-16 and E7016 electrodes. Samples of tensile strength cut from two weld joint plates. The tensile test result shows that the electrode type influences the welding strength, this effect by chemical compositions, and the mechanical properties of the core electrode material used. The tensile strength obtained in the welding metal using the E7016 electrode is better than the E309L-16 electrode. The highest tensile strength is 46.83 kgf at the E7016 electrode, while the number of the tensile strength of the E309L-16 electrode is 46.13 kgf.

Keywords: Dissimilar Metal weld, SA.240 Tp.304 Stainless Steel, SA36 Carbon Steel, E309L-16 electrode, E7016 electrode, SMAW.

1. Introduction

The joining of metals by the welding process is increasingly applied due to design demands and costs, such as in shipping trains, steel frames, pressure vessels, and piping systems. Welding that is often used in the construction filed is generally welding that uses a welding method with a protected metal arc flame called a Shielded Metal Arc Welding (SMAW). The SMAW process is a widely used cause of most practical applications, easier to operate, can be used for all kinds of welding positions, and is more efficient [1-5]. Electrodes are one of the parameters that influence the

*Corresponding author: azwinur@pnl.ac.id

strength of welding joints, therefore electrode type selection is very important in the welding process. The chemical element in the electrode coating is an element that becomes the welding parameter and it also influences the quality of the welding results. One of the defects in welding could be from electrode types used during the welding process, the electrodes also affect the toughness, hardness, and tensile strength of the welding results [6,7].

The strength of welding results is one of the objectives of welding, especially welding with different materials such as carbon steel material with stainless steel material, this is influenced by arc voltage, current magnitude, welding speed, electrode type, and electric polarity. The problem in welding of austenitic stainless steel is the formation of residual stress and distortion due to the expansion of stainless steel that is greater than carbon steel, decreased corrosion resistance, decreased mechanical properties, and brittleness due to the formation of precipitate chrome carbide between austenite grain boundaries [8]. However, the metal alloys can still be strengthened through various processes such as shot peening, heat treatment, and other treatments [9,10].

Welding of dissimilar material is a metal welding process that has different physical, mechanical, thermal, and metallurgical properties so that the characteristics of the weld joint between the two materials demand to be investigated. One of the cases is welding between stainless steel and carbon steel materials because the two types of material joints produce different microstructure and mechanical properties in the welded area. Control of the microstructure of the weld zone, especially when the root pass is very important because it can form a mixed phase of austenite, ferrite, and martensite [11]. Previous research conducted on the effect of the type of electrode on the results of welding and welding of dissimilar metal to obtain a good connection strength value [12-14]. Besides, the aims of this study to determine the effect of electrode type on the chemical composition of the alloy in the welding area, hardness, and the tensile strength characteristics of dissimilar welding joints between stainless steel SA.240 Tp.304 and SA.36 carbon steel materials.

2. Material and Method

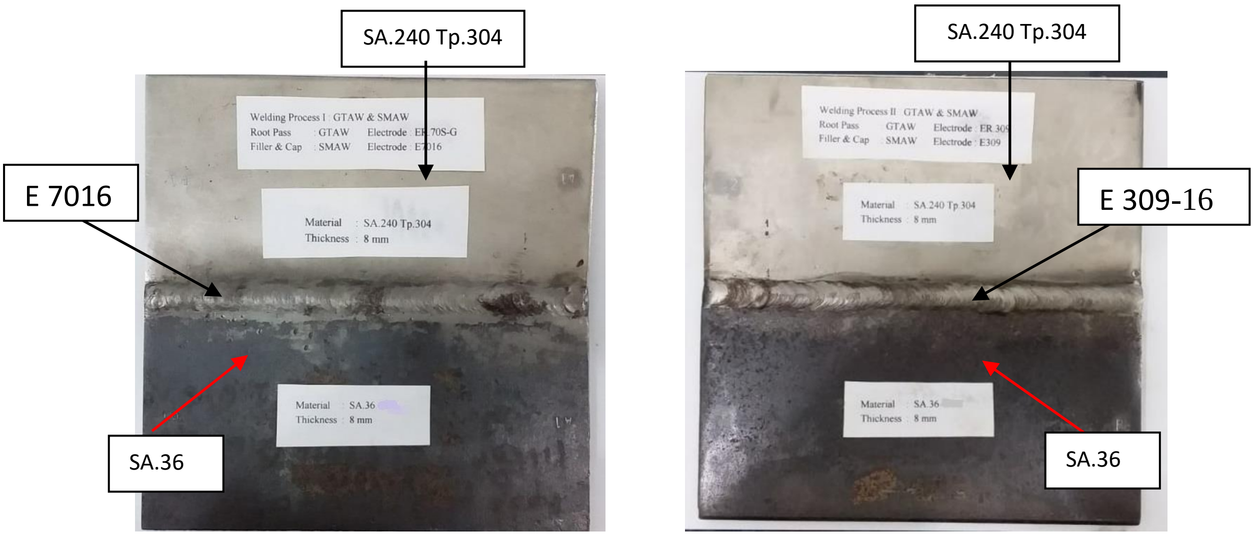
Materials used in this experiment were stainless steel SA.240 Tp.304 and SA.36 steel through the GTAW and SMAW welding processes. Dimensions of both plates are 8 x 250 x 150 mm and argon gas used during the GTAW welding process. Early-stage of this experiment was varying the type of electrodes such as E7016 Ø3.2 mm and E309L-16 Ø3.2 mm electrodes. Sample 1 welds Stainless Steel SA.240 Tp.304 and carbon steel SA.36 by using E7016 Ø 3.2 mm electrode, while specimen 2 joins stainless steel SA.240 Tp.304 and carbon steel SA.36 by using E309-16 Ø 3.2 mm electrode. The welding position carried out for both specimens is under the hand position or 1G position. The butt joint in this experiment used a single V type, gap distance of 3 mm, face root 2 mm, butt angle of 60^0. The process of making creating a butt joint as shown in Fig. 1.

Fig. 1 - Process of the machined butt joint.

Table 1 - Welding parameters and electrode variations

Electrode variations	Layers (Process)	I (A)	V (volt)	TS-Travel speed (mm/min)	Heat Input (kJ/mm)
Sample 1:	Root (GTAW	90	15	80	1.0
E 7016 electrode.	Filler (SMAW)	60	26	120	0.8
SA.36-SA.240 Tp.304	Cap (SMAW)	65	26	120	0.8
Sample 2:	Root (GTAW	100	11	70	0.9
E 309-16 electrode.	Filler (SMAW)	90	24	100	1.3
SA.36-SA.240 Tp.304	Cap (SMAW)	85	24	100	1.2

Before the welding process, first shaped the butt joint on both metal alloys, then the two workpieces welded using a GTAW root pass, the polarity used DCEN and currents set as shown in Table 1. The sample 1 welded, filler pass, and capped by using the E7016 electrode (Fig. 2a). After that welding on sample 2 welded, filler pass, and capped by using the E309-16 electrode (Fig. 2b). The welding defect examination was carried out by using the NDT (Non-Destructive Test) penetrant with a removable solvent (visible) technique [15], this inspection was carried out to obtain welding product with free from welding defects and to confirm the data accuracy, if the welding defect found beyond tolerance, then will be repeated the welding process or reproduce the sample (Fig. 3).



(a) **(b)**

Fig. 2 - Welded plates by using (a) the E 7016 and (b) the E 309 electrodes.

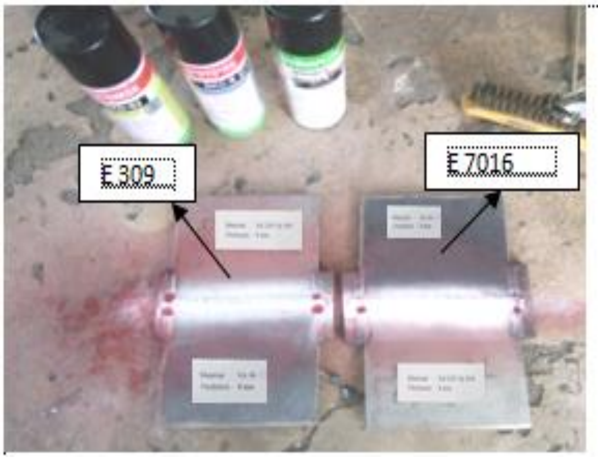


Fig. 3 - NDT Penetrant method of a solvent removable system for both samples with differences of the electrode

The chemical composition of metal alloys is identified through Positive Material Identification (PMI) testing. Some areas were identified as shown in Fig. 4a, such as the base metal (BM) area for both alloys (SA.240 Tp.304 and SA 36), the Heat affected zone (HAZ) area for both alloys (SA.240 Tp.304 and SA 36), and the welded area (weldment) for both electrodes (E7016 and E309L-16). Vickers's hardness used in this experiment is to test the strength of metal alloys with horizontal spread position on BM, HAZ, welded surface area. Hardness testing points were taken about 16 points and the distribution of the point as shown in Fig. 4b. A load of 1 kg is applied for up to 20 seconds [16]. Tensile test samples were cut from welding products after it is be previously confirmed that the welding product does not exceed the tolerance of welding defect, the tensile test sample refers to the ASTM-E8 standard. Tensile test samples were manufactured about three samples of each, such as metal welding with E309L-16 electrodes and welding with E7016 electrodes. The dimensions of the tensile test sample that follows the ASTM-E8 standard as shown in Fig. 5.

(a) (b)

Fig. 4 - (a) Identification of the chemical composition and (b) hardness of welded samples

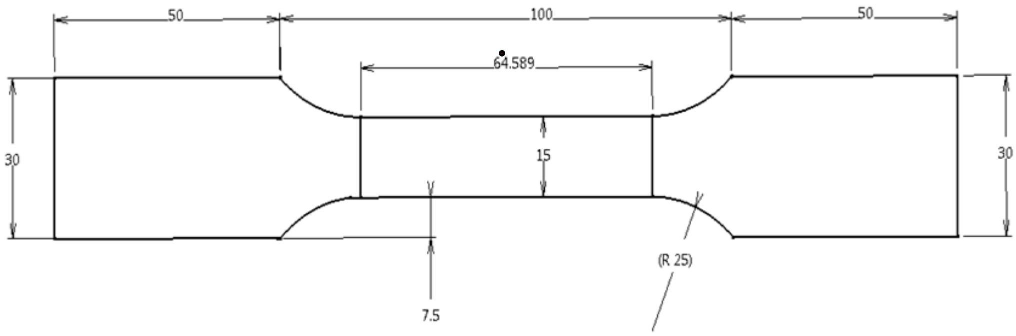


Fig. 5 - The dimension of the tensile sample [17].

3. Results and Discussion

The material used in this experiment is carbon steel SA.36 and stainless steel SA.240 Tp.304. The SA.36 plate steel is one of the strengthening material and ductile for structure material with a fine grain structure, and can be used for hot or cold working conditions. Two types of electrodes that using for dissimilar metal welding are E309 and E7016 electrodes. The chemical composition of materials was taken several positions through Positive Material Identification (PMI) on the E309 and E7016 electrodes as shown in Table 2. The chemical composition of the welded area appears affected by the chemical composition of both BM. The dominant Fe element followed by Fe then Cr for both BM.

Table 2 - Chemical compositions of materials taken at some places

Electrodes	Position	Element (wt.%)										
		Cr	Fe	P	S	Zr	Ag	Mn	Ni	Si	Co	Cu
E309-16	BM SA.240 Tp.304	18.37	71.87	0.00	0.02	-	-	-	-	-	0.19	0.03
	HAZ-SA.240 Tp.304	5.55	88.54	0.00	0.00	0.14	0.40	-	-	-	-	-
	Weldment	5.55	88.54	0.00	0.00	0.14	0.14	-	-	-	-	-
	HAZ-A.36	0.69	96.99	0.00	0.00	-	-	1.76	-	0.00	-	-
	BM A.36	0.03	99.03	0.00	0.02	-	-	0.42	-	0.50	0.42	-
E7016	BM SA.240 TP.304	18.37	71.87	0.00	0.02	-	-	-	-	-	0.19	0.03
	HAZ-SA.240 Tp.304	9.70	72.51	1.15	0.00	0.24	0.76	-	-	-	-	-
	Weldment	9.70	72.51	1.15	0.00	0.24	0.76	-	-	-	-	-
	HAZ-A.36	5.37	83.43	0.00	0.00	-	-	1.70	1.82	-	-	-
	BM A.36	0.03	99.03	0.00	0.00	-	-	0.42	-	0.50	0.42	-

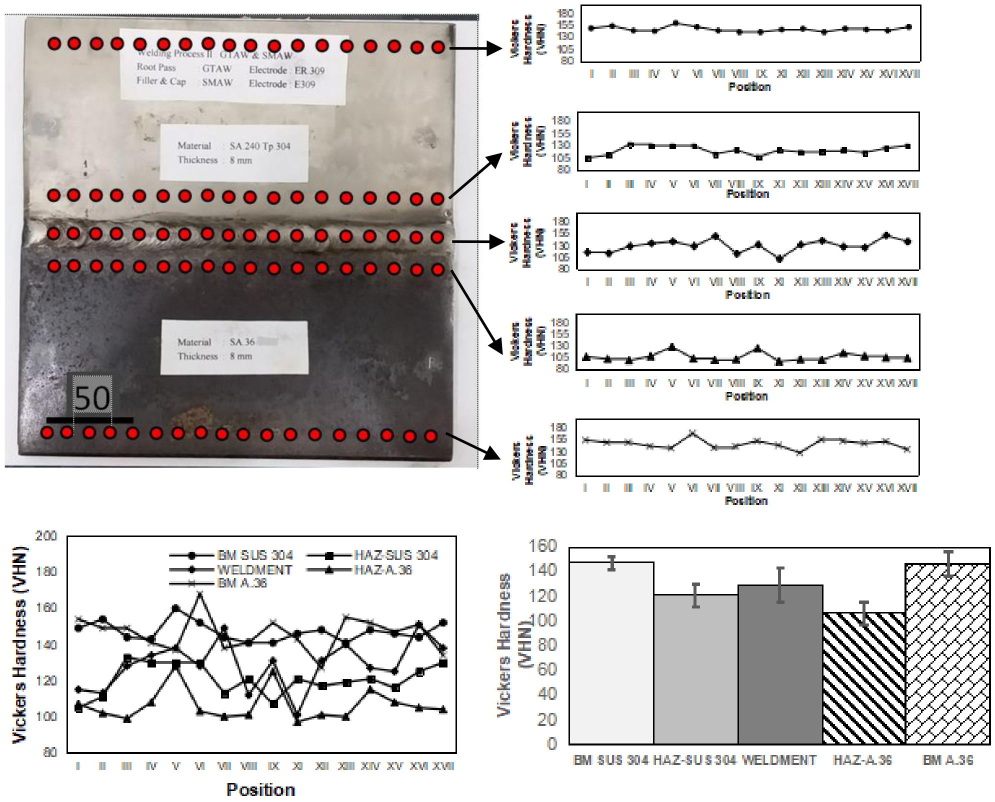
The hardness of materials tested on the surface of both different materials with the location at BM, HAZ, and welded areas. Tests are carried out each section with a horizontal direction of each about 16 points respectively. Fig. 6 shows the hardness value tested on the sample of dissimilar welded metals between the SA.240 Tp.304 stainless steel and SA.36 carbon steel alloys with the E309L-16 electrode. The hardness of the welding area looks high in the welded area which is 129 VHN when compared to the HAZ-SA.240 Tp.304 area which is 121 VHN and the HAZ-SA.36 area is 106 VHN (on average). While the hardness of surface BM-SA.240 Tp.304 is 147 VHN and BM-SA.36 is 146. The number of surface hardness from dissimilar welded metals with the E7016 electrode in the welding area was also high (148 VHN), when compared to the HAZ-SA.240 Tp.304 area which is 120 VHN and the HAZ-SA.36 area is 116 VHN. While the surface hardness of BM-SA.240 Tp.304 is 151 VHN and BM-SA.36 is 139 VHN. A comparison of the average hardness value in the welded area of two electrodes looks slightly higher on the weld products with the E7016 electrode compared to the E309L-16 electrode.

The high value of the surface hardness in the welded area indicates the good quality of welding results. The HAZ area for both materials tends to be lower than BM, this is caused by the heat from melt electrodes that can affect the hardness of BM in the HAZ area. The heat is needed to melt the electrodes so they can joint two metal parts during the welding process. This heat can affect the structural changes of both BM metal alloys that affected by heat. The structure of the metal plate is usually fine-flat elongated due to the influence of the rolling process. Besides the rolling process can produce residual stress on the plate of metal alloy. The fine grain structure and residual stress on the material can induce an increase in the hardness value of plate metal. The heat from the welding process can affect the base metal plate around the welded area, the area of heat-affected is called the HAZ area. The heat leads to changes in the metal grains structure that usually in coarse micro-structure shape. The heat also affects stress release, thereby eliminating residual stress due to rolling. Changes in grain structure from fine-flat elongated to coarse and stress release induce a decrease in material hardness. Systematic and numerical systematic have been investigated to correlate mechanical properties in the HAZ area using high fidelity micro-mechanical models and meso-scale mechanical analysis [18,19]. The temperature and stress areas calculated using the finite element method have been studied with the welded laser process with plate area. The results obtained are the temperature decay rate in the melting zone is lower than in solids. Coarse grains occur in the heat-affected zone and grain refinement and recrystallization occur in the fusion zone [20]. The fusion zone is characterized by bead width, bead height, and depth of penetration. The hardness value in the HAZ area is higher than the weld area and base metal, due to the rapid cooling rate, so that the grain is getting smoother the HAZ area [21].

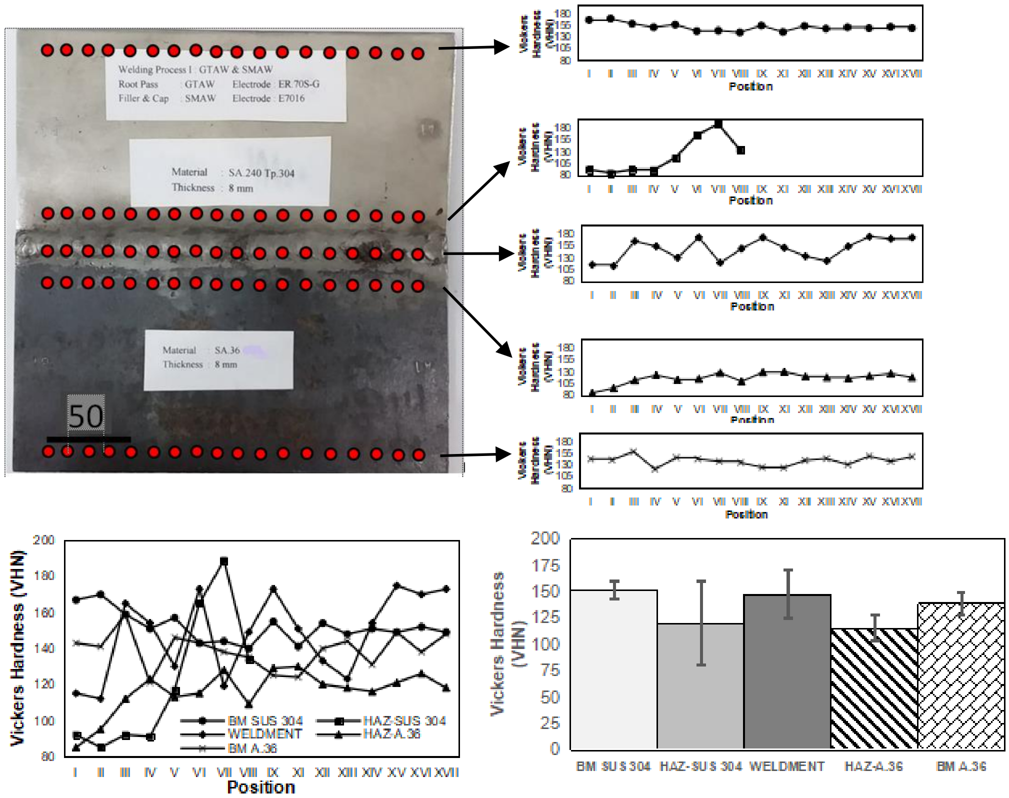
Tensile testing is carried out to determine tensile properties of welding dissimilar metals between steel steels SA.240 Tp.304 and carbon steel SA.36 alloys as subject material in this study. The result of tensile testing shows such as strength, plasticity, or ductility which is indicated by the percentage of elongation and percentage of contraction or reduction of the cross-section of tensile samples. The tensile strength of dissimilar welding between two differences electrodes (the E309 and E7016) by using welding current as 80 Ampere (Fig. 7a). Fig. 7b shows that the highest elongation of the welding product is 11.19 % at the E309L-16 electrode and 11.16 % found at the E7016 electrode, it seen an increase of number elongation about 0.3 % on the welded product that used E309 electrode.

The highest average tensile strength of welding products with the E7016 electrode is 46.83 kgf and the E309 electrode is 46.13 kgf. The tensile test values of two electrode differences were not significantly different in strength, even though the highest value was seen on the E7016 electrode. The test sample looks fracture in the HAZ area, this shows that the welding results in this experiment are better. This is caused by the heat generated during welding so that it affects the base metal of the two plates which are joined from two different materials. The heat affects the shape and size of the grains, where previously the flat-finer elongated changed into the coarse grain. Besides, this heat also affects the residual stress due to the plate rolling process, the heat induces stress release on the plate. The flat-fine elongated grain structure extends and the residual stress on the BM plate is caused by the rolling process during the production of the plate metal alloy. The heat behavior which is one of the physical phenomena that occurs during the welding process is very important to study of the width and depth of weld penetration, understanding of the changes in the microstructure that influenced BM affected by heat or residual stresses that arise during the welding process. If the welding energy is increased, the metal particles begun to grow gradually, and the morphology of the particles also beguns to change, from an almost near-square irregular to a round shape in phase [22]. Coarse grain zone that occurs in the HAZ area can diminishes of the tensile strength and impact toughness [23].

Overall, it can be seen that the results of the dissimilar welding of alloys through the SMAW process in this experiment were very successful in joining two different plate metals, such as SA.240 Tp.304 and SA.36. This can be confirmed by the high hardness value in the weld area and the tensile test sample also shows fractures in the HAZ region. The HAZ area is the weakest region because it is affected by heat during the welding process, it can be seen from the results of the hardness test that the HAZ area is indeed the weakest area of the joining process with dissimilar metal welding in this experiment. The influence of heat in the HAZ region is also divided into three thermal sections, namely high temperature re-transformation zone close to weld metal, medium temperature re-transformation zone, tempered zone close to BM that is not affected by heat. However, for the HAZ-tempere zone region is far from the fusion line of the welded portion which becomes the weakest region in the HAZ of the welded part, and fractures can occur depending on the value of the heat input energy during welding [24].

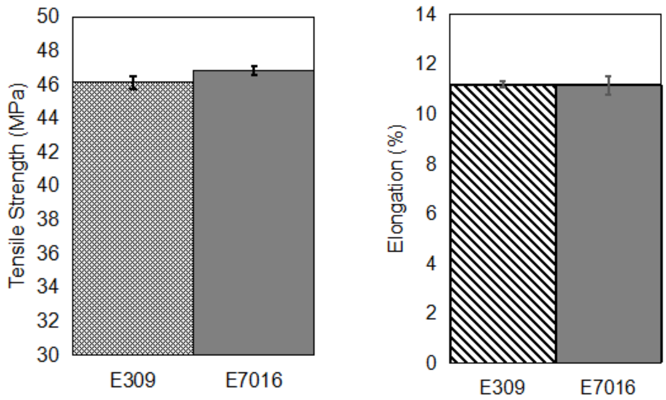


(a)



(b)

Fig. 6 - Hardness distribution at base metal, HAZ, and welded area for (a) E309 and (b) E7016 electrodes



(a) **(b)**

Fig. 7 - (a) Tensile strength (MPa) and (b) elongation of welding products with different electrodes

4. Conclusion

Dissimilar welding of stainless steel SA.240 Tp.304 and carbon steel SA.36 by using the SMAW welding process with two variations of electrodes, such as E7016 and E309-16. It can be concluded that the type of electrode greatly influences the average hardness value in the weld area. The hardness value of dissimilar metal welding is seen high on the E7016 electrode which is 148 VHN and the hardness value on the E309L-16 electrode is 129 VHN. The lowest hardness value is seen in the HAZ area, this is due to the influence of heat by melting electrodes during the welding process. While the highest hardness value is seen in both BM, this is caused by the rolling process during producing the metal plate. The number of tensile strength and elongation from dissimilar metal welding products does not significantly influence to joining of two materials, namely the number of the tensile strength of the E7016 electrode is 46.83 kgf, while E309 electrode is 46.13 kgf. Although dissimilar welding is strongly influenced by chemical elements and the mechanical properties of the core electrode material used. The element of chemical alloying looks slightly different between BM-SA.240 Tp.304 and BM-SA.36, this can be seen from the number of Fe and Cr in the metal alloy composition. Nevertheless, this experiment was very successful in joining two different materials between stainless steel SA.240 Tp.304 and carbon steel SA.36 through the GTAW process for the root pass, while the filler pass, and capping are welded through the SMAW process. Two electrodes such as E7016 and E309-16, can also be used to weld two plate materials SA.240 Tp.304 and SA.36 through the SMAW welding process.

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