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Comparative Study of Welding Material Elasticity with the SMAW Process for 2G Positions Between Before and After Using Welding Machines with Augmented Reality Technology

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Abstract

The high cost of certification and the low pass percentage in welding certification are common issues for beginner welders. The use of Augmented Reality (AR) technology is expected to solve these issues. The results of the penetrant, bending, and tensile tests showed that the welder who had used the AR welding machine produced better welding specimens than before they practiced using the AR welding machine. Welding is performed using the Shielded Metal Arc Welding (SMAW) procedure at the 2G position. The study was divided into three stages: (1) welding on a conventional welding machine to assess the competence of three beginner welders before practicing with an AR welding machine, (2) welding training with an AR welding machine for nine days, and (3) welding on a conventional welding machine to assess the effect of training with an AR welding machine on the competence of beginner welders. The penetrant, tensile, and bending test results for the three welders in stage (1) were not acceptable for ASME. They completed three levels of difficulty (basic, intermediate, and advanced) on the AR welding machine in stage (2) before continuing to stage (3). The results of their penetrant and tensile tests at stage (3) were acceptable for ASME The bending test results at stage (3) were still not acceptable for ASME, however none of the specimens were broken along the width of the specimen as in several of the specimens at stage (1). The research results are expected to serve as a guideline for welding education, training, and certification organizations interested in incorporating AR welding machines into their training and certification activities.

1. Introduction

Ships will continue to be produced as the primary mode of sea transportation in Indonesia, whether by government or private shipyards. Shipyards must be prepared to repair existing ships in addition to building new ones. According to data held by the Ministry of Transportation of the Republic of Indonesia, Indonesia had a total of 100.025 ships in August 2022, including 4.908 passenger ships, 50.425 fishing boats, and 44.692 cargo ships [1]. The welding process is definitely involved in the process of fabricating a new ship at the shipyard, as well as when the ship is making repairs, for example, welding work when the ship is changing plates is also very necessary. Welding is the process of joining two or more metal parts with heat energy. Welding is a critical activity in the process of building steel ships because it is used to join plates in almost every part of the ship. Welding is composed of various procedures, including Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW), Gas Tungsten Arc Welding (GTAW), and Submerged Arc Welding (SAW). SMAW is the most often used welding process in the industrial sector, particularly in shipbuilding. SMAW is considered the simplest arc welding process because the equipment used is easily moved from one location to another and the overall setup is relatively inexpensive. Furthermore, because this process uses various types of electrodes, there are lots of applications for joining various metals and their alloys [2].

According to the Asian Welding Federation (AWF), the welding sector has a labor supply requirement of 100.000 people. There is still a deficit of 50.000 competent employees within that amount [3]. This requirement is still not completely available and professionally acknowledged; PT. Kampuh Welding Indonesia, one of Indonesia's leading welder certification organizations, has only performed 3,000 welder competence certificates till 2022 [4]. The world of education in Indonesia also helps to developing welding competency, with one example being the Madura State Polytechnic (POLTERA) through the

D3 Study Program in Shipbuilding Engineering and Heavy Equipment Mechanical Engineering. The high cost of certification and the low possibility of completion are some of the problems that students confront when participating in the welder competency certification.

Welder competence can be proven with competency certificate from Professional Certification Institute. Welder qualification based on the regulation of Ministry for Labour Republic Indonesia as follows [5]: class 1 welder (graduate from test in weld position 1G, 2G, 3G, 4G, 5G and 6G), class 2 welder (graduate from the test in weld position 1G, 2G, 3G, and 4G), class 3 welder (graduate from the test in weld position 1G and 2G). Weld position shown on the Figure 1. One of the issues with uncertified beginner welders is the high cost of training and the high probability of failure because their understanding of the welding world is still limited. For class III welders, the average cost of the SMAW welding competency certification test is Rp. 16.000.000,00 to Rp. 21.000.000,00, with a training period of 6 to 12 days.

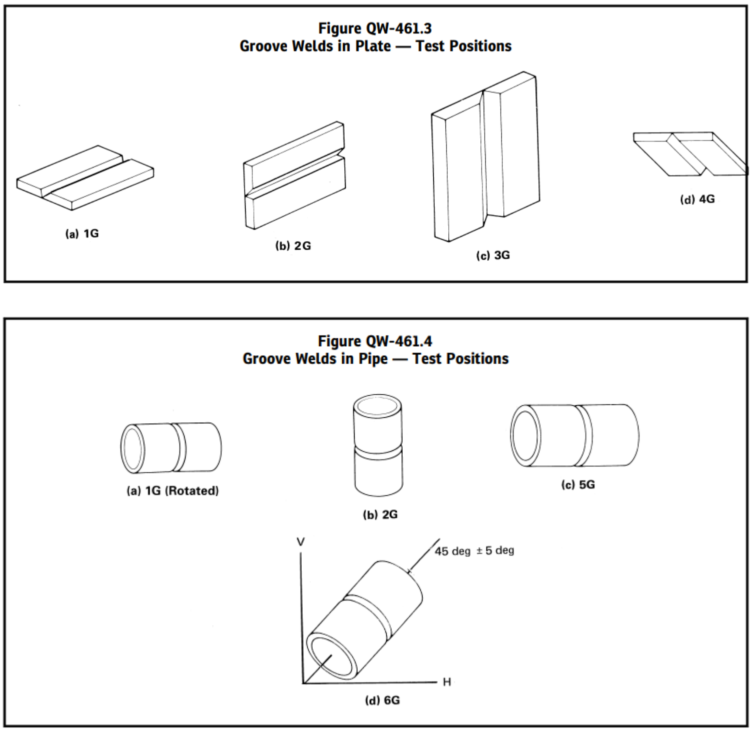


Figure 1. Welding Position According to ASME Section IX [6]

Okimoto, et al. [7] has carry out research for application Augmented Reality (AR) in welding education with welding machine SOLDAMATIC. Results from this research are students were initially very motivated to do the training, especially for the high degree of novelty both the use of the equipment, not knowing AR technology, as the practical application of welding technique. The AR training in welding occurred at the start of the course, anticipating the period of practice on real equipment. The views were very satisfactory by the introduction of technology in teaching, but were reported difficulties in visual accommodation while using the equipment [7]. Park & Seo [8] created an AR that works to overcome the inherent problems of augmented/virtual reality-based welding training systems. The newly designed system meets the requirements for presence, hand-eye coordination, welding posture versatility, weld form diversity, and weld diagnostics. Three approaches are used to design an ideal welding training system: augmented reality, neural networks, and writable content. As a result, it is hoped that by implementing the proposed augmented reality welding training system in this case learning, it can be used as an educational tool to grow experienced welders in a short period of time [8]. Wells & Miller [9] have also conducted research on the effects of Virtual Reality (VR) on GMAW welding processes. The results of their research is that using a VR technology application within the context of a one-hour-long GMAW process training impacted welding skill performance as determined by Certified Welding Inspectors (CWI) who used a weld evaluation rubric based on American Welding Society (AWS) standards. One-hundred-and-one students from Iowa State University participated in our study. Participants were randomly placed into one of four protocol groups: (1) 100% live welding, (2) 100% VR welding, (3) 50% live welding/50% VR welding, or (4) 50% VR welding/50% live welding. A one-way analysis of variance (ANOVA) indicated there were no statistically significant differences ($p>0,05$) in total weld scores between participants in the four training protocol groups. We recommend this study be replicated [9]. Fariya and Triwilaswandio [10] have carry out research in welding simulator based on computer program to replace conventional electrode. Results from this research are training participant can used welding simulator in 4 (four) days practice and reduced training cost 18%. In their research, Mawahib, et al. [11] investigated the impact of the power source produced by a generator engine on welding joints, which produced wormholes and cracks when the electric current was too low. Therefore, tensile and impact tests were performed on a variety of electrode diameters, and superior results were obtained for the tensile and impact tests on electrodes with a diameter of 3,2 mm at plate thicknesses of 8 and 10 mm, respectively. Several studies have shown that welding machines equipped with AR and/or VR technology are effective at developing welder skills and reducing consumables during training, but no one has compared the effectiveness of AR welding machines for beginner welders in terms of quality welding results in conventional welding machines.

Figure 2. The Application of Augmented Reality Technology in Welding Activities

One of the solutions for increase graduation chance for beginner welders its use AR weld technology is shown in Figure 2. AR is combination from item or shape in virtual reality which is applied to actual reality in two dimensional or three dimensional, so it can be seen, touched and heard [12]. The use of AR technology on welding machines is expected to reduce the amount of consumable material used while the welder prepares for competency certification and to improve the quality of welding results in the workshop. AR welding machine in this research is a product from SOLDAMATIC which owned by POLTERA. Beginner welders in this study are defined as new students of the D3 Shipbuilding Engineering Study Program (second semester) who have never done welding before. The objective of this research was to investigate the effects of training using an AR welding machine on the quality of welding results for beginner welders while welding with a conventional welding machine. The quality of the welding results evaluated is determined by penetrant, tensile, and bending tests performed before and after the beginner welder practice using AR welding machine. This research is important because it is impossible for a welder to weld using an AR welding machine to connect between plates or pipes in the world of shipbuilding, and it is also not designed to use an AR welding machine forever in the world of education, so knowing the effectiveness of the AR welding machine being evaluated from the quality of the welding results from a beginner welder becomes a very important activity. The results presented from the research are expected to be a guideline for welding education, training and certification institutions to be able to involve AR welding machines in their training and certification activities.

2. Methods

The implementation of this research begins with a literature study and data search. The Welding Procedure Specifications (WPS) used refers to a journal written by Rahmatika, et al. [13]. The material used is an SA-36 low-carbon steel plate with a thickness of 10 mm. The welded joint design is a butt joint-single V-groove connection with a joint angle of 70°, as shown in Figure 3. The specimen was fit up with a root gap of 3,2 mm. SMAW welding is processed with a 2G (flat) welding position. The E7016 electrode with a diameter of 2,6 mm with DCEN polarity is used for the root pass, while the filler uses an E7018 electrode with a diameter of 3,2 mm with DCEP polarity [13]. After determining the WPS used, 3 (three) students were sought as representatives of the beginner welders. The students involved were second-semester students of Shipbuilding Engineering Department, Madura State Polytechnic. The names of the students involved are A. Mudzakir Farisi, Eko Maulana, and Irbat Fanani. The selected students are then asked to do welding on a conventional welding machine. After carrying out the welding, the students carried out a destructive test in the form of a tensile and bending test. Furthermore, students who carry out welding on conventional welding machines, then students will carry out welding on welding machines with AR technology for 9 (nine) days. Welding in the AR welding machine is divided into three levels of difficulty, that is:

1. Beginner, with a determined passing grade not less than 90;
2. Intermediate, with a determined passing score of not less than 85;
3. Advanced, with a specified passing score of not less than 80.

The threshold value is determined based on an assessment for practical welding performed at Madura State Polytechnic, where students are not permitted to receive a score lower than 81 in order to receive an A (81-100). The Welding Procedure Specification (WPS) used in the AR welding machine is made as similar as possible to welding in a conventional welding machine, as shown in Table 1. The number of layers that can be accommodated by an AR welding machine can be seen in Figure 4. It can be seen that the number of layers used is three layers.

Students return to welding on conventional welding machines when they pass the test for welding on AR welding machines by passing all three levels of difficulty. Welding in a conventional welding machine is carried out for two specimens at a 2G welding position with the SMAW process. The initial test carried out was the penetrant test, the best result from the penetrant test was then carried out a tensile test and a bending test. The result of the tensile and bending test before welding in an AR welding machine will be compared with after using the AR welding machine.

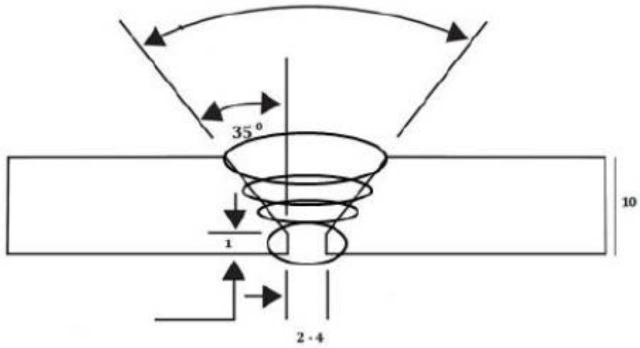


Figure 3. Welded Joint Design [13]

Table 1. AR Welding Machine WPS

Layer/Pass	Material	Process	Thickness (mm)	Position	Electrode	Diameter (mm)	Wave Pattern
Pass 1	Carbon Steel	SMAW	10	2G	E7018	2,50	Straight
Pass 2	Carbon Steel	SMAW	10	2G	E7018	3,25	Straight
Pass 3	Carbon Steel	SMAW	10	2G	E7018	3,25	Straight

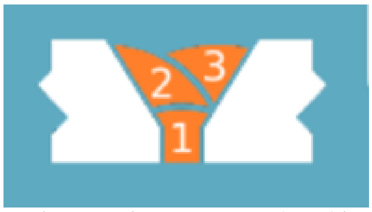


Figure 4. Welding Passes that Can be Accommodated by AR Welding Machines

2.1. Tensile Test

The tensile test is the application of a tensile force or stress to a material with the intention of knowing or detecting the strength of a material. The tensile stress used is the actual external stress or the extension of the axis of the test object [14]. According to ASME Section IX, the number and types of destructive tests carried out to qualify the welding procedure with a specimen thickness of 10 mm are 6 (six) specimens test with details: two specimens for tensile tests; two specimens for root bend test; and two specimens for the face bend. More clearly can be seen in Figure 5. The tensile test can show several ductile and brittle fracture phenomena that can be seen with the naked eye. The tensile strength of a material can be known if the line of force coincides with the axis of the material so that the load occurs in a straight tensile load. Specimens for tensile tests according to ASME Section IX can be seen in Figure 6.

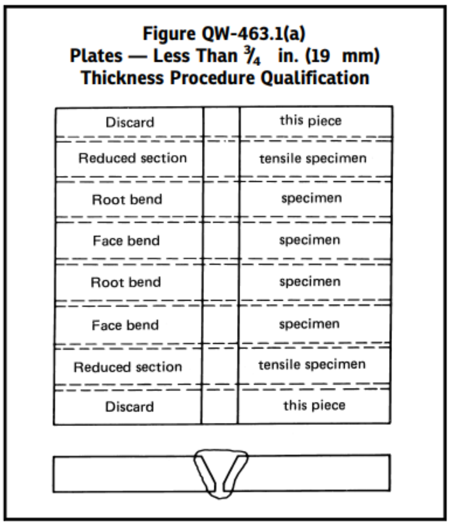


Figure 5. Cutting Plan for Destructive Test According to ASME Section IX [6]

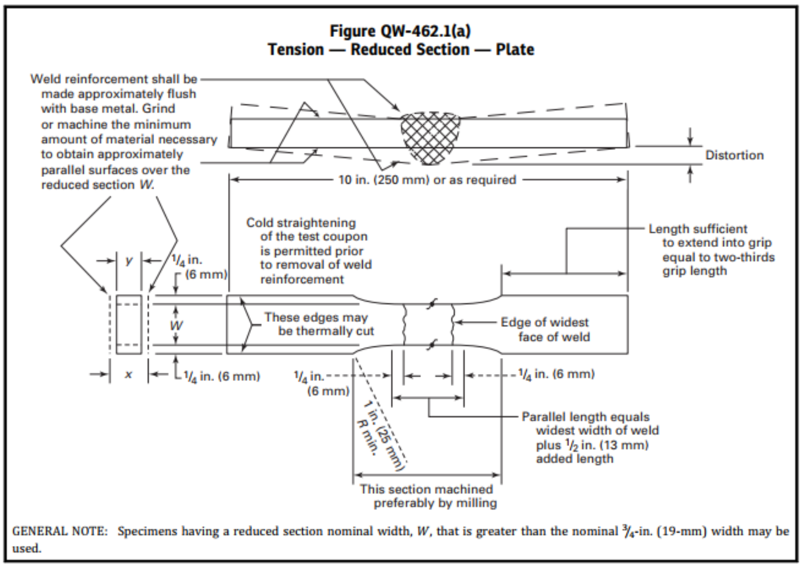


Figure 6. Tensile Test Specimen According to ASME Section IX [6]

The weld specimen that has been subjected to a tensile test must meet the acceptance criteria for the tensile test in accordance with the ASME BPVC Section IX standard referring to QW-153.1 [6], namely, to be declared to have passed the tensile test, the tensile strength of the specimen must be no less than:

a. The specified minimum tensile strength of the base metal;
b. If the base metal consists of two base metals with different minimum tensile strengths, the minimum tensile strength is determined by the weakest base metal;
c. The minimum tensile strength of the weld metal, if the standard requires the use of a weld metal with a lower tensile strength than the base metal at room temperature;
d. If the specimen breaks on the base metal outside the weld or outside the weld fusion line, the test is declared to have passed if the minimum tensile strength is 5% less than the base metal's minimum tensile strength.

2.2. Bending Test

The manufacture of bending test specimens refers to the ASME Section IX standard for bending test, which can be seen in Figure 7. In the bending test treatment, the upper part of the specimen undergoes a compression process and the lower part undergoes a tensile process so that the lower part of the specimen is fractured because it is unable to withstand tensile stress [15].

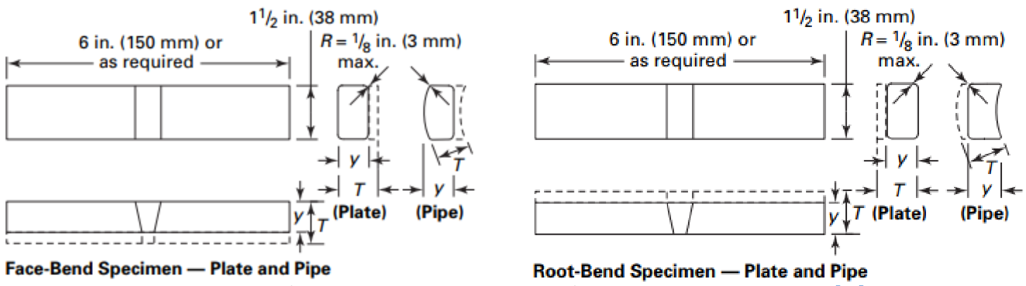


Figure 7. Bending Test Specimen According to ASME Section IX [6]

3. Results and Discussion

3.1. Welding with an Augmented Reality Welding Machine

Welding in an AR welding machine takes 9 days, with 3 days for the beginner level, 3 days for the intermediate level, and 9 days for the advanced level. The number of days used for welding on AR welding machines is determined by Professional Certification Institutions such as PT. Kampuh Welding Indonesia and PT. PAL Indonesia, where the training and certification period is 8-12 days. Table 2 shows the welding parameters included in the AR welding machine, as well as the values for each parameter. Based on the 5 (five) welding parameters, namely work angle, travel angle, travel speed, aim, and arc length, it can be seen that A. Mudzakir Farisi has the highest score for the beginner difficulty level with an overall score of 94,73; for the intermediate difficulty level, Eko Maulana has the highest score with an overall score of 94,13; and for the advanced difficulty level, Eko Maulana has the highest score with an overall score of 87,73. Beginner welders can return to traditional welding machines after 9 (nine) days of training on AR welding machines and passing the threshold value at each level of difficulty. Figure 8 illustrates the three beginner welders able to pass the predetermined threshold value at each level of difficulty, permitting them to return to welding in the 2G position on conventional welding machines.

Table 2. Details Score for Welding Parameters at the AR Welding Machine

No	Student Name	Levelling of the AR Welding Machine	Welding Parameters					Overall Score
			Work Angle	Travel Angle	Travel Speed	Aim	Arc Length	
1.	A. Mudzakir Farisi	Beginner	96,00	95,67	96,67	98,00	87,33	94,73
			97,33	96,67	96,00	98,33	85,33	94,73
			98,00	93,67	94,00	95,67	88,67	94,00
		Intermediate	93,33	96,33	92,67	96,33	86,67	93,07
			97,33	96,33	90,67	95,33	85,67	93,07
			97,00	95,67	90,33	96,33	87,67	93,40
		Advanced	84,67	94,67	73,67	96,67	87,33	87,40
			88,67	89,00	79,33	92,33	75,67	85,00
			84,67	84,67	81,33	94,00	79,33	84,80
2.	Eko Maulana	Beginner	94,67	96,67	96,33	95,33	86,33	93,87
			93,00	96,67	94,67	98,67	88,67	94,34
			96,00	95,67	95,00	95,53	86,67	93,77
		Intermediate	98,67	95,00	92,67	97,00	86,00	93,87
			98,00	96,33	92,33	97,33	85,33	93,86
			97,67	98,00	95,00	96,67	83,33	94,13
		Advanced	98,33	96,00	67,00	96,00	81,33	87,73
			97,67	94,33	69,33	97,33	80,00	87,73
			95,33	93,67	73,00	90,67	83,33	87,20
3.	Irbat Fanani	Beginner	96,00	94,00	96,33	97,67	84,00	93,60
			92,67	96,33	95,33	97,33	83,00	92,93
			95,00	98,33	96,67	97,00	85,00	94,40
		Intermediate	97,67	97,67	89,67	95,67	83,33	92,80
			97,33	95,33	89,00	98,00	88,67	93,67
			98,67	93,33	91,33	97,67	85,67	93,33
		Advanced	92,67	86,33	63,67	96,00	68,30	81,39
			97,33	88,67	56,67	97,00	77,33	83,40
			96,33	93,67	54,33	96,67	76,00	83,40

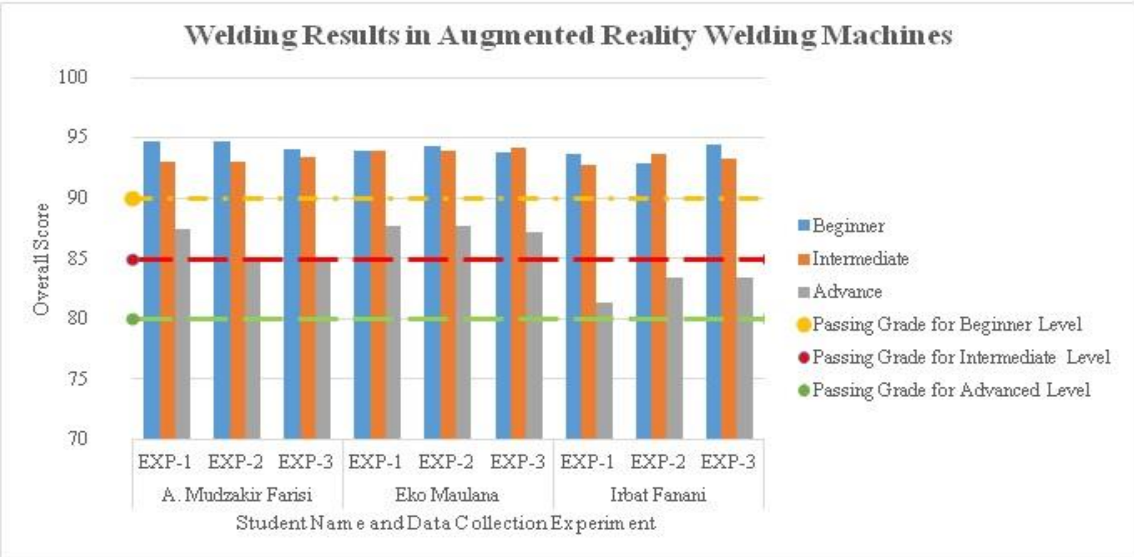


Figure 8. Welding Results in AR Welding Machines

3.2. Welding with Conventional Welding Machine

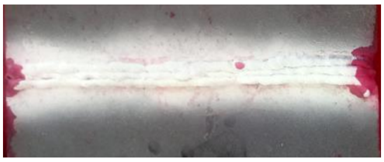
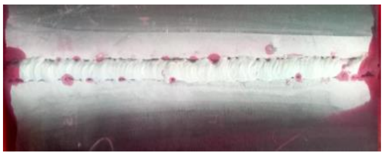
The three students welded in a conventional welding machine under two conditions: before and after using the AR welding machine. Students are given the opportunity to do welding four times, with details two times before and two times after using the AR welding machine. The welding results used for bending and tensile test are the best welding results based on the penetrant test accepted by ASME Section V. The results of the penetrant test are shown in Table 3.

The results shown in Table 3 are the results of welding performed by A. Mudzakir Farisi; Eko Maulana; and Irbat Fanani. Table 3 shows that after 9 days of using the AR welding machine, 3 (three) students representing beginner welders can produce better penetrant tests. The welding results before using the AR welding machine revealed that the three students had failed to meet the ASME Section V criteria, but the welding results after using the AR welding machine revealed that the three students had succeeded in meeting the criteria. According to ASME Section V Article 6, acceptance criteria are:

1. Relevant linear indication (>1,5 mm);
2. Relevant rounded indication (>5,0 mm);
3. Four or more relevant rounded indications in a straight line with a distance of ≤ 1,5 mm, from one end of the indication to the other.

As a result, the use of the AR welding machine has a significant influence on the visual test (penetrant test) and can be used as a consideration for the implementation of welder training and certification.

Table 3. Penetrant Test Results Before and After using the AR Welding Machine

No.	Student Name	Condition	Penetrant Test Photo	Type of Defect	Remark
1.	A. Mudzakir Farisi	Before using the AR welding machines		Rounded defects in three locations with the largest defect size is 3,6 mm; linear defects with a length of 89,3 mm	Reject
2.	A. Mudzakir Farisi	After using the AR welding machines		Rounded defects with the defect size is 1,44 mm	Accept
3.	Eko Maulana	Before using the AR welding machines		Rounded defects in seven locations with the largest defect size is 18 mm; linear defects with a length of 14 mm	Reject
4.	Eko Maulana	After using the AR welding machines		Rounded defects in four locations with the largest defect size is 3,5 mm; linear defects with a length of 1 mm	Accept
5.	Irbat Fanani	Before using the AR welding machines		Rounded defects in thirteen locations with the largest defect size is 20 mm; linear defects with a length of 32 mm	Reject
6.	Irbat Fanani	After using the AR welding machines		There are ten rounded defects, with the largest size being 4 mm and the distance between rounds being more than 1,5 mm	Accept

3.3. Result of Tensile and Bending Test

Table 3 shows the tensile test results of the three beginner welders. According to Table 4 and Figure 9, the results of the tensile test performed by the beginner welder using the AR welding machine show that no tensile stress exceeds the minimum tensile strength of SA-36 steel (less than 400 N/mm^2). The tensile test results after the beginner welder performed welding on the AR welding machine revealed that the resulting tensile stress was able to exceed the tensile strength threshold for SA-36 steel (all specimens produced a maximum tensile stress value of more than 400 N/mm^2).

Table 5 shows a visualization of the tensile test specimen results. All tensile test specimens, with the exception of the welder on behalf of A. Mudzakir Farisi, suffered fractures in the base metal after the welder performed welding on the AR welding machine. Based on the tensile test results in terms of maximum stress generated and fracture of the specimen on the base metal after the welder performs welding on the AR welding machine, it is clear that the use of the AR welding machine has a significant impact on the beginner welder's welding quality.

The bending test is performed in accordance with ASME Section IX, with the condition that the guided-bend specimens shall have no open discontinuity in the weld or heat-affected zone exceeding 3 mm, measured in any direction on the convex surface of the specimen after bending [6]. All specimens from the bending test before the beginner welder practiced using the AR welding machine were not accepted by ASME because the length of the open discontinuity was greater than 3 mm, as shown in Table 6. The bending test specimen for welding results showed a smaller maximum open discontinuity length after the welder practiced using the AR welding machine than before using the AR welding machine. There is also a specimen accepted by ASME, with a maximum open discontinuity length of 2,9 mm.

Table 4. Result of Tensile Test

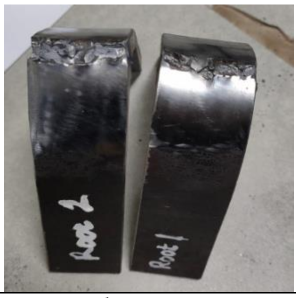
Student Name	Component	Specimen 1		Specimen 2	
		Before using the AR Welding Machine	After using the AR Welding Machine	Before using the AR Welding Machine	After using the AR Welding Machine
A Mudzakir Farisi	L_0 (mm)	270,50	296,45	270,50	296,45
	L_1 (mm)	281,20	306,75	280,65	308,00
	W_0 (mm)	19,30	19,30	19,50	21,00
	W_1 (mm)	17,45	16,55	17,20	17,40
	t_0 (mm)	9,60	10,00	9,60	10,35
	t_1 (mm)	7,30	9,00	8,20	8,60
	A_0 (mm^2)	185,28	193,00	188,16	217,35
	P_{max} (N)	73917	79269	73162	99025
	σ_{max} (N/mm^2)	398,95	410,72	388,83	455,60
	ΔL (mm)	10,70	10,30	10,15	11,55
	e (%)	3,96	3,47	3,75	3,90
	E (N/mm^2)	100,86	118,21	103,62	116,94
Eko Maulana	L_0 (mm)	263,30	297,60	263,30	297,60
	L_1 (mm)	270,20	305,47	271,20	304,25
	W_0 (mm)	22,11	21,85	21,10	22,20
	W_1 (mm)	20,20	15,75	20,40	16,40
	t_0 (mm)	9,05	9,85	9,05	10,00
	t_1 (mm)	8,00	6,10	9,40	4,25
	A_0 (mm^2)	190,00	195,00	190,00	195,00
	P_{max} (N)	74615	83826	67814	82342
	σ_{max} (N/mm^2)	392,71	429,88	356,92	422,27
	ΔL (mm)	6,90	7,87	7,90	6,65
	e (%)	2,62	2,64	3,00	2,23
	E (N/mm^2)	149,86	162,56	118,96	188,97
Irbat Fanani	L_0 (mm)	261,40	284,50	261,40	284,50
	L_1 (mm)	274,65	298,30	273,60	298,25
	W_0 (mm)	20,80	21,25	19,00	21,60
	W_1 (mm)	18,00	15,30	17,55	14,80
	t_0 (mm)	9,65	9,40	9,00	9,00
	t_1 (mm)	7,40	5,55	8,10	5,65
	A_0 (mm^2)	200,00	199,75	198,00	194,40
	P_{max} (N)	75129	86147	78720	85279
	σ_{max} (N/mm^2)	375,65	431,27	397,58	438,68
	ΔL (mm)	13,25	13,80	12,20	13,75
	e (%)	5,07	4,85	4,67	4,83
	E (N/mm^2)	74,11	88,91	85,19	90,77

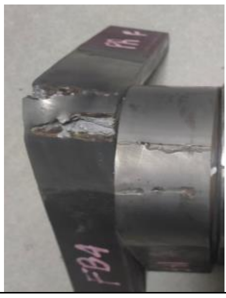
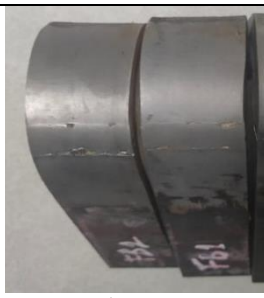
Table 5. Tensile Test Photo Results Before and After using the AR Welding Machine

No.	Student Name	Tensile Test Photo Before using the AR Welding Machine	Tensile Test Photo After using the AR Welding Machine	Results
1.	A. Mudzakir Farisi			The tensile test results before and after using the AR welding machine show that the fracture is in the weld metal
2.	Eko Maulana			The tensile test results before using the AR welding machine revealed that a fracture occurred in the weld metal, whereas the fracture occurred in the base metal after using the AR welding machine

No.	Student Name	Tensile Test Photo Before using the AR Welding Machine	Tensile Test Photo After using the AR Welding Machine	Results
3.	Irbat Fanani			The tensile test results before using the AR welding machine revealed that a fracture occurred in the weld metal, whereas the fracture occurred in the base metal after using the AR welding machine

Table 6. Bending Test Photo Results Before and After using the AR Welding Machine

No.	Student Name	Bending Test Photo Before using the AR Welding Machine	Bending Test Photo After using the AR Welding Machine	Results
1.	A. Mudzakir Farisi	Face Bend  Root Bend 	Face Bend  Root Bend 	The bending test results showed that before using the AR welding machine, the specimen was broken into two parts, whereas after using the AR welding machine, it looked much better but still did not meet the criteria
2.	Eko Maulana	Face Bend  Root Bend 	Face Bend  Root Bend 	The bending test results showed that after using the AR welding machine, the beginner welder produced better welds but still did not meet the criteria
3.	Irbat Fanani	Face Bend	Face Bend	The bending test results showed that after using the AR welding machine, the beginner welder produced better welds

No.	Student Name	Bending Test Photo Before using the AR Welding Machine	Bending Test Photo After using the AR Welding Machine	Results
		 Root Bend 	 Root Bend 	but still did not meet the criteria

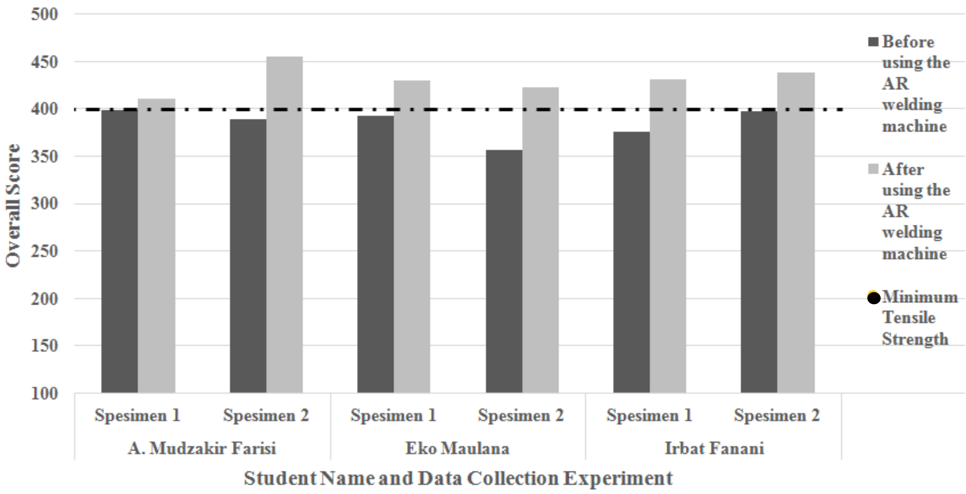


Figure 9. Tensile Test Result

Table 7. Result of Bending Test

No.	Student Name	Name of Specimen	Maximum Open Discontinuity Length (mm)			
			Before using the AR Welding Machine	Remark	After using the AR Welding Machine	Remark
1	A Mudzakir Farisi	Face bend 1	37,55	Reject	9,40	Reject
		Face bend 2	36,50	Reject	7,20	Reject
		Root bend 1	36,30	Reject	2,90	Accept
		Root bend 2	37,00	Reject	37,00	Reject
2	Eko Maulana	Face bend 1	11,05	Reject	3,80	Reject
		Face bend 2	46,50	Reject	7,90	Reject
		Root bend 1	10,50	Reject	5,20	Reject
		Root bend 2	11,80	Reject	7,85	Reject
3	Irbat Fanani	Face bend 1	36,10	Reject	21,00	Reject
		Face bend 2	38,10	Reject	32,10	Reject
		Root bend 1	18,10	Reject	18,10	Reject
		Root bend 2	12,00	Reject	12,05	Reject

Table 6 shows a visual representation of the bending test results. According to Table 7, the results of the welding before A. Mudzakir Farisi and Irbat Fanani used the AR welding machine, the specimen tested for bending was broken along the width of the specimen, but the results obtained after the beginner welder used the AR welding machine did not meet the ASME criteria but there were no broken specimens along the width of the specimen.

The DT and NDT tests were performed by technicians from the Madura State Polytechnic's DT-NDT laboratory. Rioes Putrananto Ulmi, the technician, already has a competency certificate for DT-NDT testing, which allows the results to be accounted for. The DT-NDT test was also conducted under the direct supervision of a BNSP Welding Inspector certified lecturer on behalf of Anauta Lungiding Angga Risdianto and a JWES Welding Engineer certified lecturer on behalf of Arief Syarifuddin.

4. Conclusion

The three beginner welders used the AR welding machine to finish their SMAW welding training in the 2G position. They welded conventionally before and after the training to evaluate the effectiveness of training with AR welding machine in aspects of penetrant, tensile, and bending test. They had to pass three degrees of difficulty on the AR welding machine before being permitted to perform the second conventional welding. A comparison of the quality of their welding results before and after using the AR welding machine showed a significant improvement. These results can be used as data by Professional Certification Institutions for the implementation of AR welding machines in competency and certification training activities.

Suggestions for future research include evaluating the use of AR welding machines for position, process, and other welding materials, and directly involving Professional Certification Institutions during research activities and data collection. Professional Certification Institutions are expected to provide feedback on the effectiveness of using AR welding machines to improve welding quality. Subjects for research can use a professional welder whose certificate will expire. Its purpose is to investigate the effect of the AR welding machine on professional welders so that it can be used for activities to extend the welder's expired certificate.

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