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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

Arief Syarifuddin[1)], Erdina Arianti[2)*)], Kusnindar Priohutomo[2)], Rosi Dwi Yulfani[2)], Berlian Arswendo Adietya[3)], Aurista Miftahatul Ilmah[1)], Taufan Prasetyo[1)]

[1)] Shipbuilding Engineering Department, Madura State Polytechnic, Sampang 69281, Indonesia
[2)] Research Center for Hydrodynamics Technology, National Research and Innovation Agency, Surabaya 60112, Indonesia
[3)] Naval Architecture, Diponegoro University, Semarang 50275, Indonesia
[*)] Corresponding Author : erdina.arianti@brin.go.id

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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. The penetrant test after beginner welder practiced using the AR welding machine produces rounded defects with a defect size of 1,44 mm (accepted by ASME Section V), whereas before they practiced using the AR welding machine it produces defects that cannot be accepted by the criteria. The maximum open discontinuity length in the bending test on the welded specimen after welder practiced using the AR welding machine is 2,90 mm (accepted by ASME Section IX), whereas the bending test before welder practiced using the AR welding machine is not accepted by the citeria. The tensile test results after welder practiced using the AR welding machine were 410,00 and 455,66 N/mm^2 for the maximum tensile stress. This value exceeds the minimum tensile strength of SA-36 carbon steel, which is 400 N/mm^2. When compared to the specimen before the welder practiced using the AR welding machine, the modulus of elasticity produced after the welder practiced using the AR welding machine is also smaller, indicating that the material has better elasticity. Based on the results of the tests, it can be seen that the AR welding machine can be used for the implementation of competency certification because the quality of the weld results is better, there are fewer risks (sparks, eye irritation, and burns), and the use of welding consumables is reduced.

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.

Figure 1. The application of Augmented Reality Technology in Welding Activities

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. For that, its important welder competence. 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 [2]: 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 2. 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.

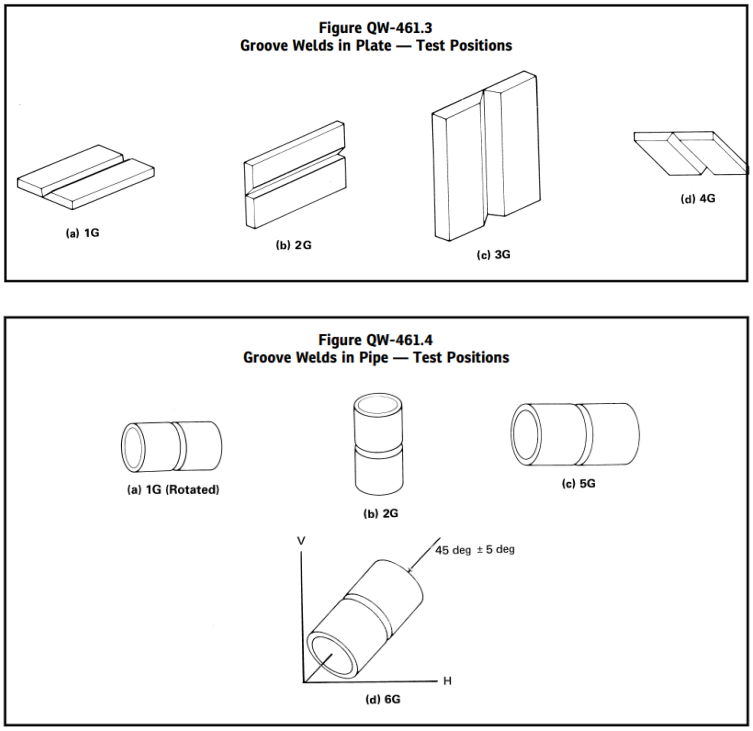


Figure 2. Welding Position According to ASME Section IX [3]

One of the solution for increase graduation chance for beginner welders its use Augmented Reality (AR) Weld Technology is shown in Figure 1. 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 [4]. 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 based on tensile and bending tests. AR welding machine in this research is a product from SOLDAMATIC which owned by Madura State Polytechnic.

Okimoto, et al [5] has carry out research for application 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 [5].

Fariya and Triwilaswandio [6] have carry out research in welding simulator based on computer program to replace conventional electroda. Results from this research is training participant can used welding simulator in 4 days practice and reduced training cost 18%. Another research explain there is no research focused on the effectivity of AR welding machine based on welding quality in conventional welding machine. For that, this paper research focused on comparation for elasticity material use conventional and AR welding machine with beginner welders.

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 Amelia, et al in 2021. 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 [7]. 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 Faris, Eko, and Irbat. 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 Augmented Reality (AR) technology for 7 (seven) 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 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 5. In Figure 5, it can be seen that the number of layers used is three layers.

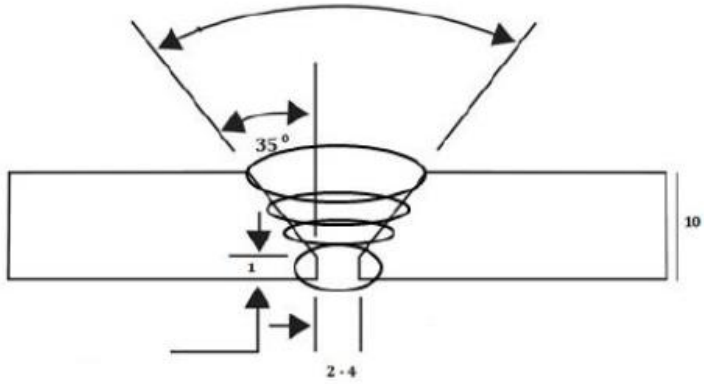


Figure 4. Welded Joint Design [7]

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.

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 [8]. 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 properties resulting from the tensile test are as follows [9]:

1. Maximum tensile stress (σ) is the maximum stress that can be borne by the material before a fracture occurs.

$$\sigma = \frac{P}{A_0} \quad (1)$$

σ is maximum tensile stress (N/mm^2), P is maximum load (N), and A_o is initial cross-sectional area (mm^2).

2. Maximum strain (e) can show the increase in the length of material after fracture to its initial length. Strain is the ratio of the increase in length (ΔL) to the initial length. Strain can be expressed as a percentage of length with units of percent (%) [10]. Expressed by the formula:

$$e = \frac{\Delta L}{L_0} \times 100\% = \frac{L_i - L_0}{L_0} \times 100\% \quad (2)$$

Li is the length after fracture (mm), Lo is the initial length (mm), is the strain (%).

3. The modulus of elasticity is a measure of the stiffness of a material on the stress-strain graph. The modulus of elasticity can be calculated from the slope of the linear elastic line.

$$E = \frac{\sigma_y}{e} \quad (3)$$

E is the modulus of elasticity (N/mm^2), σ_y is the yield strength (N/mm^2), and e is the strain (%).

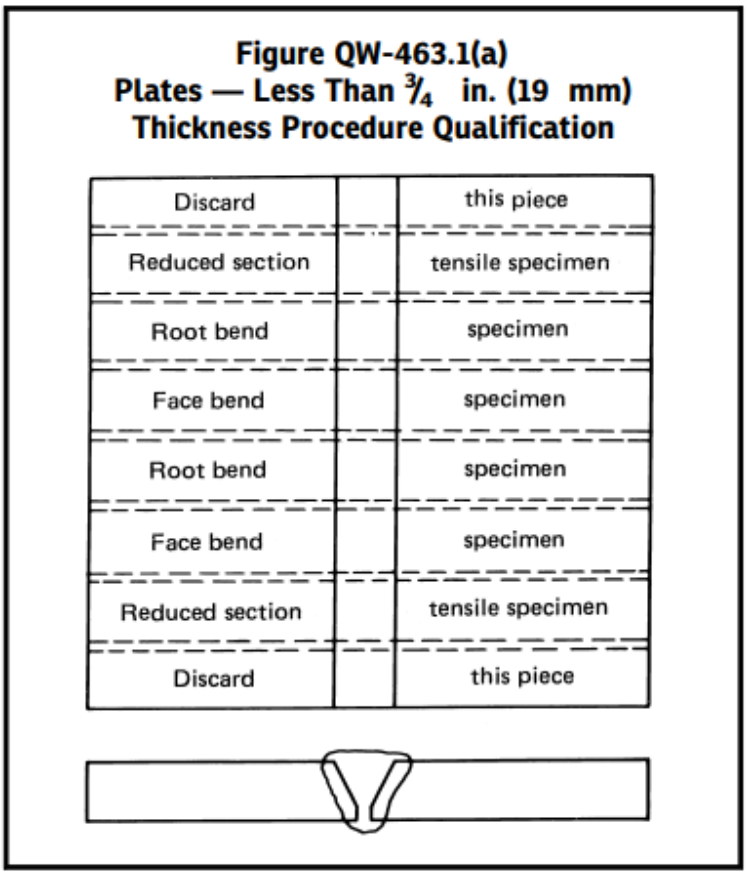


Figure 5. Cutting Plan for Destructive Test According to ASME Section IX [3]

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.

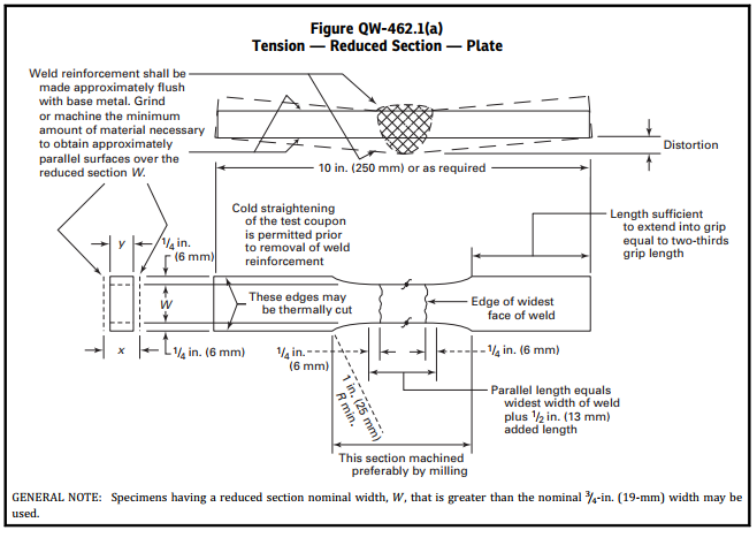


Figure 6. Tensile Test Specimen According to ASME Section IX [3]

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 [11].

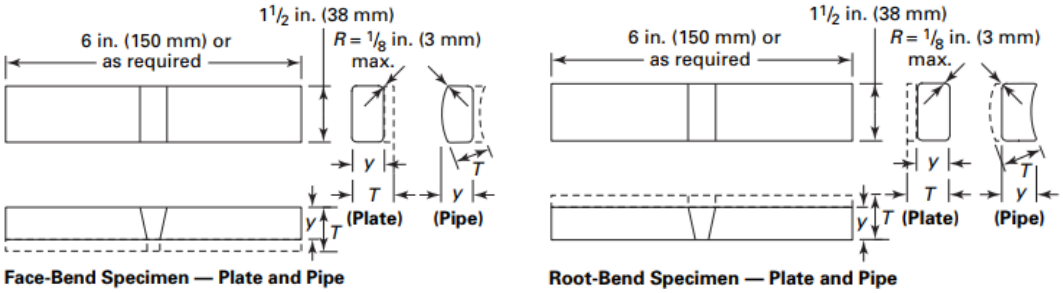


Figure 7. Bending Test Specimen According to ASME Section IX [3]

3. Results and Discussion

3.1. Welding with an Augmented Reality Welding Machine

Welding in an AR welding machine takes 8 days, with 3 days for the beginner level, 3 days for the intermediate level, and 2 days for the advanced level. Figure 8 shows the welding results obtained in an AR welding machine. Figure 8 shows that the three students can pass the passing grade set for the three available levels on the AR welding machine. The data in the figure is the overall score. The component for the overall score assessment is the average value of the technique parameters, which include work angle, travel angle, travel speed, aim, arc length, and equipment settings (consisting of amperage, inclusion, spatter, and porosity). The highest score for the beginner level is 94,67 on behalf of A. Mudzakir Farisi, the highest score for the intermediate level is 98 on behalf of the Eko Maulana, and the highest score for the advanced level is 87 on behalf of Eko Maulana.

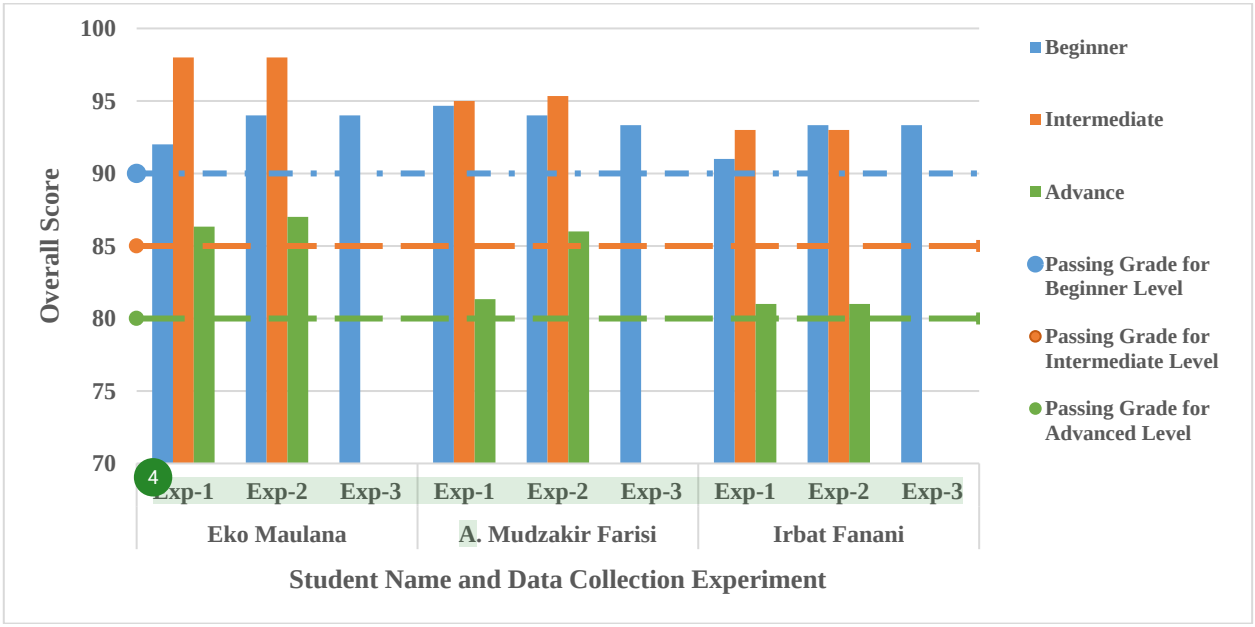
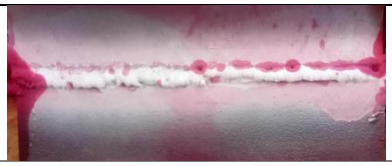


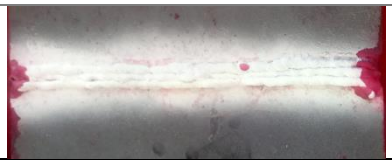
Figure 8. Welding Results in AR Welding Machines

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 2. The results shown in Table 2 are the results of welding performed by A. Mudzakir Farisi. The penetrant test specimens presented in Table 2 are specimens from the second welding, both before and after using the AR welding machine, in order to obtain a comparison with the same conditions. The penetrant test results in Table 2 also show that before using the AR welding machine, the penetrant test did not accepted by ASME, but after using the AR welding machine, the penetrant test results met the criteria.

Table 2. Penetrant Test Results Before and After using the AR Welding Machine

No.	Condition	Penetrant Test Photo	Type of Defect	Remark
1.	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.	After using the AR welding machines		Rounded defects with the defect size is 1,44 mm	Accept

3.3. Result of Tensile and Bending Test

Table 3 describes the comparison of tensile test results on two specimens both before and after beginner welders practiced using the AR welding machine. the increase in length (ΔL) of the welded specimen in the tensile test was greater after the beginner welders practiced using the AR welding machine. The increase in length is linear with the percentage of strain value (e) which is getting bigger so that the modulus of elasticity (E) is getting smaller. The increase in length is linear with the percentage of the strain value (e) becoming larger so that the modulus of elasticity (E) is getting smaller. The tensile stress value in specimen 1 is accepted by ASME Section IX with a minimum tensile strength of SA-36 carbon steel of 400 N/mm^2 both before and after beginner welders practiced using the AR welding machine, as shown in Figure 9. In specimen 2, the tensile stress value is not accepted by ASME when the beginner welders before practicing using the AR welding machine, while after the beginner welders practiced using the AR welding machine, the tensile stress value is accepted by ASME.

Table 3. Result of Tensile Test

No.	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
1	L_0 (mm)	270,50	296,45	270,50	296,45
2	L_1 (mm)	279,65	306,75	271,75	308,00
3	W_0 (mm)	19,30	19,30	19,50	21,00
4	W_1 (mm)	17,45	16,55	17,20	17,4
5	t_0 (mm)	9,60	10,00	9,60	10,35
6	t_1 (mm)	7,30	9,00	8,20	8,6
7	A_0 (mm^2)	185,28	193,00	188,16	217,35
8	P_{max} (N)	83.917	79.269	73.162	99.025
9	σ_{max} (N/mm^2)	452,92	410,72	388,83	455,60
10	ΔL (mm)	9,15	10,30	1,25	11,55
11	e (%)	3,38	3,47	0,46	3,90
12	E (N/mm^2)	133,90	118,21	841,43	116,94

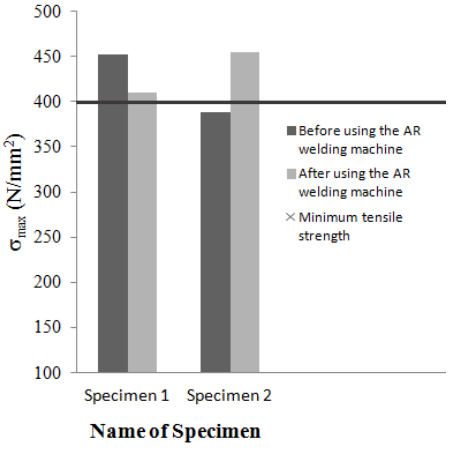


Figure 9. Bending Test Result

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 [3]. All specimens from the bending test before the novice 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 4. 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 Bending Test

Name of Specimen	Maximum Open Discontinuity Length (mm)			
	Before using the AR Welding Machine	Remark	After using the AR Welding Machine	Remark
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

4. Conclusion

The 2G position welding for the SMAW process performed by students on an Augmented Reality (AR) welding machine demonstrates that all students have successfully passed the passing grade for each welding level set by the machine. The highest score for the beginner level is 94,67 on behalf of A. Mudzakir Farisi, the highest score for the intermediate level is 98 on behalf of the Eko Maulana, and the highest score for the advanced level is 87 on behalf of Eko Maulana. The results for the penetrant test before and after beginner welders practiced using the AR welding machine showed that the best penetrant test results were obtained by students on behalf of A. Mudzakir Farisi with rounded defects with a defect size of 1,44 mm after he practiced using the AR welding machine that was accepted by ASME Section V. Before he practiced using an AR welding machine, the penetrant tests showed round defects at three locations, with the largest defect size 3,6 mm and linear defects with a length of 89,3 mm where the defects were not accepted by ASME. Bending and tensile tests were carried out on the same specimen as the penetrant test. Before the welder practiced using the AR welding machine, the maximum tensile stress on the specimen was 452,92 and 388,83 N/mm^2. The minimum tensile strength for SA-36 carbon steel, according to ASME Section IX, is 400,00 N/mm^2. So there was one specimen before the welder practiced using the AR welding machine, which ASME did not accept. The maximum tensile stress on the test specimen after the welder practiced using the AR welding machine were 410,00 and 455,66 N/mm^2, both of which exceeded the minimum tensile strength accepted by ASME. The bending test results for all specimens before the welder practiced using the AR welding machine were not accepted by ASME Section IX, with the maximum open discontinuity length of 37,55 mm in the specimen from Face Bend 1. While the results of the bending test after the welder practiced using the AR welding machine, there was one specimen accepted by ASME with a maximum open discontinuity length of 2,9 mm in the specimen from Root Bend 1, but it was not accepted by the standard for the other specimens. Based on the results of the tests, it can be seen that the AR welding machine can be used for the implementation of competency certification because the quality of the weld results is better, there are fewer risks (sparks, eye irritation, and burns), and the use of welding consumables is reduced.

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