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Visual Inspection and Non-Destructive Test (NDT) on ASTM A36 Welded Joints Produced by GMAW

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Welding, GMAW, visual inspection, non destructive test, ASTM A36

Abstract

Low-carbon steel is often used for welding joints, whether in the form of structural steel or other materials; the application of this material is used in shipbuilding, bridge construction, and other fields. Welding inspection is needed to determine the quality of the weld. Visual inspection and non-destructive testing (NDT) are techniques in welding inspection. This study aims to determine the results of visual inspection and non-destructive testing (NDT) on welding joints of low-carbon steel produced by GMAW. The welding joints used are V-butt joints with a bevel angle of 30^0, 10 mm thick plate, 2.6 mm root gap, variations in welding layers: 3 layers (root pass, filler pass, and capping), and 4 layers (root pass, 2 filler passes, and capping), filler metal ER 70S-6 0.8 mm, and CO_2. Volts, current, travel distance, and shielding gas flow rate are welding parameters. The tests carried out were visual inspection referring to limits for imperfections in ISO 6520-1, non-destructive tests (NDT) that were carried out, namely penetrant tests and radiography tests. The visual inspection and non-destructive testing (NDT) on specimen 1 reveal an internal defect, specifically a lack of fusion; the specimen should be rejected. Specimen 2 shows an imperfection in the surface area, namely in the form of spatter (2 spots), and there are internal imperfections in the form of porosities with an area of less than 3%. The specimen should be accepted.

1. Introduction

Indonesia is a maritime nation that continues to develop in its fields, such as the building of floating structures, offshore platforms, and other things, the era of global competition has driven Indonesia to carry out developments in all industrial sectors. In this situation, the welding process is crucial, especially for production and fabrication [1].

Welding is a technique for joining metals and non-metals by raising the material's temperature to the welding temperature and using a filler metal or not. [2] One type of fusion welding that offers the benefits of quick welding speed and oxide layer reduction is gas metal arc welding (GMAW) [3].

The welding process is widely used in shipbuilding and the construction industry to transport liquids such as water and oil [4], Ship structures, are made of thousands of steel plate sections that are welded together at joints, but welding at joints can generate weld defect that can result in fatigue cracks. [5]. Defects in welding consist of external and internal defects. External defects found on the surface of the weld, such as undercuts, cracks, incomplete penetration, fusion, and others, while internal defects are porosity, slag inclusions, internal lack of fusion, and others [6][7]. In welding, there are difficulties in optimizing welding parameters to produce a uniform bead; this is due to the effect of gravity at different welding positions [4].

Low-carbon steel with the ASTM A36 designation is frequently utilized in the nautical sector because of its weldability. The composition of the shielding gas is claimed to be crucial in the GMAW technique to screen the weld metal from air contamination or other contaminants [8], Besides that, the shape of the seam also affects its mechanical strength [9].

In effective welding quality control, visual inspection is one of the basic forms of evaluation of weld results. In basic control evaluation, reference to the evaluation of weld results is in the form of standards or codes that are used as criteria for evaluating weld results to be accepted or rejected, in addition to further inspection in the form of a non-destructive test that can also be done as a supplement [10]. Limits for surface, joint geometry, and internal defects are outlined in ISO 6520-1 with quality level C for hull structure [11].

Non-Destructive Testing (NDT) is a method of testing materials without damaging them [12], The intended inspection is the evaluation of welded joints in the form of materials, components, and defects found in welded joints without damaging the material. NDT can be used to ensure the quality of raw materials, processes, and fabrication [13][14].

The research focuses on visual inspection and NDT in the form of penetrant tests and radiography tests on GMAW welding joints with low-carbon steel material, namely ASTM A36, which is commonly used in ship structures so that it can be known whether there are defects or not and the causes of welding defects.

2. Materials & Methods

The GMAW welding process uses the Welding Procedure Specification (WPS) for GMAW on specimen 1 and specimen 2 with the following details:

Table 1 *Welding procedure specification (WPS)*

	Specimen 1	Specimen 2
Material	ASTM A36	ASTM A36
Dimension	150 x 50 x 10 mm	150 x 50 x 10 mm
Joint Type	Single V-Groove	Single V-Groove
Welding Position	3G/PF (Vertical Up)	3G/PF (Vertical Up)
Consumable Class	AWS ER70S-6	AWS ER70S-6
Filler Metal (Dia)	0.8 mm	0.8 mm
Current	DCEP	DCEP
Number Of Layer	3 Layers	4 Layers
Cleaning Method	Grinding	Grinding
Shielding Gas	CO_2	CO_2
Gas Flow Rate	15 L/min	15 L/min

Table 2 contains the parameters for specimen 1, and Table 3 contains the data for specimen 2.

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Table 2 *Specimen parameters 1*

Parameter	Root	Filler	Capping
Volt Range (V)	18-19	19-20	18.5-19.5
Amp. Range (A)	88-90	75-78	76-78
Travel Speed (cm/min)	7-8	6.5-7.5	6.25-7.25
Welding Technique	Convex weave	Zig-zag weave	Zig-zag weave

Table 3 *Specimen parameters 2*

Parameter	Root	Filler	Filler	Capping
Volt Range (V)	22-23	24-25	24-25	18.5-19.5
Amp. Range (A)	85-90	115-120	115-120	110-115
Travel Speed (cm/min)	9-11	10-12	10-12	10-11
Welding Techinque	Convex weave	Convex weave	Convex weave	Convex weave

Joint details on specimens 1 and 2 can be seen in Figure 1, as follows:

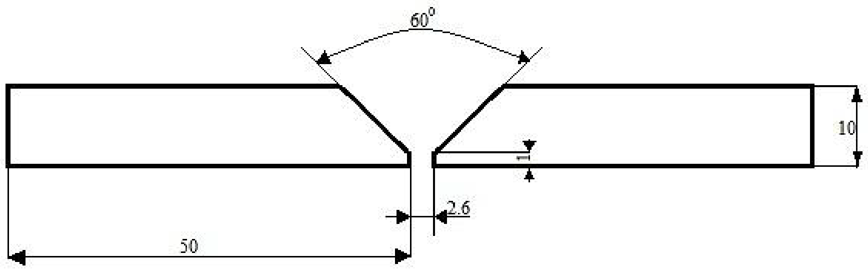


Fig. 1 *Joint detail specimen 1 and specimen 2*

The steps leading up to the welding process are as follows: first, two 150 x 50 x 10 mm pieces of ASTM A36 plate are cut; next, a 60-degree angle is made in the groove following the joint detail in Figure 1, and finally, tack welding is performed. Figure 2 illustrates this process.

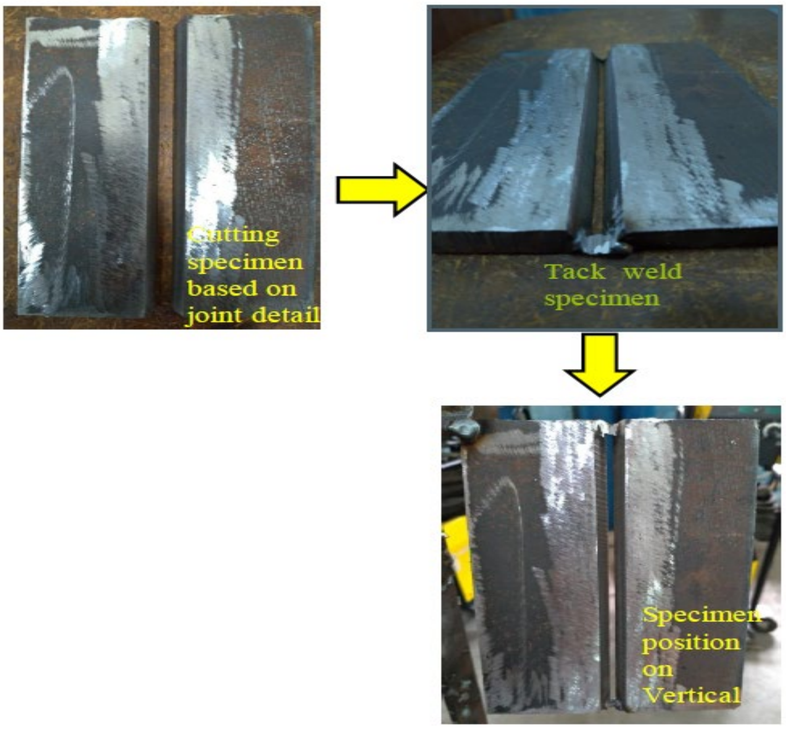
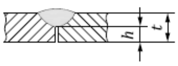
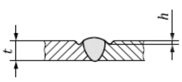
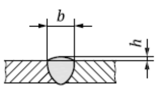
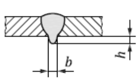


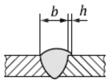
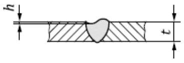
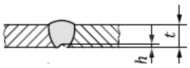
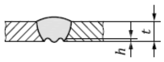
Fig. 2 *Stages of preparation on specimen 1*

Then, three layers of welding were applied: the root pass, which was followed by brush wheel cleaning; a filler pass, which was cleaned with a brush wheel, grinding to create a path; and finally, a capping pass. Referring to Table 2, specimen parameter one is disposed of, with 1.5 cm clearance at either end, followed by an examination. Figure 3 shows the steps of the process. By the guidelines in Table 3, this was likewise done on Specimen 2.

Visual inspection uses limits for surface and joint geometry imperfections in ISO 6520-1, with details in Table 4 as follows:

Table 4 *Limits for surface and joint geometry imperfections in ISO 6520-1 [11]*

Imperfection Designation	Remarks	t (mm)	Acceptance (Level C)
Crack	-	≥ 0.5	Not Permitted
Surface Pore	Maximum single pore for butt weld	> 3	d ≥ 0.3 s; but max 3 mm
Lack of fusion	-	≥ 0.5	Not Permitted
Incomplete Root Penetration	Only for single side butt welds 	≥ 0.5	Not Permitted
Intermitten Undercut		> 3	h ≤ 0.1 t, but max 0.5 mm
Excess Weld Metal	Smooth transition is required 	≥ 0.5	h ≤ 1 mm + 0.15 b, but max 7 mm
Excess Penetration		≥ 3	h ≤ 1 mm + 0.6 b, but max 4 mm

Overlap		≥ 0.5	Not Permitted
Incompletely Fillet Groove	Smooth transition is required 	> 3	h ≤ 0.1 t, but max 1 mm
Root Concavity	Smooth transition is required 	> 3	h ≤ 0.1 t, but max 1 mm
Shringkage Groove	Smooth transition is required 	> 3	h ≤ 0.1 t, but max 1 mm
Root Porosity	Spongy formation at root weld	≥ 0.5	Not Permitted
Poor Restart	-	≥ 0.5	Not Permitted
Stray Arc	-	≥ 0.5	Not Permitted
Spatter	-	≥ 0.5	Acceptance depends on application
Linear missalignment	-	> 3	h ≤ 0.15 t, but max 4 mm

t = wall or plate thickness (nominal size)
s = nominal butt weld thickness
h = height or width of imperfection
b = width of weld reonforcment

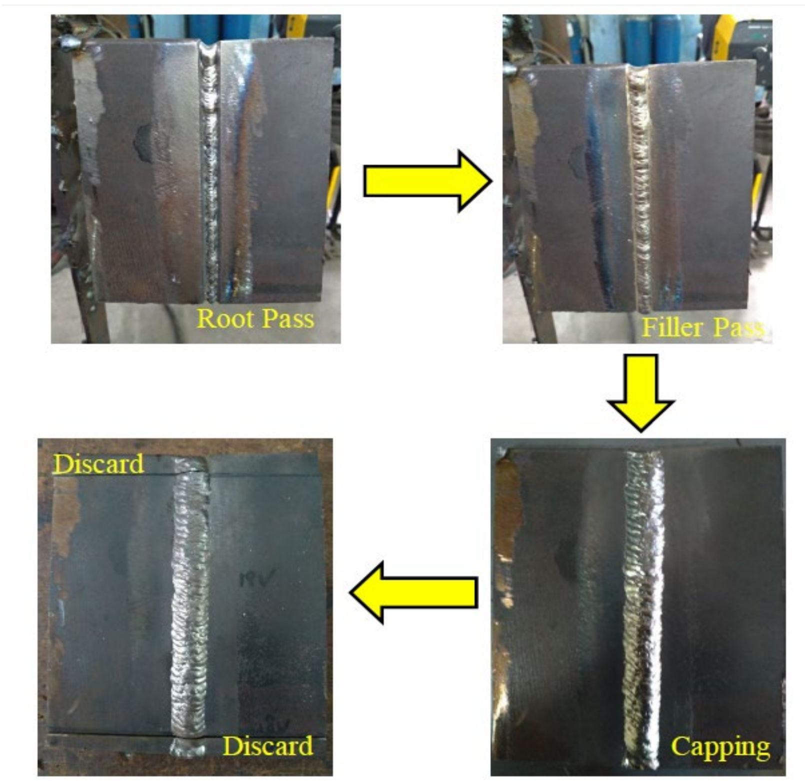


Fig. 3 *Stages of welding on specimen 1*

The radiography test and penetrant test are the NDT techniques that are applied. Using the Magnaflux SKL-SP2 penetrant, SKC-S cleaner, and SKD-S2 developer, the penetrant test procedure consists of cleaning the welded specimen using the wipe with clothes method, brushing on the penetrant for 12 minutes, wiping with dry rags sprayed with cleaner and wiping in the direction indicated by the welding groove, spraying on the developer for 5 minutes, and observing.

Table 5 below demonstrates the limits for internal defects in ISO 6520-1 during a radiography test using the General Electric DXR250C-UW machine, 140 kV xray potentials, analysis, and image capturing.

Table 5 *Limits for internal imperfections in ISO 6520-1 [11]*

Imperfection Designation	Remarks	t (mm)	Acceptance (Level C)
Crack	All type of crack except microcracks and crater crack	≥ 0.5	Not Permitted
Gas Pore/Porosity	Maximum dimension of the area of the imperfections	≥ 0.5	Multilayer: ≤ 3%
	Maximum dimension for single pore	≥ 0.5	d ≤ 0.3 s, but max 4 mm
Slag Inclusions	-	≥ 0.5	h ≤ 0.4 s, but max 4 mm
			l ≤ s, but max 75 mm
Lack of fusion	-	≥ 0.5	Not Permitted
Lack of penetration	-	≥ 0.5	Not Permitted

t = wall or plate thickness (nominal size)

s = nominal butt weld thickness

h = height or width of imperfection

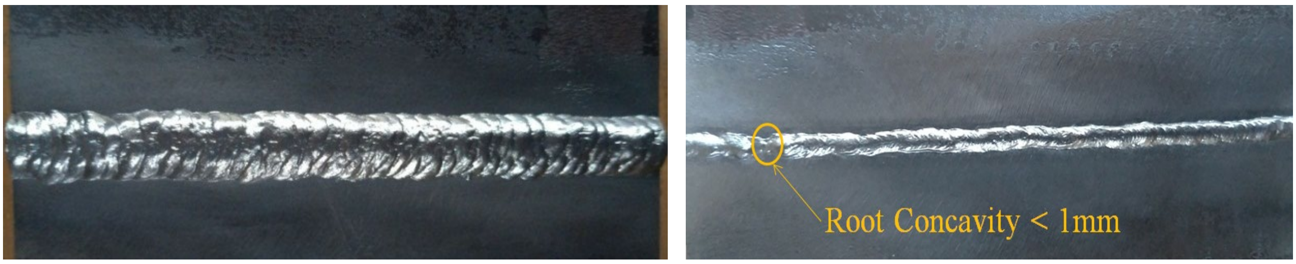
l = length of imperfection in longitudinal direction of the weld

3. Results and Discussion

The results of welding on specimen 1 can be seen in Figure 4 in the form of surface and root weld results. Figure 4a. shows excess weld metal of 2 mm. If, according to the acceptance criteria in Table 6, h ≤ 3.25 mm, where h is measured at 2 mm, it is accepted.

There is Figure 4b. The results of the root area welding show that there is an imperfection in the form of a root concavity. If you look at the acceptance criteria in Table 6, then h ≤ 1 mm, where h is measured as 0 mm, so it is accepted. Root concavity is caused by an unstable welder who weaves the weld at that root pass, sucking back but leaving the two edges together, which shrinks the weld pool [15][16][17], low heat input arising from the welder's instability during the weaving of the weld bead is another factor [18]. Apart from that, there is an imperfection in the form of excess penetration. If you look at the acceptance criteria in Table 6, then the h max is 4 mm, where h is measured at 1 mm, so it is accepted.

The data shows that the visual inspection on specimen 1 is accepted so that it can be continued for the first stage of the NDT process, namely the penetrant test.



(a) **(b)**

Fig. 4 *(a) Visual weld surface area specimen 1; (b) Visual weld of the root area specimen 1*

Table 6 *Visual inspection on specimen 1*

Imperfection Designation	Visual Inspection	Result
Crack	-	Accepted
Surface Pore	-	Accepted
Lack of fusion	-	Accepted
Incomplete Root Penetration	-	Accepted
Intermitten Undercut	-	Accepted
Excess Weld Metal	2 mm	Accepted (h ≤ 3.25 mm)
Excess Penetration	1 mm	Accepted h ≤ 4 mm
Overlap	-	Accepted
Incompletely Fillet Groove	-	Accepted
Root Concavity	1 spot (0 mm)	Accepted (h ≤ 1 mm)
Shringkage Groove	-	Accepted
Root Porosity	-	Accepted
Poor Restart	-	Accepted
Stray Arc	-	Accepted
Spatter	-	Accepted
Linear missalignment	-	Accepted

t = 10 mm
s = 10 mm
h = height or width of imperfection
b = 15 mm

The results of welding on specimen 2 can be seen in Figure 5 in the form of surface and root weld results. Figure 5a, it shows an excess weld metal of 2 mm. If you look at the acceptance criteria in Table 7, then h is 3.175 mm, where h is measured at 2 mm, so accept. In addition, there are imperfections in the form of spatter; there are two spots. If you look at the acceptance criteria in Table 7, it is stated that they are adjusted to the application, so they are accepted.

In Figure 5b. imperfection in the form of excess penetration, if you look at the acceptance criteria in Table 7, then h max is 4 mm, where h is measured at 1 mm, so it is accepted.

The data shows that the visual inspection on specimen 2 is accepted so that it can be continued for the first stage of the NDT process, namely the penetrant test.

(a) (b)

Fig. 5 *(a) Visual weld surface area specimen 2; (b) Visual weld of the root area specimen 2*

Table 7 *Visual inspection on specimen 2*

Imperfection Designation	Visual Inspection	Result
Crack	-	Accepted
Surface Pore	-	Accepted
Lack of fusion	-	Accepted
Incomplete Root Penetration	-	Accepted
Intermitten Undercut	-	Accepted
Excess Weld Metal	2 mm	Accepted (h ≤ 3.175 mm)
Excess Penetration	1 mm	Accepted (h ≤ 4 mm)
Overlap	-	Accepted
Incompletely Fillet Groove	-	Accepted
Root Concavity	-	Accepted
Shringkage Groove	-	Accepted
Root Porosity	-	Accepted
Poor Restart	-	Accepted
Stray Arc	-	Accepted
Spatter	2 Spot	Accepted
Linear missalignment	-	Accepted

t = 10 mm
s = 10 mm
h = height or width of imperfection
b = 14.5 mm

Interpretation of the penetrant test on specimen 1 can be seen in Figure 6 in the form of the surface and root areas of the weld results. In Figure 6a, there are no weld defects in the surface area, and in Figure 6b, there are also no weld defects in the root area.

Table 8 *Interpretation of penetrant test on specimen 1 and specimen 2*

Specimen	Weld Area	Imperfection	Result
Specimen 1	Surface	-	Accepted
	Root	-	
Specimen 2	Surface	Spatter on two spot	Accepted
	Root	-	

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(a) **(b)**

Fig. 6 *(a) Penetrant interpretation surface area of specimen 1; (b) Penetrant interpretation root area of specimen 1*

Interpretation of the penetrant test on specimen 2 can be seen in Figure 7a. There is an imperfection in the form of a spatter (2 spots) on the surface area. The reason is that the voltage at the root weld, as seen in Table 7, is too large [12][16] namely 22–23 V if seen in Table 6, another cause is that the gas flow rate is not constant due to dirty gas nozzles [19], adjusted to the application, so it is accepted. In Figure 7b, there are no weld defects in the root area.

(a) **(b)**

Fig. 7 *(a) Penetrant interpretation surface area of specimen 2; (b) Penetrant interpretation root area of specimen 2*

In Table 8. it shows that the results of specimen 1 and specimen 2 welds were declared accepted in the penetrant test; this also refers to the acceptance criteria for surface and joint geometry imperfections in ISO 6520-1 shown in tables 6 and 7, so that it can be continued for the NDT process Stage 2, which is the radiography x-ray test.

Interpretation of the x-ray radiography of specimen 1 can be seen in Figure 8. There is an imperfection in the form of a lack of fusion in the filler pass area; the cause is due to the low voltage on the filler pass [16], which can be seen from Table 2 only around 19–20 V. It is recommended to use a filler pass with a voltage of more than 20 V or (globular transfer mode) [20], weaving the weld pool too quickly between the sidewalls is another factor contributing to the lack of fusion [21]. This can be seen in Table 2 and Table 3. In specimen 1, in the filler layer, the travel speed is 6.5–7.5 cm/min, compared to specimen 2, where the travel speed is 10–12 cm/min. Therefore, the results are rejected according to the ISO 6520-1 Table 9 limits for internal defects on specimen 1.

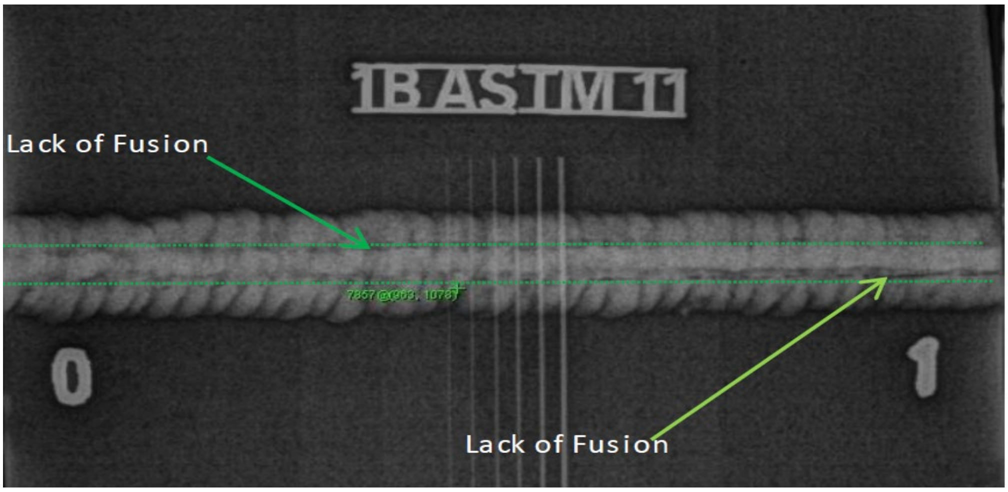

Fig. 8 *Radiography interpretation on specimen 1*

Table 9 *Limits for internal defect on specimen 1*

Imperfection Designation	Radiography Interpretation	Result
Crack	-	Accepted
Gas Pore/Porosity	-	Accepted
Slag Inclusions	-	Accepted
Lack of fusion	Yes (on filler pass)	Rejected
Lack of penetration	-	Accepted

Interpretation of the x-ray radiography of specimen 2 can be seen in Figure 9. There are imperfections in the form of porosities; the cause is due to a problem with the CO_2 gas regulator heater, which causes condensation on the regulator, so the heat generated by the regulator is not optimal, causing porosity [16][22], In addition, contamination of the shielding gas by an unclean gas nozzle might result in porosity [19]. Table 10 shows that the porosity size is less than 3 mm, or that the largest is only 1.96 mm, and that the maximum dimension of the area of the porosities is less than 3%; therefore, the results are acceptable when compared to the limits for internal defects in ISO 6520-1, Liverie P. et al. state that while porosity can raise effective stress, the maximum effective stress threshold is met if porosity is less than 2.5 mm or ¼ of the material thickness [23], Welds that have porosity and are accepted by the criteria have reasonable strength. Where severe defects significantly reduce the strength, less serious defects do not significantly reduce the strength because they are accepted within the criteria [24].

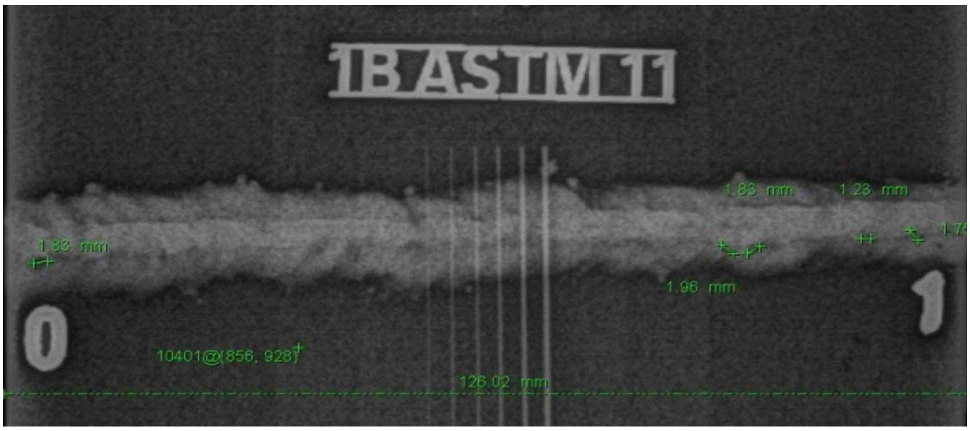

Fig. 9 *Radiography interpretation on specimen 2*

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Table 10 *Limits for internal defect on specimen 2*

Imperfection Designation	Radiography Interpretation	Result
Crack	-	Accepted
Gas Pore/Porosity	Area porosities ≤ 3%	Accepted
	d = 1.96 mm	Accepted (d ≤ 3 mm)
Slag Inclusions	-	Accepted
Lack of fusion	-	Accepted
Lack of penetration	-	Accepted

4. Conclusion

The results of welding low carbon steel with ASTM A36 type indicate that specimen 1 has an internal defect, specifically a lack of fusion, which is brought on by the voltage on the filler pass being insufficient, weaving the weld pool too quickly between the sidewalls is another factor contributing to the lack of fusion, If this defect exceeds the limits for internal defects in ISO 6520-1, the specimen should be rejected.

Whereas in specimen 2, after visual and NDT tests in the form of a penetrant test and radiography x-ray test, it shows that there is an imperfection in the surface area, namely in the form of spatter (2 spots), which is caused by the voltage at the root pass being too large, another cause is that the gas flow rate is not constant due to dirty gas nozzles, so according to the limits for surface and joint geometry imperfections in ISO 6520-1, they are accepted, and there are internal imperfections in the form of porosities with an area of less than 3%, and the largest size of the porosity is only 1.96 mm or less than 3 mm, if you refer to the limits for internal imperfections in ISO 6520-1, they are accepted.

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Conflict of Interest

The author declares no conflict of interest in publishing this paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Febri Budi Darsono, Akhmad Nurdin, Sudibtia Titio Koin;* ***data collection:*** *Khoirul Huda, Andri Setyawan;* ***analysis and interpretation of results:*** *Khaleb Thomas, Tasih Mulyono, Rahmat Doni Widodo, Rusiyanto;* ***draft manuscript preparation:*** *Deni Fajar Fitriyana. All authors reviewed the results and approved the final version of the manuscript.*

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