

# Analysis of Electrode Arc Welding Joint Defects by Non-Destructive Testing

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## Abstract

Welding is the standard assembly technique in metal construction, and its quality depends on the proper execution of the operation. Weld joint analysis involves implementing inspection techniques to verify, without destructive testing, the condition of the weld bead and detect any surface or internal defects. This research aims to evaluate the condition of the weld bead. We analyzed internal and surface defects after non-destructive testing on metallic samples (visual inspection, dye penetrant testing, and radiographic testing). The results show that defects are less frequent in thinner materials. Conversely, in thicker materials, defects are more numerous, and their frequency increases with thickness. These observations were experimentally verified. Defects are often related to multiple welding passes, welder qualifications, or material selection. This analysis can contribute to improving inspection techniques, thus facilitating the localization of irregularities and reducing defects during welding operations.

## Keywords

Analysis, Defects, Electric Arc Welding, Non-Destructive Testing

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## 1. Introduction

Welding is an industrial process used for the assembly of metal parts which consists of ensuring the permanent connection of two or more constituent parts of identical or different nature, either by heating, or by pressure, or by the simultaneous action of both, heat and pressure. Welding can be carried out with or without filler metal [1]. The most common welding processes can be classified as arc welding, oxyacetylene welding, resistance welding, energy beam welding and solid state welding. Electric arc welding is the most widely used process in Mali

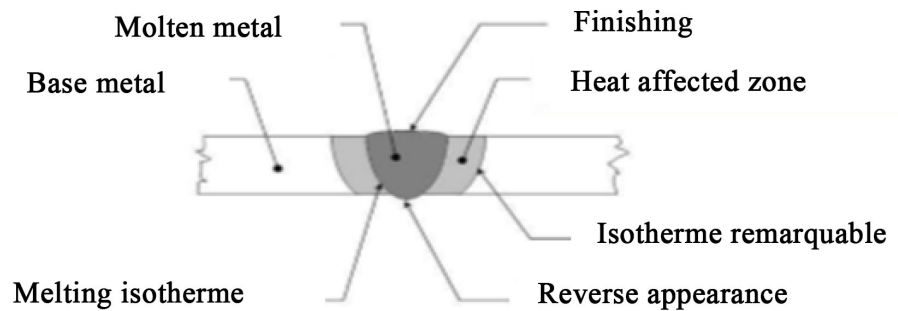
[2]. The quality of a welded joint depends on several factors such as welding parameters, nature of the material to be welded, filler material and the welder etc. In practice, welding is used in large construction sites such as the manufacture of boat hulls, also in the manufacture of fuel tanks, cistern tanks, metal frames, automobile hulls, etc. Welding seam defect analysis can help improve welding quality. Achieving strong, thin, and perfectly sealed weld joints requires weld joint analysis for certain metal construction applications. Indeed, the study and analysis of defects in welding joints after non-destructive testing is necessary to improve welding quality. They allow for a watertight, resistant weld, rapid implementation and great flexibility. Several studies have been carried out on electric arc welding cords such as: non-destructive (radiographic and penetrant testing) and destructive (tensile and hardness testing) testing of the electric arc welding bead on large diameter S355JR steel tubes, of the same thickness with different preheating temperatures [3]. Research on welding bead defects in pipeline welding [1]. He also had studies on non-destructive testing such as: penetrant testing, magnetic particle testing, radiography, eddy current testing and ultrasound [4]. In addition, spectral analysis in non-destructive testing by ultrasound [5] etc.

Previous studies did not take into account the variation in thicknesses and internal or external non-destructive testing [1] [3]-[5]. In contrast, this research is based on the study and analysis of defects in coated electrode electric arc weld joints by non-destructive testing (visual and dimensional inspection, dye penetrant testing and radiography) on different thicknesses.

Unlike previous studies, our work is based on the study and analysis of defects in electric arc welding joints with coated electrodes using non-destructive testing on different thicknesses. The aim of this research is to analyze electric arc welding joints in order to improve welding quality and propose the best choices of parameters and the nature of the material for the production of gasoline tanks, cistern tanks, metal frames, etc. The main objective is to characterize the defects of arc welding joints with coated electrode by non-destructive testing (penetrant testing and radiography) on different thicknesses. Where the specific objectives for these non-destructive tests carried out during the research can be seen as visual and dimensional control, penetrant testing and radiography.

## 2. Different Welding Processes and Non-Destructive Testing Techniques

Among the assembly processes, welding occupies an important place in all areas of industry, because it allows the construction forms to be adapted as best as possible to the constraints that they are called upon to withstand in service [6]. Metal welding is a permanent joining technique that establishes metallic continuity between two welded parts. This operation can be likened to a local operation of metallurgical development and heat treatment giving a crystalline structure depending both on the chemical composition developed and the heat treatment as shown in **Figure 1**.



**Figure 1.** Weld bead.

There are many welding processes whose principles and implementation are very different. For some, the assembly is obtained by local fusion of the elements to be joined, for others, metallic continuity is obtained without fusion by purely mechanical effects. These processes can easily be classified according to the energies used as shown in **Figure 2** [7].

Electrochemical Energy	Electrothermal Energy		Mechanical Energy	Focused Energy
Oxyacetylene	Electric Arc		Electric resistance	Explosion welding
Aluminothermic	manual welding with coated electrode		Induction welding	Ultrasonic welding
	Gas-shielded welding	TIG refractory electrode	Spot welding	Friction wilding
		MIG-MAG fusible electrode		
	flux welding		Seam welding	
	Other	Plasma welding	Flash welding	
		Hydrogen welding		
		Vertical sub-slag welding		
		Rotary arc welding		
			Boss welding	

**Figure 2.** Classifications of welding processes [8].


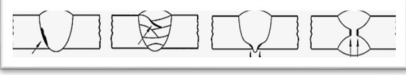
▪ **Non-destructive testing (NDT):**

The NDT analysis is based on methods that allow the structural integrity of welded joints to be characterized, without damaging them, during production or use. These techniques are used to detect many types of defects. Non-destructive testing: Visual and dimensional testing, penetrant testing, radiographic testing, etc. They are carried out according to standards by certified people. The different (NDT) methods used are diverse according to [9]. The choice of a method depends on:

- ✓The part to be checked;
- ✓The type of control to be carried out;
- ✓The conditions under which the control must be carried out [10].

### 3. Some Welding Defects

There are several types of welding defects and several techniques to prevent and correct them. Welding defects are generally inherent to welding processes. They depend on several factors: poor execution, metal quality, cleanliness of the areas to be welded and the choice of the process itself as shown in **Figure 3**.

Defects	Causes	Means of Prevention
 <p>Reassure at the root    crater backfill</p> <p>Concavities</p>	<ul style="list-style-type: none"> <li>- Joints too narrow or too small</li> <li>- Base metal incompatible with filler metal...</li> </ul>	<ul style="list-style-type: none"> <li>- Accurately measure the bevel angles</li> <li>- Correctly choose the filler metal</li> </ul>
 <p>Lack of lateral fusion concerning the edges to be welded    Lack of blending between the passes    Lack of fusion at the root of the weld</p> <p>Lack of Fusion or Incomplete Fusion</p>	<ul style="list-style-type: none"> <li>- Welding current too low</li> <li>- Multiple passes</li> <li>- Welding speed too high...</li> </ul>	<ul style="list-style-type: none"> <li>- Increase the current intensity</li> <li>- Reduce travel speed and preheat thick pieces</li> <li>- Properly arrange the beads in multi-pass welds...</li> </ul>

**Figure 3.** Some welding defect.

### 4. Materials and Methods

The production of strong welding joints that are both thin and perfectly watertight requires this analysis for certain metal construction applications. The objective of this section is to analyze the arc welding seams. In order to propose the best choices of welding parameters and nature of material for the production of gasoline tanks, tank tanks, metal frames, etc.

Experimental study of the arc welding process with coated electrode for the welding operation uses the materials listed in **Table 1**.

The method used for the shielded arc welding operation will be described.

**Table 1.** Materials used for welding.

<p>Welding machine with coated electrode is brand e DON MMA-300S</p>	
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**Continued**

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Base metal used: Mild steel  
and designation S235JR



Filler metal used: Cellulosic  
electrode (RC) designation  
SAFER NF 510P



The welding of the specimens is performed using the following welding parameters:

- The electrodes used have diameters (2.5 mm, 3 mm, and 4 mm).
- The weld joint is performed with 2 to 7 welding passes depending on the thickness of the specimens, with an internal pass on the opposite side.

The feed rate of the filler metal is adjusted by the operator to optimize the welding arc, as shown in following **Figure 4** and **Figure 5**.



**Figure 4.** Setting the parameters.



**Figure 5.** Welding operation.

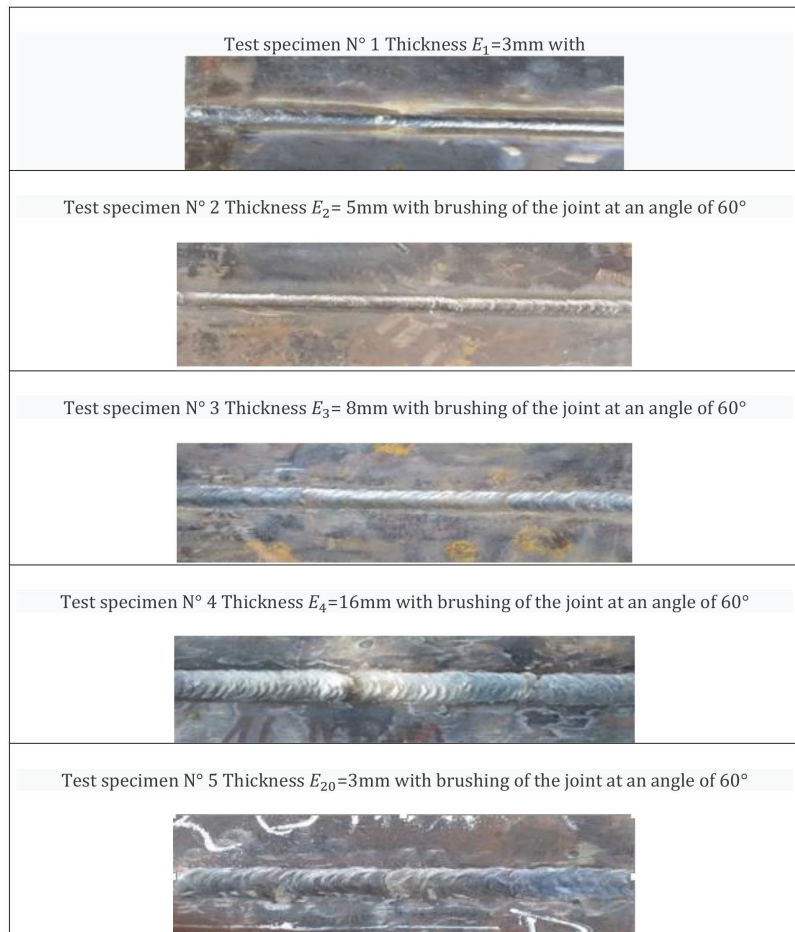
The current intensity and voltage values are determined according to the DMOS (Description of Welding Procedure). The welding of the beads is carried out according to the welding procedure. **Figure 6** below represents the different test pieces for the welding operation. The choice of welding parameters depends on the thickness of the experimental piece, given in **Table 2** below.

**Table 2.** Welding parameters.

Passas	Setting	Test tube used with thicknesses in mm				
		E1	E2	E3	E4	E5
1	Electrode used (diameter in mm)	2.2	2.2	3.2	3.2	3.2
	Wilding Speed	312	260.86	230.76	240	238.09
	Number of electrodes	0.5	3.5	3	3	3
	Soudaghe current (A)	185	215	143	280	284
2	Electrode used (diameter in mm)	3.2	3.2	4	4	4
	Wilding Speed	206.89	260.86	230.76	240	238.09
	Number of electrodes	2	4	4	2	2
	Soudaghe current (A)	229	284	355	448	452
3	Electrode used (diameter in mm)			4	4	4
	Wilding Speed			184.04	196.07	200
	Number of electrodes			2.5	2.5	2
	Soudaghe current (A)			448	455	469
4	Electrode used (diameter in mm)					4
	Wilding Speed					200
	Number of electrodes					2.5
	Soudaghe current (A)					469
5	Electrode used (diameter in mm)					4
	Wilding Speed					200
	Number of electrodes					3
	Soudaghe current (A)					469
6	Electrode used (diameter in mm)					4
	Wilding Speed					196.07
	Number of electrodes					3
	Soudaghe current (A)					487
7	Electrode used (diameter in mm)					4

## Continued

Welding Speed	200
Number of electrodes	5
Soudaghe current (A)	476



**Figure 6.** Welded specimens of different thicknesses.

Production of test specimens:

Before welding the sheets using the same welding process, the specimens were cut using a grinder as shown in **Figure 7**.

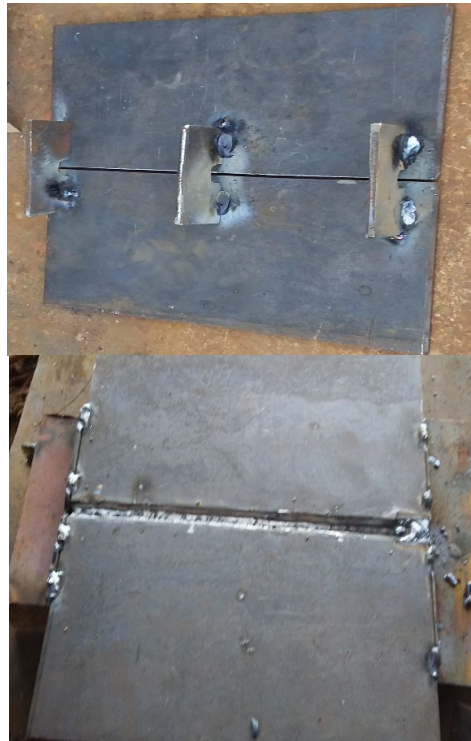


**Figure 7.** Cutting the sheets.

The test pieces for the different tests have the following dimensions for  $300 \times 150 \times E_n$ , in which 300 represents length, 150 represents width and the last one  $E_n$  corresponds to thickness while  $n$  is the number of the test piece which varies from 1 to 5.

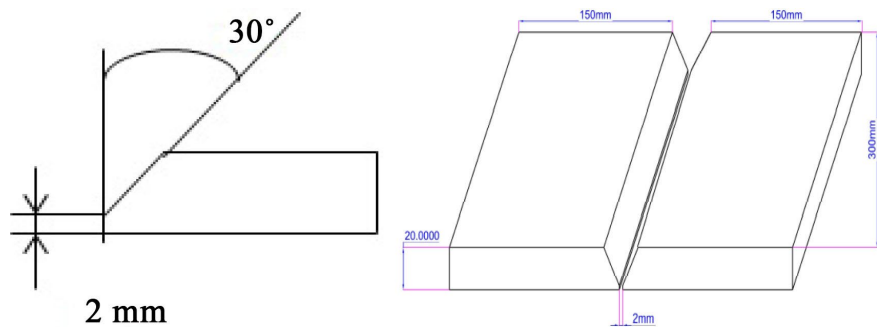
Preparation of test tubes:

First of all, sheets are prepared to be assembled by cutting with a chainsaw to obtain rectangular sheets to facilitate the production of the test pieces as shown in **Figure 8**.



**Figure 8.** Preparation of test pieces before welding.

The dimensions of the sheets are  $300 \text{ mm} \times 150 \text{ mm} \times (E) \text{ mm}$ . These sheets are chamfered at an angle of  $60^\circ$  then adjusted with a gap of  $2 \text{ mm}$  according to the welding parameters carried out during welding according to **Figure 9**.



**Figure 9.** Diagram of the test piece with dimensions before welding.

Welding of test pieces:

Welding is an operation which consists of joining two or more constituent parts of an assembly, in such a way as to ensure continuity between the parts to be joined as shown in **Figure 10** [11].

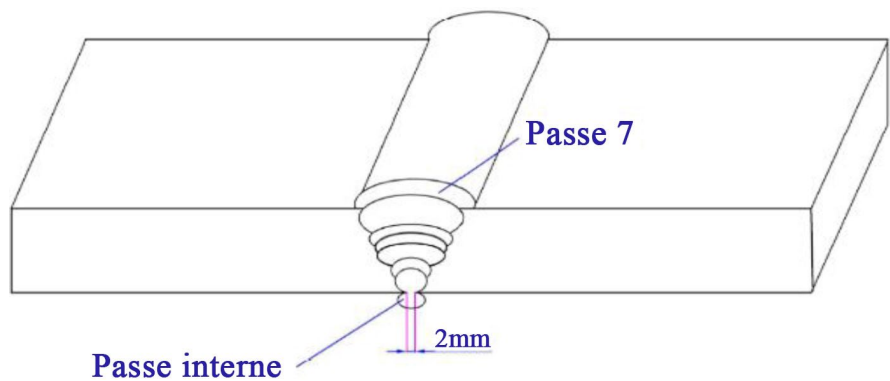


**Figure 10.** Electric arc welding station with coated electrode.

The type of welding used is electric arc welding with coated electrode:

The coating of the electrode deposits a protective slag on the molten metal. This process has made great progress over the last thirty years, thanks mainly to new electrode manufacturing techniques. The speed of weld execution is important and is linked to the fact that the heat input is very localized [12].

The weld bead is made from 2 to 7 welding passes depending on the thickness of the specimens with an internal pass following **Figure 11**.



**Figure 11.** Diagram of the test piece after welding.







Non-destructive testing techniques applied to welded joints:

Equipment used for non-destructive testing:

Tools used for visual inspection.

The following tools in **Table 3**, managed by the welding coordinator, are available at a centralized location [13]:

**Table 3.** Tools used for visual inspection.

VT welding gauge	
Caliper	
Graduated steel ruler	
Cord measurement gauge	
Magnifying glass	
Thickness gauge	

**Lighting:** Good lighting is essential.

Inspection lenses: Magnification should not exceed 2 to 2.5 diameters. If higher magnification is required, use a binocular microscope as shown in **Figure 12**.

Optical observation can gradually progress from sight to the use of a hand torch and mirror, to the addition of a magnifying glass and a light source.

In order to achieve accessibility, remote probe units are available which must have the following properties.

- Wide field of vision.
- Absence of image distortion.
- Accurate preservation of color values.
- Adequacy of lighting [14] [15].

The device used for our analysis is a SONY HD 8 GB camera.

Angle gap: 29.8 mm.

Extended Zoom: 50X.

Empty LCD panel: 2.7.





Figure 12. The radioactive source.

Machine or radioactive source used for radiographic testing.

The machine used in the radiography test is an Iridium 192 brand generator of the radioactive source according to the photos in Figure 13.



Figure 13. The radioactive source.

Source size [ $\phi \times h$ ] in mm: 5 × 8.

Activity room sizes [ $\phi \times h$ ]: 3.0 × 2.0.

Source ID: HCW063/Iridium.

Source case type/material: HAT/HCT capsule/Iridium.

ISO 2919:1999 classification code: C66545.

Sealed source control method: immersion test (boiling liquid) according to ISO9978:1992 Result < 200 Bq.

Special form for radioactive materials Certificate No: PL/0029/S (Rev.1).

Additional information:

The source identification number is a unique number legibly engraved on the source capsule container type/No UK-12S/02/2019.

Materials and equipment used for the penetrant test:

The product used for the penetrant test is FLUXO P125: Figure 14;

Colored Penetrant-Sensitivity 2-Penetrant Testing.



Figure 14. Colored penetrant-sensitivity 2-penetrant testing.

### Description and Composition of the Penetrating Liquid.

Colored Penetrant Washable with water or removable with solvent for Penetrant Testing.

Type 2—Sensitivity 2 (according to EN ISO 3452-2).

Operating temperature: 10°C to 50°C.

Can also be used at low temperatures (below 10°C). Penetration time may need to be increased.

Composition: combination of surfactants, intense red colorant in a de-aromatized petroleum with a high flash point.

#### Related Products:

White Developer (R175 - R180);

Solvent/Cleaner (S190 - N130);

Standards and Approvals;

NF EN ISO 3452-2-NF EN 571-1;

NF EN ISO 3452-6—Low temperature penetrant testing;

PMUC—Products and Materials Usable in Power Plants;

ASTM E1417;

ASME BOILER AND PRESSURE VESSEL CODE, SECTION V;

ASTM E-165;

RCC-M Code;

Low Sulfur and Halogen Content.

#### Properties:

Performance: 100% detection of defects on 50µm and 30µm Ni-Cr shims;

Appearance and Color: Red liquid;

Density: 855 kg/m<sup>3</sup>;

Flash point: > 82°C;

Viscosity: approximately 3 mm<sup>2</sup>/s (40°C);

Compatibility: with all metals and certain ceramics.

Sensitivity 2 according to ISO 3452-2 for the range:

FLUXO P125 + FLUXO R175 and: FLUXO P125 + FLUXO R180.

#### Shelf Life/Storage:

5-year shelf life (storage at room temperature);

Keep away from moisture;

Keep packaging closed between uses;

See the Safety Data Sheet.

#### Packaging:

Aerosol 500 ml NET-Aerosol 300ml NET;

10 L drum - 5 L drum - 200 L drum.

#### Performing the visual inspection:

This is the first check carried out after welding the test pieces.

After cleaning the welded joints, we carried out our inspection using a magnifying glass and a video camera.

#### Visual inspection steps:

Visual control requires a minimum of means to be implemented:

Wire brush (to remove paint chips);  
 Cloth and degreaser;  
 Mirror for observing an area that is not directly visible;  
 Magnifying glass to improve the analysis of a defect;  
 Side lamp.  
 In our research, the visual inspection did not detect any clear defects.  
 Performing the radiographic test:  
 The stages of the test:  
 Marking out the work area;  
 Projector Installation and Accessory Connection;  
 Ejection of the source;  
 Removal of tags;  
 Projector storage;  
 Film development;  
 Drying of films;  
 Interpretation of films.  
 Performing the penetrant test:  
 The steps of the penetrant test are shown in **Table 4**, reporting:

**Table 4.** The steps of the test.

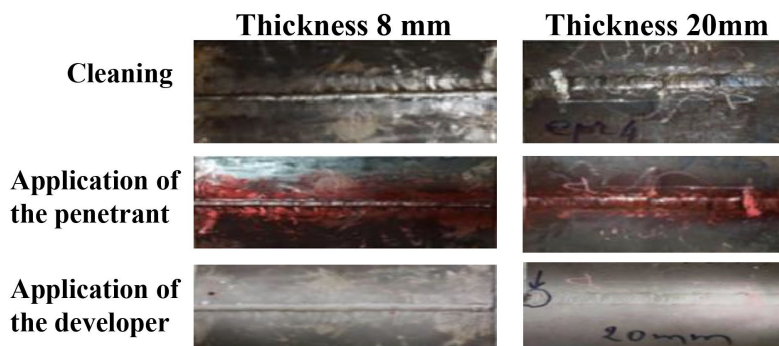
<b>Penetrant Examination:</b> <i>Liquid penetrant examination</i>	<b>Report N°</b>	<b>21-8299/ODIR-6M1</b>		
<b>Case Reference:</b> <i>Contract reference</i>	<i>21-8299/ODIR</i>			
<b>Penetrant Examination:</b> <i>Inspected equipment</i>	<b>Welded Test Cuts:</b> <i>(Test specimen, made of 8 mm and 20 mm sheet metal)</i>	<b>Material</b>	<i>Carbon Steel</i>	
<b>Reference Plan:</b> <i>Reference drawing</i>	N/A			
<b>Objective of the Exam:</b> <i>Subject of the examination</i>	<b>Defect Identification Drain Unblocker(s):</b> <i>Search for leading fault(s)</i>			
<b>Stage of Examination</b>	<i>After welding</i>	<b>Place of Examination</b>	<i>ODIR SEBNIKORO</i>	
<b>Date of Examination</b>	<i>30/10/2021</i>	<b>Operator(s)</b>		
<b>Conditions of Implementation</b> <i>Conditions of execution to</i>	<b>Following:</b> ASME VIII	<b>Version:</b> 2010		
<b>Surface Rough</b>	<input checked="" type="checkbox"/> <i>Rough</i>	<i>Ground</i>	<i>Other</i>	<i>Other</i>
<b>Preparation Surface:</b> <i>Preliminary cleaning</i>	<input checked="" type="checkbox"/> <i>Brushing</i>	<i>Degreasing</i>	<i>Other</i>	

## Continued

<b>Penetrant</b>	FLUXO <i>Brand</i>	<b>Type:</b> P125	<b>N° Lot:</b> L150521-001 <i>Batch N°</i>
<b>Pre-Emulsified</b> <i>Water washable</i>	<input checked="" type="checkbox"/> <i>Colored</i>	<b>Fluorescent</b>	<b>Temperature:</b> 28°C
<input checked="" type="checkbox"/> <i>Spraying</i>		<i>Brushing</i>	<b>Penetration Time:</b> 20 min <i>Impregnation time</i>
<i>Excess penetrant removal</i>		<input checked="" type="checkbox"/> <i>Water</i>	
<b>Solvent</b>	<b>Brand:</b>	<b>Type:</b>	<b>N° lot:</b> <i>Serial N°</i>
<b>Drying</b>	<input checked="" type="checkbox"/> <i>Cloth</i> <i>Rag</i>	<i>Other</i>	
<b>Developer</b>	<i>Brand</i> FLUXO	<b>Type:</b> R175	<b>N° Lot:</b> L151108-001 <i>Batch N°</i>
<b>Dry</b>	<input type="checkbox"/> <i>Water based</i>	<input checked="" type="checkbox"/> <i>Solvent based</i>	<i>Reveal time: 30 minutes</i>
<b>Examination</b>	<b>Spraying</b> <input type="checkbox"/> <i>Natural</i> <i>Day light</i>	<b>Other</b> <input checked="" type="checkbox"/> <i>Artificial</i> <i>Artificial light</i>	<b>Ambient Lighting:</b> ≥100 lux <i>Ambient light</i>
	<input type="checkbox"/> <b>Lamp UV</b> <i>UV lamp</i>	<b>Intensity:</b> μw/cm <sup>2</sup> <i>Intensity</i>	<b>Stray White Light:</b> lux <i>White light interference</i>
<b>Final Cleaning</b>		<input type="checkbox"/> <i>No</i>	<input type="checkbox"/> <i>Yes</i>
<b>Other Information</b>			

## 5. The Results Obtained after the Tests

Penetrant Test Results: For the 8mm specimen, the inspected weld does not show any out-of-tolerance indications when tested by penetrant testing according to ASME VIII Section 5 (see attached photo).

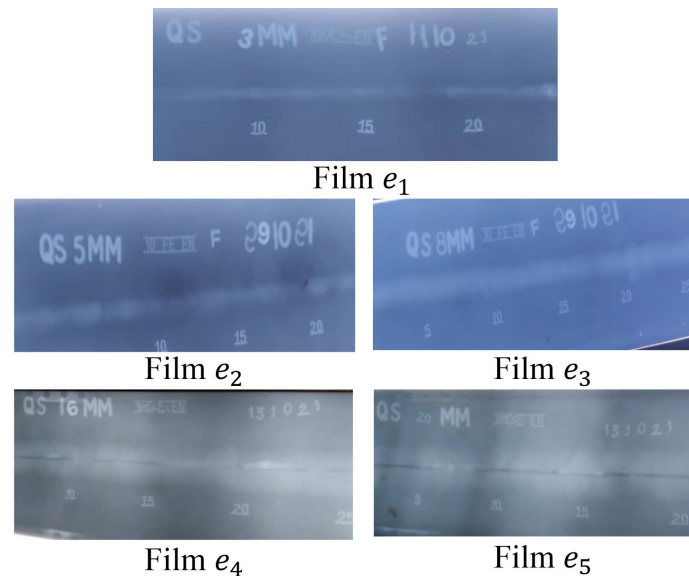


**Figure 15.** Specimens during and after the penetrant test.

On the other hand, for the 20 mm test piece, the controlled weld shows rounded indications outside the tolerance when tested by penetrant testing according to ASME VIII Section 5 (See attached photo) as shown in **Figure 15**.

## 6. Results of the Radiographic Test

The X-ray films of specimens E3, E5, and E8 do not show any major defects. However, unlike specimens E16 and E20, a lack of fusion is observed at the weld bead. These defects are sometimes linked to multiple welding passes, the welder’s qualifications, or even the choice of filler materials compared to the base materials, as shown in **Figure 16** and **Table 5**.



**Figure 16.** X-ray films of the specimens after testing.

**Table 5.** Results of radiographic inspection of carbon steel samples from 05 test tubes.

Results of the Radiographic Examination Radiography of 05 Carbon Steel Test Specimens				Affair: 80121/010-CND-BAR- Job 2021
				Report N° 1 80121/010-CND-BAR- 2021-S
				Page: N°: <u>01/01</u>
Gamma Rays	Type: <u>IR 192</u>	Size: <u>3 × 2</u>	Activity: <u>2.39</u>	Time Exposure: <u>15~20 mm</u>
Films	Type:	Single Film	Double Film	
Screen	Type: AA400	Front: Yes	Intermediate: Back: <u>Yes</u>	Backscatter:
Development Processing	Temp:	Time Developer: <u>5 mn</u>	Time Fixator: <u>10 mn</u>	Development
IQI Penetrometers	Type: <u>Wire Type</u>	S Source Side F Film Side	Sensibility: Sensibility:	

Continued

Controlled Area/Room: 100% Welds + ZAT  
 Inspected area/Spool/ISO

Weld Number Diameter Number Diameter Schedule	Type of Defect													Results						
	Film N°	Density on average	Medium density	IQI Din Visible Wire	Linear defect	Lack of fusion	Root concavity	Excess penetration	Start stop	Undercuts	Cap undercut	Slag lines	Tungsten inclusion	Porosity	Worm hole	Shrinkage cavity	Position of defects	Accepted	To be repaired	Rejected (to be cut out)
Test 3 mm	1	2 - 4	0.125																	
Test 5 mm	1	2 - 4	0.125																	
Test 8 mm	1	2 - 4	0.25																	
Test 16 mm	1		0.25		X											00 - 250		X		
Test 20 mm	1		0.25		X											00 - 250		X		
Date of Exam:	29-Oct-21			Specifications: Codes: ASME B 31.3 Procedure:					Isometry in the Appendix Sketch Attached: Yes/No							Date: 29/10/2021				

### 7. Discussion and Interpretation of Results

Trials	Faults				
	E1 = 3 mm	E2 = 5 mm	E3 = 8 mm	E4 = 16 mm	E5 = 20 mm
Test Tubes					
Number of Passes	02	02	03	03	07
Visual and Dimensional Control					
X-Ray				X	X
Dyeing				X	X

The results and films obtained from the radiographic test show that, for low thicknesses, the defects are reduced. Case of specimens E1 and E2, where there

are only 3 welding passes. This explains the reduction in defects. On the other hand, for large thicknesses, defects are generally observed. Case of specimens E4 and E5, where there are several welding passes. This sometimes causes lack of fusion or other types of defects etc. Likewise, the results and photos found by the penetrant test show, for low thicknesses, fewer defects. Case of the Epe = 8 mm specimens where there are only 3 welding passes. This explains the reduction in defects. On the other hand, for large thicknesses, defects are observed more often.

Case of Epe = 20 specimens, where there are several welding passes. This sometimes causes the presence of shrinkage at the end of the bead or other types of surface or internal defects, etc.

In multi-pass welding, a lack of penetration is defined as a partial failure of fusion of the edges to be welded, leaving a gap between them. This lack of penetration is due to an insufficient current or an excessively high travel speed. Insufficient preheating can also cause a lack of weld penetration. Solidification defects, on the other hand, are hidden shrinkage cavities. A root shrinkage cavity appears beneath the weld during solidification, while a crater shrinkage cavity is a cavity in a weld that is not corrected before the next pass is executed. Lack of fusion between passes is caused by inadequate cleaning between passes, or cumulative heat input can lead to defects such as lack of fusion.

## 8. General Conclusions

The quality of a weld depends on the proper execution of the welding operation, but there will be no certainty about the condition of the weld if it is not certified by a reliable and secure control.

There are many possible welding defects, but also many control techniques.

The work we carried out gave us the opportunity to analyze the defects in arc-welding beads with coated electrodes using radiography and penetrant testing at different thicknesses.

The results obtained from the radiographic and penetrant testing were very encouraging. Fewer defects were detected in thin specimens, unlike in thick specimens.

Defects are sometimes linked to multiple welding passes, the welder's qualification or even the choice of material.

Non-destructive testing (NDT) applied to welded joints during our research:

- Visual and dimensional inspection.
- Dye penetrant testing.
- Radiographic inspection.

These methods allow us to characterize the structural integrity of welded joints without damaging them during production or use.

They can be considered as validation criteria for products in metal construction. Other testing methods can be used to obtain greater certainty regarding the

product being examined.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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<http://archives.univ-biskra.dz/bitstream/123456789/4985/1/BENEDDEB%20Mostefa.pdf>
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