ISSN: 2456-3676

# Experimental Analysis of Surface Defects in Electric Arc Welding Joints with Coated Electrode by Penetrant Test on Different Thicknesses

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doi: 10.51505/IJAEMR.2022.7202 URL: http://dx.doi.org/10.51505/IJAEMR.2022.7202

## Abstract

Welding is considered today as the standard joining operation in steel construction. Its purpose is to ensure the continuity of the material to be assembled, the quality of which depends on the proper functioning of the welding technique.

Penetrant testing is a non-destructive test that consists of implementing investigative techniques to judge "without destruction" the state of the weld joint. The final objective of this work is to develop an opinion on the suitability of the welding joint of different thicknesses. Thus, metal specimens of different thicknesses were inspected.

The results obtained show that, for small thicknesses, the defects are minimal and increase considerably, proportionally with an increase in the thickness of the welded parts.

This analysis can be a way to facilitate the location of surface defects in order to reduce defects during welding operations.

**Keywords:** Fault analysis, Penetrant Testing, Electric arc welding.

## Introduction

### *1.1. Introduction the problem:*

Welding is an industrial process widely used for the assembly of metal parts which consists in 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 the two, heat and pressure. Welding can be done with or without filler metal (BENEDDEB, 2012). In practice, welding is used in large construction sites such as the manufacture of boat hulls, also in the manufacture of gasoline tanks, tank tanks, metal frames, automobile hulls, etc...

The most common welding processes can be classified as: electric arc welding, oxyacetylene welding, resistance welding, energy beam welding and solid-state welding. Electric arc welding is the most widely used process in the Republic of Mali (Thiam, 2020), so this study is done on the weld bead of this type of welding.

The quality of a welding joint depends on several factors such as the welding parameters, the nature of the material to be welded, the filler material and the welder etc...

The study of the defects of the welding joints can make it possible to improve the quality of welding. The realization of fine and perfectly sealed resistant welding joints are conditions to be fulfilled in order to obtain good quality. The inspection of the welding joints makes it possible to control and analyze the quality.

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ISSN: 2456-3676

Penetrant testing is one of the methods used for the study and inspection of defects in electric arc welding joints.
Several studies have been carried out on electric arc welding beads such as:
Non-destructive (radiographic and penetrant test) and destructive (tensile and hardness test) testing of the electric arc welding bead on large-diameter S355JR steel tubes, of the same thickness with different preheating temperatures (BOUZAROURA, 2014).
It also had research on non-destructive testing such as: penetrant testing, magnetic particle inspection, radiography, eddy currents and ultrasound(Ali, 2018), more spectral analyzes in non-destructive testing by Ultrasound (Bouchefirat et Dib, 2019).
Contrary to previous studies, our work is based on the inspection of defects in electric arc welding joints with coated electrodes by penetrant testing on different thicknesses.
The purpose of this research is to inspect electric arc welding joints in order to propose the best choices of parameters and the nature of material that can improve welding quality.

### *1.2. Different welding defects*

A perfectly made weld joint does not exist, because all weld joints contain imperfections of different natures such as: porosities, cracks, inclusions, shrinkage, etc.
These imperfections should be evaluated to determine if they will have a negative effect on the welded joints. They are evaluated by the acceptance criteria specified in the standard, but only an imperfection exceeding the limits of the acceptance criteria will be considered as a defect(BEGHDAOUI, 2020). Welded joints, by their nature, contain discontinuities of different types and sizes. Below a certain acceptable level, they are not considered harmful. Beyond this level, they are considered faults. The level of acceptance varies according to the nature of the service to be provided.
Generally, the discontinuities encountered in welds are:

- Porosity;
- Slag inclusions (gaseous inclusion or solid inclusion);
- Incomplete fusion;
- Cracks.

## 2 Method

### *2.1. The specimen's fabrication*

The base material used for the manufacture of the specimens is a mild steel, designation S235JR and whose mechanical characteristics are shown in the following table 1 and the chemical composition of the base metal material is shown in the table 2.

Table 1: Mechanical characteristics of the base metal

| Norm | Name | Elastic limit | $R_m$, e≥3 | A% | Testing temperature |
|---|---|---|---|---|---|
| ISO 9001 | S235JR | 235MPa | 360-510MPa | 25% | $20^0$C |

Table 2: Chemical composition of the base metal material

| C% | Si% | Mn% | P% | S% | N% | Cu% | CEV% |
|---|---|---|---|---|---|---|---|
| 0.119% | 0.397% | 0.020% | 0.014% | 0.002% | 0.010% | 0.043% | 0.016% |

The filler metal used is the metal coated electrode for manual electric arc welding, the characteristics of which are shown in the following Table 3:

Table 3: Filler metal characteristics

| Designation | Grade | Base coating | Welding current | Welding configuration |
|---|---|---|---|---|
| SAFER NF 510 P | 3Y H5 | Diameter: 2.5 - 5.0 mm | AC / DC (+) | Any position for butt welding except vertical down (PA, PF, PC, PE). |

Before welding the sheets, the specimens are cut with a grinder to have specific dimensions.

The dimensions of the test pieces are: Length: 300, width 150, Thickness: $E_n$, n is the number of the test piece which varies from 1 to 5. The specimens' specifications are shown on the following
Figure 1

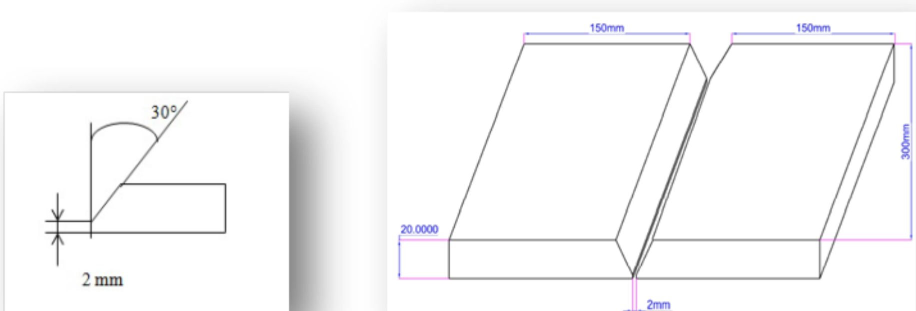


Figure 1: Specimens' specifications

*2.2. Welding operation:*

With coated electrode electric arc welding, the electrode coating deposits a protective slag on the molten metal. This process has made great progress in the last thirty years, due to new techniques for manufacturing electrodes. The speed of execution of the welds is important and is related to the fact that the heat input is very localized (BEGHDAOUI, 2020).
Welding of specimens is carried out with the following welding parameters:
The electrodes used diameters (2.5mm, 3mm and 4mm).

The speed of execution of the welds is important and is linked to the fact that the heat input is very localized (HICHEM, 2013).
The weld bead is carried out from 2 to 7 welding passes depending on the thickness of the specimens with an internal pass shown in Figure 2

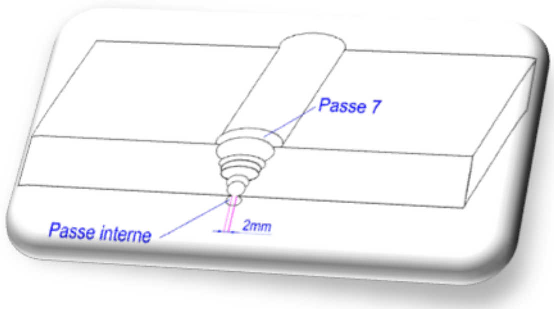


Figure 2: Welding operation

After welding, some welded specimens ready for testing are showed in the following Figure 3.

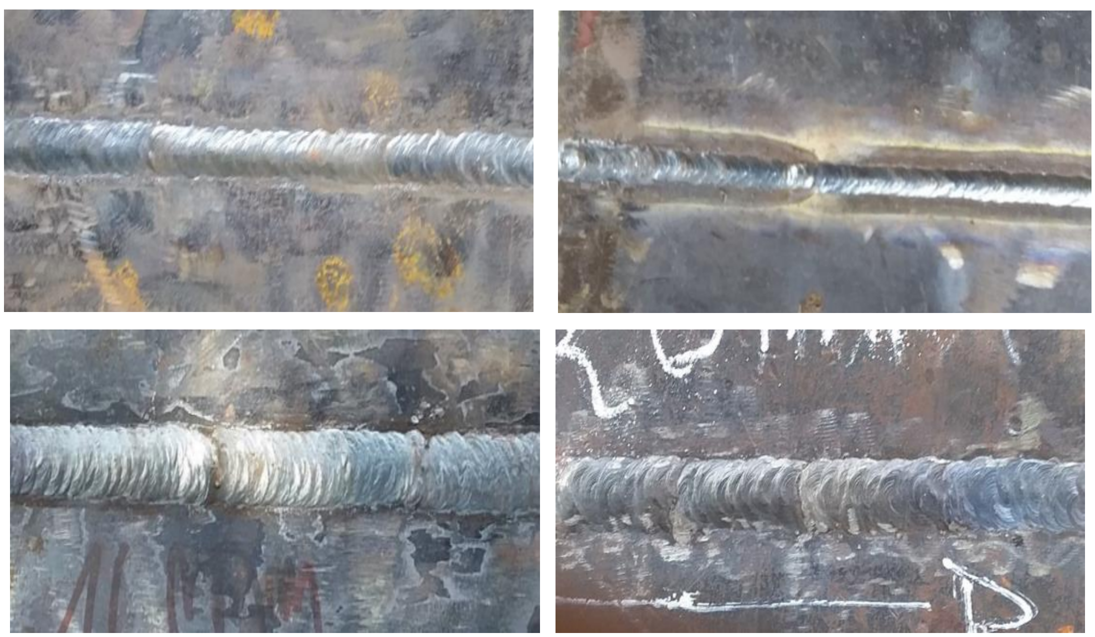

Figure 3: Welded specimens ready for testing

*2.3. Penetrant testing*

Penetrant testing is a non-destructive testing method whose objective is to locate surface discontinuities in materials, such as pitting, cracks, shrinkage, etc.
It is based on the principle of capillarity. The materials, procedures and equipment used in PT are such that they facilitate capillarity and make it possible to detect defects and interpret them.
This method is based on a phenomenon by which a penetrating liquid, contained in

discontinuities, oozes on the surface of the material. The use of a penetrant improves the visibility of the discontinuity for the human eye (TLILI et al., s. d.).

The procedure respects some steps as follow and shown on the figure 4:

- The surface is prepared
- A penetrating liquid is applied to the surface
- By capillarity, the liquid penetrates the discontinuities (cracks, porosity, etc.) emerging at the surface
- Excess liquid is removed from the surface
- A developer is applied to "suck" the penetrant towards the surface of the part
- The part is visually inspected under appropriate lighting
- The room is cleaned again (VIENS, 2005).

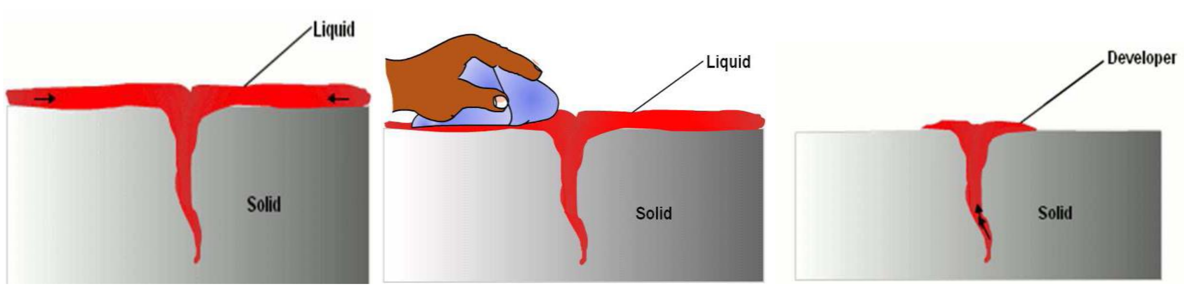


Figure 4: Procedural steps

The advantages of this method are: Very sensitive to surface discontinuities, Relatively easy to use, Can be used on a wide variety of materials and complex part geometries , Large areas can be inspected quickly and at low cost, Clues appear directly on the inspected part, The sets of aerosol products allow the portability of the method(VIENS, 2005) and the disadvantages are: it only detects defects with a certain volume, it cannot be used on porous and absorbent materials, it does not detect internal faults, it requires clean and well degreased surfaces, it uses harmful, flammable or volatile products (Feriel, s. d.).

The following tables 4 and 5 show the different reports on the execution of the penetrant test on the welded specimens.

Table 4: Report No1 on the execution of the penetrant test

| *Liquid Penetrant Examination* | | *Report N°* | **21-8299/ODIR-6M1** |
|---|---|---|---|
| *Contract reference* | 21-8299/ODIR | | |
| Inspected equipment | Welded Specimens – *(ép. de tôle 8 mm et 20mm)* | *Material* | *Carbon Steel* |
| *Reference drawing* | N/A | | |
| *Subject of the examination* | *Search for leading fault (s)* | | |
| *Stage of examination* | *After welding* | *Place of examination* | ODIR SEBNIKORO |
| *Date of examination* | 30/10/2021 | *Operator(s)* | |

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ISSN: 2456-3676

Table 5: Report No2 on the execution of the penetrant test

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Conditions of execution to* | ASME VIII | | | | *Version* | 2010 | |
| *Surface rough :* | ☒*Rough* | | *Grounded* | | *Other* | | *Other* |
| *Preliminary cleaning* | ☒ *Brushing* | | *Degreasing* | | | | *Other* |
| *Penetrant* | *Brand :* FLUXO | | *Type :* P125 | | | | *Batch N°:* L150521-001 |
| *Water washable* | ☒ *colored* | | *Fluorescent* | | | | *Température :*28 °C |
| | ☒ *Spraying* | | *Brushing* | | *Immersion* | *Impregnation time :* 20 min | |
| *Excess penetrant removal:* | | | ☒ *Water* | | | | |
| Solvent | *Brand :* | | *Type :* | | | *Serial N°* | |
| *Drying :* | ☒ *Rag* | | | | *Other :* | | |
| *Developer :* | *Brand :* | FLUXO | *Type :* | R175 | | *Batch N°:* L151108-001 | |
| ☐ *Dry* | ☐ *Water based* | | ☒ *Solvent based* | | | Reveal Duration 30min | |
| | ☒*Spraying* | | ☐ *other* | | | | |
| *Examination* | ☐*Day light* | | ☒*Artificial Artifcial light* | | | Lumiere ambient : ≥ 100 lux *Ambiant light* | |
| | ☐*UV lamp* | | *Intensiy :* µw/cm² | | | *White light interference: lux* | |
| *Final cleaning* | | | ☐ *No* | | | ☒ *Yes* | |
| *Other Informations* | | | | | | | |

## 3 Results and interpretations

For the 8mm specimen, the controlled weld does not show any out-of-tolerance indications on penetrant examination according to ASME VIII section 5, shown on the following figure5.

On the other hand, for the 20mm specimen, the controlled weld shows rounded indications out of tolerance on penetrant examination according to ASME VIII section 5, shown on the following figure 5.

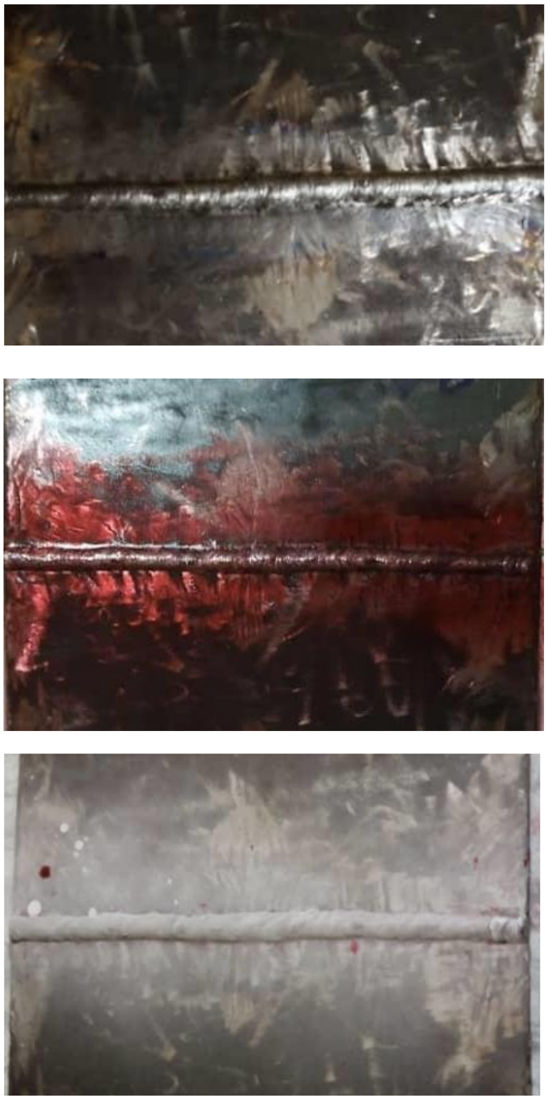

Fig 5: Thickness: 8mm


Fig 6: Thickness: 20 mm

The results obtained with this bleeding test show that, for small thicknesses, the defects are reduced (case of the specimens Epe=8mm where there are only 3 welding passes). On the other hand, for large thicknesses, defects are generally observed (case of specimens Epe=20 mm, where there are several welding passes); this sometimes causes a lack of fusion, the presence of shrinkage at the end of the bead or other types of superficial or internal defects, etc.

**4 Conclusions**

The work that we carried out, gave a possibility, to analyze the superficial defects of the arc welding joints with coated electrode by the penetrant test.

According to the ASME VIII standard, the weld bead of the Epe: 8 mm specimen did not show any out-of-tolerance indications on penetrant examination section 5 (figure 5). On the other hand, the inspected welds of the specimen Epe=20mm present rounded indications out of tolerance on examination by penetrant testing according to ASME VIII section 5 (figure 6).
The results obtained by the bleeding test on welded specimens of different thicknesses were very clear. Because, we did not detect any defect on the test piece of low thickness 8mm. Unlike the large 20 mm thick specimen, the presence of shrinkage was observed at the end of the bead, defects sometimes linked to multiple welding passes, the qualification of the welder or even the choice of materials.

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