

NON-DESTRUCTIVE TESTING OF DISSIMILAR WELDED JOINTS

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ABSTRACT

This paper presents research's results of non-destructive examination of dissimilar welded samples. The samples were made using sheets of austenitic stainless steel and carbon steel welded through the method of MAG welding with tubular wire. The samples were subjected to non-destructive testing in order to analyse the integrity of the welded seam, heat affected zone and the adjacent area of the weld.

KEYWORDS: non-destructive testing, austenitic stainless steel, carbon steel, dissimilar welded join, MAG welding

1. Introduction

Quality assessment can be put into practice by knowing the quality characteristics that are linked to a system of indices, indicators and coefficients. The assessment is required by the complexity of products and processes, being able to synthetically express a number of aspects of quality [1, 2].

The quality inspection of welded joints is an extremely complex branch, with many methods, techniques, and analysis and evaluation tools available. In order to be able to understand and use the quality assessment methods, a study of the specialized terminology currently used in this field, a terminology to be used in this paper, was also carried out. Terminology have been defined as: welding, imperfection, etc. [2-4].

The inspection methods for welded joints were presented and their classification in the three categories - the production process, the integrity of the product under examination and the number of products checked [4].

The imperfections of welded joints represent any deviation from shape, size, continuity, structure, appearance, composition or properties prescribed for a particular seam in the technological documentation. These have the effect of reducing resistance and worsening behavior in the exploitation of a welded joint. [5, 6].

Because the nonconformities can affect the performance and longevity of welded joints, early detection and correction is essential to ensure that the welded structures meet their designing purpose. After detecting the nonconformities in welded joints, an assessment should be made to determine their

severity and the appropriate measures to be taken. Even the hardest to detected imperfection may encounter an inadequate welded structure to achieve its intended purpose [6, 7].

Detection techniques must be sensitive enough to detect dangerous discontinuities. It is necessary to repair the defects that damage the structural integrity of the welded joint. Welds do not have to be perfect; they must be within the permissible work limits specified in the quality standards used during the welded structure inspection [4, 6, 7].

After analysing the specialty literature in order to highlight the welding processes used to obtain dissimilar welding joints the following processes were identified:

- gas metal arc welding, MIG/MAG, with normal and tubular wire [8-10];
- gas tungsten arc welding, WIG [11-13];
- friction welding [14];
- electron beam welding [15];
- fiber laser welding [16], etc.

The MIG/MAG process is the most used for manufacturing dissimilar joints and the combination between stainless steels and structural steels is widely used because of the economic benefits.

Examination of welded joints begins with the examination of the materials used in the welding process and ends with the final examination of the resulting joint. The final examination consists in checking the welded joint using different non-destructive methods. These methods are classified in two categories [17-19]: destructive and non-destructive examination.

The non-destructive examination methods used to examine the welded structure are chosen by taking

into account the geometry of the part, the surface and the accessibility of the part to be examined.

The methods used to verify the structures are divided into two categories, and namely [17, 18]:

- Methods to highlight surface and near surface imperfections that are dependent on the surface area and accessibility to the examination.

These include:

- Visual Testing (VT) - used to detect surface imperfections and also as an integrated part of the others non-destructive methods.

- Penetrant Testing (PT) - used to detect imperfections which are open to the surface of the tested material. It is applied on metallic materials, but also on non-metallic materials, e.g., ceramics.

- Magnetic Testing (MT) - used for the detection of surface imperfections and below the surface in ferromagnetic forgings, castings and welds including the heat affecting zones using the continuous. Its sensitivity is reduced rapidly with the depth.

- Eddy Current Testing (ET) - used for the detection of surface breaking and near surface planar defects and it is applied on welds of almost any configuration.

- The methods used to identify inner imperfections are dependent on the geometric geometry of the part to be examined. Most commonly used are Ultrasound Testing (UT) and Radiographic Testing (RT), both used to detect inner and surface imperfections in welds. They can be applied on any type of material, taking into account the specific limitations for each method and the security norm for radiographic testing.

- In addition to the methods mentioned, the following method is also evaluated:

- leak Test (LT) - highlights fluid leaks.

- Infrared Thermography (TT) - allows the detection of defects in layered, coated, glued, composite materials; measuring the thickness of coatings or coatings; characterization of materials in terms of thermal behavior; evaluation of the structure of polymeric composite materials, analysis or measurement of the heat flux provided by the examined

product (heat exists or is produced independently of the examination process).

- Acoustic Emission (AT)- allows monitoring the structures integrity, report losses through leakage, the early detection of cracks or even when they appear, characterizing the behavior of materials.

This paper presents the applications of different non-destructive methods in order to identify the imperfections in dissimilar welded joints. To achieve the proposed activities, the following steps were taken establishment of welding technology used for sample making, welded joints making, mechanical and chemical cleaning (degreasing) of samples, Visual Testing, Penetrant Testing, Ultrasound Testing, Radiographic Testing.

2. Experimental data

2.1. Sample description

At present, the joint between two dissimilar materials, steel carbon, S235JR + AR and a stainless steel austenitic, X2CrNiMo17-12-2, are often used, for this reason for making the experiments was chosen to perform a dissimilar welded joint.

Carbon steel and austenitic stainless steel were used as materials for the samples, the two steels being representative of the classes they belong to.

The experimental plan consists of the following steps: choice of the basic material, choice of the welding groove: type and geometry, choice of the welding process, selection of the filler material and execution of the welded joints.

The chemical composition and the mechanical proprieties of the base materials are presented in Table 1 and Table 2.

The selection of the filler material for making the dissimilar welded joint from the range of materials made available was done by means of an analysis. The analysis was made using the software Autodesk Inventor. This consisted of a series of stress and fatigue strength for the type of groove chosen at the previous point.

Table 1. Chemical composition of the base materials [20, 21]

Chemical Composition	C %	Cr %	Mn %	Mo %	N %	Ni %	P %	S %	Si %
X2CrNiMo17-12-2 EN ISO 100088-3	0.03	16-18	2	2-3	0.10	10-14	0.045	0.03	0.75
S235JR + AR EN10027-2	0.17	-	1.40	-	0.012	-	0.035	0.035	-

Table 2. Mechanical proprieties of the base materials [20, 21]

Properties	X2CrNiMo17-12-2 -Value	S235JR + AR - Value
Yield strength (R_{p02})	170 N/mm ²	Max. 235 N/mm ²
Tensile Strength (R_m)	485 N/mm ²	360-510 N/mm ²
Elongation (A_5)	min. 40%	Max. 26 %

As a result of the analysis, T 23 12 L PC / M 1 is the best choice for making the dissimilar welded joints between carbon steel S235JR + AR and austenitic stainless steel X2CrNiMo17-12-2.

Subsequently, the chemical composition of the wire used, and the mechanical properties of the melt metal are presented in Table 3, respectively Table 4.

Table 3. Chemical composition of the filler material [22]

Chemical Composition	C %	Cr %	Mn %	Mo %	N %	Ni %	P %	S %	Si %
T 23 12 LPC/M 1	0.04	22.85	0.60	0.162	0.0266	12.54	0.019	0.009	0.65

Table 4. Mechanical proprieties of the filler material [22]

Properties	T 23 12 LPC/M 1-Value
Yield strength (R_{p02})	460 N/mm ²
Tensile Strength (R_m)	610 N/mm ²
Elongation (A_5)	min. 31%

2.2. Welding process

The MAG process was chosen using the M21 protection gas (Ar + 18% CO₂) for welding the samples. The parameters of the welding regime used in the experiments were determined in accordance with the manufacturer's recommendations.

The following steps were taken to prepare the welding samples:

- Plate cutting to size - The base materials prepared for the experiment are the steels: S235JR+AR and X2CrNiMo17-12-2 in form of plates with the dimensions 350 mm x 225 mm x 15 mm. The cutting of the plates was performed using a Hypertherm Powermax 105 plasma cutting machine.

- The gripping of the parts for welding - The plates were fastened by using two steel plates, then placed on the welding table and subsequently the connecting to the table and to the welding source was made.

- The welding of the samples:

- Equipment used - a MIG / MAG TM 500 W Welding Machine was used to perform samples using the MAG process. For measuring the temperature between the layers, a Voltcraft IR900-30S Thermometer was used.

- The welding - The welding of the samples was conducted with a ceramic root using the MAG process. The groove configuration presented in Figure 1.

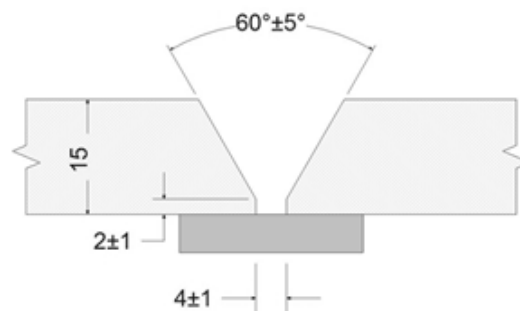


Fig. 1. The groove configuration and the positioning of the ceramic support

The set parameters were monitored during the entire welding process, ascertaining differences of maximum 3 A for the amperage and 1 V for the welding arc.

The welding parameters used are presented in Table 5.

Table 5. Welding parameters

Welding parameter	Values for the root layer	Values for the intermediate layers (3 layers)			Values for the surface layers
Welding current, I_s [A]	170 ± 10	170 ± 10			170 ± 10
Welding arc voltage, U_a [V]	29 ± 2	29 ± 2			29 ± 2
Welding speed, v_s [mm/s]	1.71	2.14	1.84.	1.79	4.8
Feed rate of welding wire, v_a [m/min]	4.8 ± 0.1	4.8 ± 0.1			4.8 ± 0.1
Gas flow (Ar 82% +18% CO ₂), D_g [l/min]	18 ± 1	18 ± 1			18 ± 1

2.3. Non-destructive examination of the samples

In order to analyse the quality of the welded joint obtained a series of non-destructive examination methods were used, after which specimens were taken to carry out the destructive tests.

In order to highlight any imperfections, present in the welded structure obtained, the sample was subjected to Visual Testing, Penetrant Testing, Ultrasound Testing and Radiographic Testing.

Visual inspection of the welded structure was performed using the direct viewing method.

2.3.1. Dry Penetrant Testing

In order to highlight the small imperfections on the surface of the test sample (which cannot be detected visually) or in the immediate vicinity of the surface, the test with penetrant liquid was used.



Fig. 2. Penetrant testing of the Miller etalon

For the examination using Penetrant Testing the following were established: ambient temperature: 20 °C; set of penetrating liquids: penetrant PFINDER 860 type and developer PFINDER 870 type; calculation of geometric sensitivity using the Miller standard and penetration and development time: 10 min.

For calculation of geometric sensitivity, the Miller etalon was used, see Figure 2. After the calculations, a geometric sensitivity of 0.965 was obtained.

Steps followed:

- Sample cleaning - the sample was chemically cleansed by degreasing: PFINDER 890 degreaser.
- Drying of the surface - forced by a hot air jet.
- Applying the PFINDER 860 penetrant:
 - The penetrant has been applied to the contact surface by spraying.
 - Dwell time used: 10 min.
- Removing the excess of penetrant - the excess penetrant was removed by washing.
- Surface drying - forced by a hot air jet.
- Application of developer PFINDER 870:
 - The developer was applied uniformly and thinly layer over the entire examined surface, only after being well agitated.
 - After application of the developer, the surface examined was allowed to dry at room temperature.
 - The development time begins immediately after surface drying; the development time was 10 minutes.
- The interpretation of the results was achieved at the end of the development time.
 - Upon examination with penetrating liquids, it was found that the piece had no detectable

imperfections by this method on the surface under consideration.

The penetrant testing kit used is presented in Figure 3, and the result obtained after the testing of the samples.

Upon examination with penetrating liquids, it was found that the piece had no detectable imperfections by this method on the surface under consideration.



Fig. 3. Penetrant testing kit

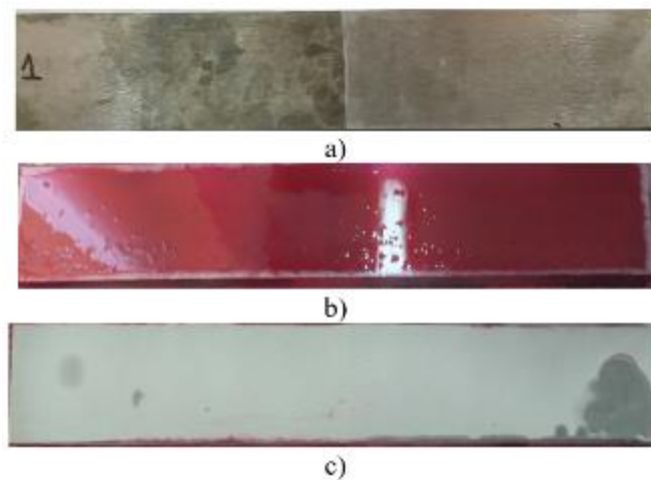


Fig. 4. Penetrant testing of the samples: a - test sample, b - application of the penetrant layer; c - the result obtained after drying by the developer

2.3.2. Ultrasound Testing

To perform the examination, an Olympus Defectoscope was used and two transducers with inclined incidence at the angles of 60° and 70°.

To see if the chosen equipment and technique can be applied to the type of joint performed, a specimen was debited from the samples, in which

imperfections with a diameter of 3 mm were formed at a depth of 6 mm on the edge of the welding seam, in cross-section. The experimental stand used for the ultrasound testing; the reflected pulse method is presented in Figure 5.

Subsequently the welded joints were subjected to ultrasound examination by the TOFD technique. In Figure 6 and 7 one of the TOFD report is presented.



Fig. 5. Ultrasound testing of the samples

Ultrasound Report

Report Date	Report Version	Data File Name	Inspection Date	Inspection Version	Hardware Type
2016 / 05 / 12	OmniscanConverter - 2.10R10	PROBA 1 ##	2016 / 05 / 11	MXU - 3.1R3	OMNI-M-UT-8C

Group 1

Setup

PI-R2 TOFD					
Beam Delay	Start (Full Path)	Range (Full Path)	PRF	Type	Averaging Factor
10.28 us	10.85 us	5.28 us	6000	UT	1
Pretrig	Rectification	Band-Pass Filter	Voltage	Gain	Mode
0.00 us	RF	Band-pass 2.00 MHz	50 V	42.00 dB	TOFD (Time-of-Flight Diffraction)
Wave Type	Sound Velocity	Pulse Width	Scan Offset	Index Offset	Scan Type
Longitudinal	5890.0 m/s	50.00 ns	0.00 mm	0.00 mm	Nonparallel
Conditional A-Scan	Gate Saved				
Off	Off				
PCS					
50.00 mm					

Gate	Start (Full Path)	Width (Full Path)	Threshold	Peak Selection	Link
I	0.00 us	6.79 us	20.00 %	Max. Peak	
A	6.79 us	10.18 us	25.00 %	Max. Peak	
B	13.58 us	6.79 us	30.00 %	Max. Peak	

Part

Material	Geometry	Thickness
STEEL, MILD	Plate	15.00 mm

Scan Area

Scan Start	Scan Length	Scan Resolution	Index Start	Index Length	Index Resolution
0.00 mm	280.00 mm	1.00 mm	0.00 mm	0.00 mm	1.00 mm
Synchro	Max. Scan Speed				
Encoder	6000.00 mm/s				

Axis	Encoder	Encoder Type	Encoder Resolution	Polarity
Scan	1	Quadrature	12.00 step/mm	Normal
Index	Off	Off	Off	Off

Fig. 6. TOFD parameters

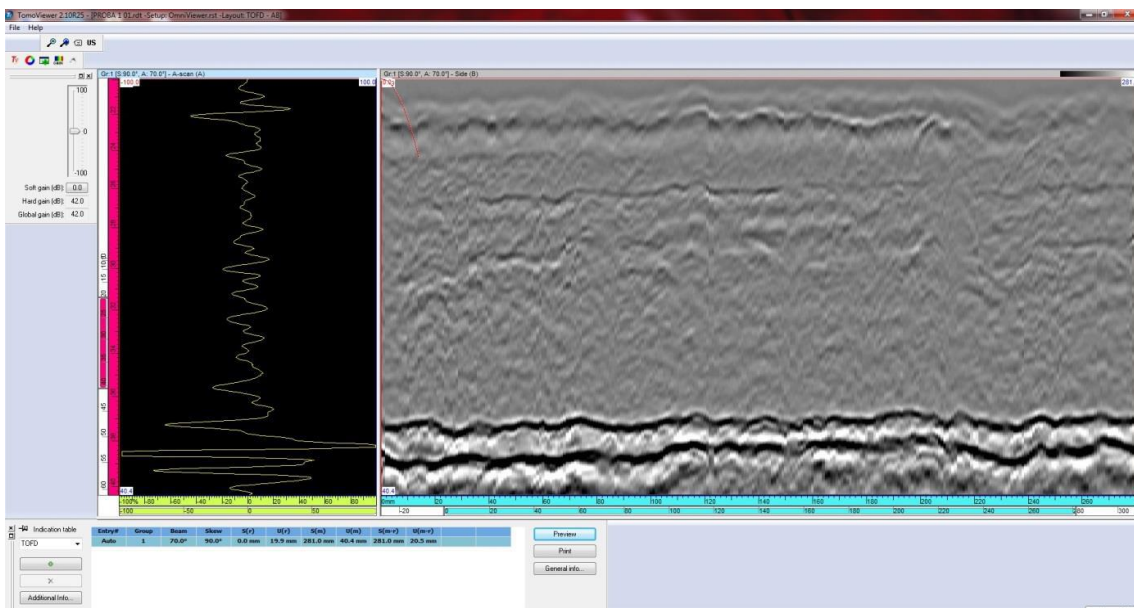


Fig. 7. TOFD report results

2.3.3. Radiographic Testing

Due to the fact that after the ultrasound examination the results were inconclusive, the samples were subsequently examined by Radiographic Testing.

The examination of the steel samples was carried out with the help of the X-ray non-destructive testing, obtaining the image on a radiographic film.

Technical data:

- Sample: dissimilar welded joint sheet between carbon steel and austenitic stainless steel.
- Material: steels S235JR and X2CrNiMo17-12-2.
- Dimensions: thickness 12 mm, length 350 mm, width 450 mm.

- Exposure geometry: Normal geometry.
- Radiography technique: a wall.
- Radiography class: Class B
- Radiographic parameters:
 - a X-ray tube parameters: U = 150KV; I = 4.5 mA;
 - a source-film distance = 500 mm;
 - an exposure time = 1 minute and 30 seconds.
- Quality indicators used: Group 1 H Fe with the following hole diameters: Visible H 4
- Film FOMAPAK BOHEMIA CZECH REPUBLIC, EU (R5 + Pb).
- Very high blackness density = 3.
- Image blur index = the number of the largest perceptible element.



Fig. 8. Radiographic film-sample 2

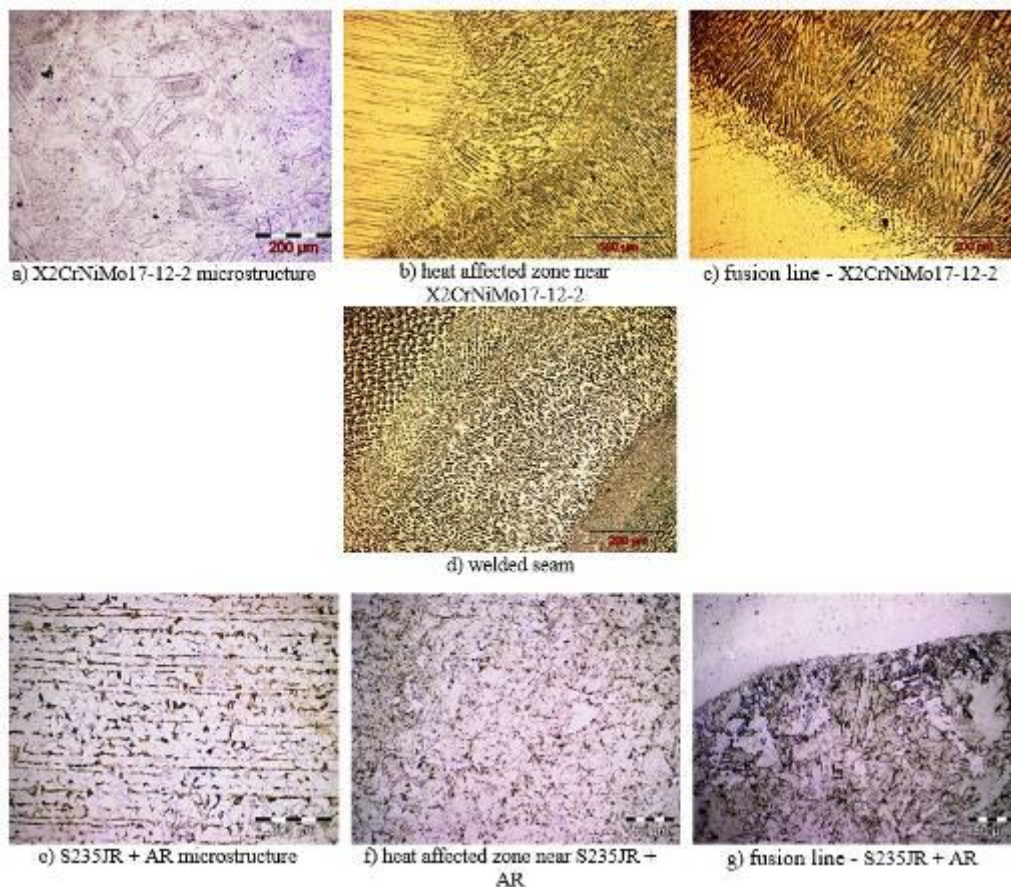


Fig. 9. Microscopic analysis

There were no imperfections of the interior highlighted using the Radiographic Testing, result which attest to the quality of the welded joint, as it can be seen from Figure 8.

In order to analyse the microstructure obtained destructive examination was applied. In figure 9 is presented the microstructure obtained in the areas of interest, namely: the heat-affected area, the fusion line, and the welded seam.

After analysing the microscopic images obtained the differences in structure can be seen, as follows:

- Stainless steel, X2CrNiMo17-12-2, shows microstructure with snail polyhedron grains and intragranular precipitations.
- Carbon steel, S235JR + AR, presents a ferrite-perlite microstructure in alternating ferrite and perlite strings.
- The fusion line between carbon steel, S235JR + AR (lower part), and deposition by welding with a high alloyed material (top). The HAZ shows the tendency to increase the granulation and the formation of the perlite and the coarse ferrite - Widmanstätten type.
- The fusion line between austenitic stainless steel, X2CrNiMo17-12-2, and welding with a high alloyed material. One biphasic ferrite and austenitic dendritic microstructure can be observed.
- In the heat affected zone near S235JR + AR a modified ferrite and perlite structure is observed.
- In the heat affected zone near X2CrNiMo17-12-2 a dendritic microstructure directed towards the direction of the thermal delta and austenite ferrite flow is observed.
- The welded seam shows a dendritic structure of delta and austenite ferrite.

3. Conclusions

From the analysis of the presented, important conclusions are drawn as follows:

- Dissimilar welded samples using the MAG welding process were created.
- After the welding process the samples were non – destructively tested.
- No imperfections have been identified following Visual Testing and Penetrant Testing.
- The result obtained using Ultrasound Testing, through the two methods of welded samples was inconclusive, due to the difference in structure between the two basic materials.
- Ultrasonic examination of austenitic stainless steel is difficult because of the grain size. Due to the fact that the austenitic stainless steel presents a coarse structure in case of ultrasound testing the grain boundary sometimes can be mistaken as a flow by the equipment. On the screen of the ultrasound defectoscope a sonic grass can be observed which can

mask small imperfections making them impossible to detect.

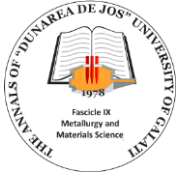
- The examination with Radiographic Testing confirmed the lack of imperfections in the welded samples.

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