GMAW WELDING PROCESS PARAMETERS OPTIMIZATION OF A DISSIMILAR JOINT IN AISI 304 AND ASTM A36 STEELS BY USING TAGUCHI METHODOLOGY

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ABSTRACT

Nowadays, investigations about dissimilar welding which is used in the petrochemical, nuclear, aerospace and automotive industries mainly under corrosive, inner water or high temperature environments, have aroused the interest of several researchers around the world. The economic efficiency of the dissimilar jointing process is one of the most important factors that has provided the possibility to use more sophisticated and expensive steels only in components that are exposed to critical conditions and to use cheaper materials that ensure the mechanical requirements in the rest of the structure. However, the difference between chemical composition, thermal expansion coefficient and microstructure of the steels in this type of joint can cause problems such as the formation of hard and brittle martensitic regions in the melting line, known as partially diluted zones (PDZ). Thus, the main goal of the presented research is to evaluate the influence of welding parameters on the mechanical properties in dissimilar joints of AISI 304 stainless steel and ASTM A36 structural steel, using the GMAW process. Therefore, the Taguchi technique was used in order to generate welding experiments with randomized parameters. An orthogonal array experiment with 9 samples was carried out in which the relationship between welding parameters (controllable factors) and mechanical properties (uncontrollable factors) were statistically evaluated. In this way, it was possible to conclude, through statistical treatments, which are the ideal welding parameters, suitable to provide the best mechanical properties for a dissimilar joint between AISI 304 and ASTM A36 steels.

Keywords: *Dissimilar Welding, GMAW, AISI 304, ASTM A36, Taguchi Experimental Design.*

INTRODUCTION

ASTM A36 steels are applicated in structural components where the physical properties are well defined to allow their use in projects that require bending and good weldability. When manufactured in steel plates, they have intermediate strength and are applied in various structural components.

AISI 304 steel is used in severe conditions (pressure and temperature) and has good mechanical resistance, whose stable nature makes it ideal for application in pipes, pressure vessels and tanks in the food, chemical and nuclear industry[(1)]. One of the challenges that is linked to the interests of the oil, naval and nuclear industries is the welding process of ASTM

A36 steel and AISI 304 stainless steel, being called the dissimilar welding process (DMW - Dissimilar Metal Welding) [2].

Dissimilar welding finds wide application in the industry due to the possibility of combining the efficiency of two materials in a single welded joint, representing material cost savings and design flexibility. In the manufacture of nuclear power plants, dissimilar welds are present in practically all conventional reactors, in the union of stainless pipes to carbon steel components[3].

However, this process can be hampered due to the difference between the chemical compositions and the coefficients of thermal expansion of the metals, which generates disadvantages in the metallurgical and mechanical properties[4]. Another aggravating factor is the generation of fragile regions of high hardness in the fusion line between the base metal and filler metal, called Partially Diluted Zones, which can compromise the mechanical strength of the dissimilar joint[5].

MATERIALS AND METHODS

Materials

As base metal for welding, ASTM A36 steel and AISI 304 steel were used, purchased as 6 meter flat bars with 2” x 3/16” profile. The welding specimens were defined with dimensions of 200mmx50mmx5mm (length x width x thickness) and a bevel angle of 30º. In figure 1, is presented the scheme of the welding joints and chamfer geometry.

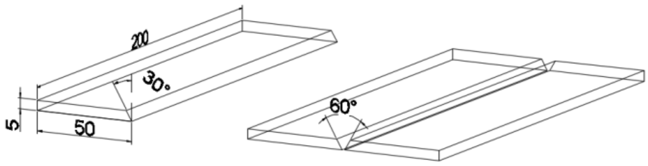

Figure 1: Test specimens for welding with 30º bevel and 60º chamfer.

As filler metal, solid wire ER309LSi with a diameter of 1 mm was used, which is made of stainless steel type Cr 24% and Ni 13%, with low carbon content, being applied to weld dissimilar joints between AISI304L steel and carbon steels. Table 1 shows the chemical composition of the wire according to the manufacturer.

Table 1: Chemical composition of ER309LSi solid wire [6].

Chemical Composition (%)									
Filler Metal	C	Cr	Ni	Mo	Mn	Si	P	S	Cu
ER309LSi	0,03 Máx.	23,0 - 25,0	12,0 - 14,0	0,75 Máx.	1,0 - 2,5	0,65 - 1,00	0,03 Máx.	0,03 Máx.	0,75 Máx.

Methods

The specimens were welded by the GMAW process (MIG) using shielding gas Ar + 2%O2 and purge gas 100%Ar, both at a flow rate of 12 l/min. Welding was performed mechanically with the plates in the flat position and the welding torch moving in the pulling direction at an angle of 90º. The torch was adapted to an MC36 cutting machine to ensure process repeatability. As a welding power source, a multiprocess machine model IMC Inversal 600 was used.

The experimental design followed the Taguchi Method, where a L9 orthogonal array was used, with a total of 9 experiments and 3 control variables at 3 different levels, these being

Tension (V), Wire Feed Speed (m/min) and Welding Speed (mm/min). In table 2, L9 orthogonal array.

Table 2: L9 Orthogonal Array.

	Input Data		
Experiment #	Voltage (V)	Wire Feed Speed (m/min)	Welding Speed (mm/min)
1	18	4,5	150
2	18	5	180
3	18	5,5	210
4	20	4,5	180
5	20	5	210
6	20	5,5	150
7	22	4,5	210
8	22	5	150
9	22	5,5	180

After performing the randomized experiments, a series of mechanical tests of Tensile Strength (MPa), Impact Strength (J) and Vickers MicroHardness (HV) were performed in order to obtain response variables for the Taguchi Design.

The manufacture of specimens for tensile and Charpy tests followed the specifications of ASTM E 8M - Standard Test Methods for Tension Testing of Metallic Materials(7) and ASTM E 23-01 Standard Test Methods for Notched Bar Impact Testing of Metallic Materials(8), respectively, being the specimens in reduced scale. Figure 2 shows the specimen removal scheme for mechanical testing of welded joints.

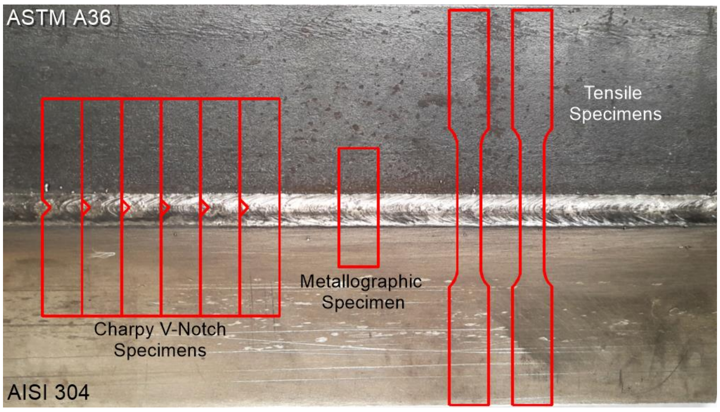

Figure 2: Scheme of removal of specimens for Charpy Impact Testing, Tensile Testing and Metallographic Analysis of weld beads.

RESULTS AND DISCUSSION

Through metallographic tests, the existence of a Partially Diluted Zone in the melting line between ASTM A36 steel and ER309LSi filler metal was identified. Through microhardness tests, it was possible to prove the high hardness of this region when compared to the hardness values of the Fusion Zone (FZ) and the Heat Affected Zone (HAZ)(9). This phenomenon was present in the 9 welding experiments. In figure 3(a), the Partially Diluted Zone (PDZ) is presented. In figure 3(b), a micrograph with Vickers indentations and the respective microhardness values for the PDZ and its periphery.

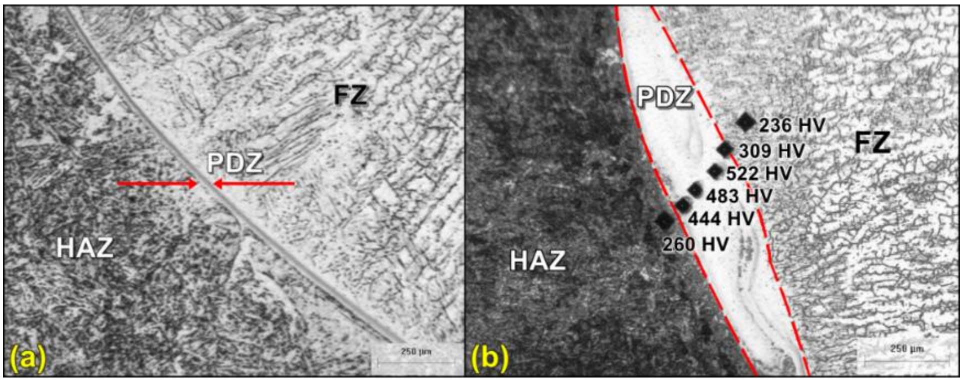

Figure 3: (a) Partially Diluted Zone formed between the ASTM A36 steel HAZ and the Fusion Zone. Electrolytic etching with 10% oxalic acid at 6V + 2% Nital. Amp.:100x. (b) Hardness profile crossing the fusion line, showing gradual hardness growth as the indentations move towards the Partially Diluted Zone.

Despite the existence of high hardness in the fusion line between the ASTM A36 steel and the filler metal, no damage was observed to the mechanical strength of the welded joints, since during the Tensile Strength tests all the specimens have fractured in the base metal, outside the welded region. Figure 4 shows the fracture pattern of the tensile test specimens and the behavior of the Stress x Elongation curve.

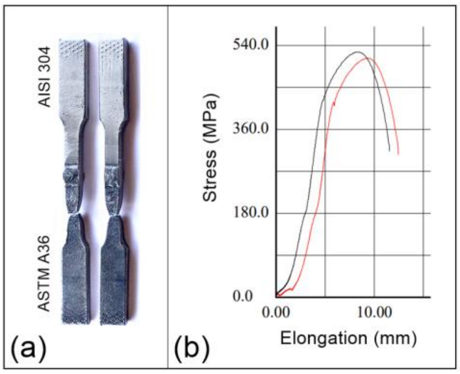

Figure 4: (a) Tensile specimens after rupture. All specimens have fractured in ASTM A36 base material, outside the welded region. (b) Stress x Elongation Curve, showing the tensile strength limits of welded joints.

With regard to impact strength in the fusion zone, the specimens showed ductile behavior in all tests. This behavior was confirmed through fractographies carried out in a Scanning Electron Microscope. Figure 5 shows a fractography of the Fusion Zone, showing a Dimple fracture surface, which confirms a ductile fracture[10].

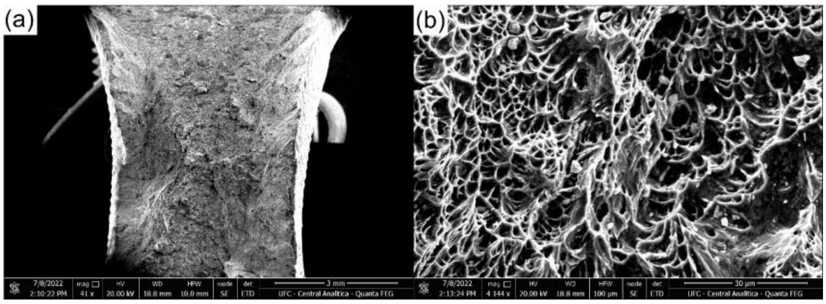

Figure 5: (a) Fracture surface. (b) Dimples appearance confirming the existence of a ductile fracture surface. 4144x magnification.

In order to obtain the optimal welding parameters, the Taguchi Experimental Design was continued, filling the L9 orthogonal array with the responses obtained in the mechanical tests. Table 3 shows the average values obtained in the tests of Tensile Strength (MPa), Impact Strength (J) in the Fusion Zone (FZ), microhardness (HV) in the Fusion Zone (FZ) and microhardness (HV) in the Partially Diluted Zone (PDZ).

Table 3: Taguchi experimental design. Welding parameters (input data) and average values of mechanical properties (output data).

	Input Data			Output Data			
Experiment #	Voltage (V)	Wire Feed Speed (m/min)	Welding Speed (mm/min)	Tensile Strength (MPa)	FZ Absorbed energy (J)	FZ MicroHardness (HV)	PDZ MicroHardness (HV)
1	18	4,5	150	519,84	58,33	230,75	455,25
2	18	5	180	513,66	55,08	227,18	452,25
3	18	5,5	210	516,75	50,75	228,31	461,29
4	20	4,5	180	515,21	41,75	228,69	426,56
5	20	5	210	516,24	60,08	209,64	449,20
6	20	5,5	150	526,02	63,33	219,31	444,67
7	22	4,5	210	519,16	47,33	231,58	477,25
8	22	5	150	526,20	50,92	236,86	434,00
9	22	5,5	180	517,95	57,33	254,13	411,33

The analysis of Taguchi's Experimental Design was performed using the Minitab software, based on two assumptions to obtain the optimal welding parameters[11]:

- "Larger is better", i.e., the higher the Tensile Strength and Energy Absorbed at Impact in the Fusion Zone, the better. This model is governed by the equation:

$$\text{S/N: } -10 \times \log(\textstyle\sum(1/Y^2)/\text{n}) \qquad (1)$$

- "Smaller is better", i.e., the lower the microhardness in the Fusion Zone and in the Partially Diluted Zone, the better. This model is governed by the equation:

$$\text{S/N: } -10 \times \log(\textstyle\sum(Y^2)/\text{n}) \qquad (2)$$

Figure 6(a) shows the optimized welding parameters to obtain higher tensile and impact strength values, and Figure 6(b) shows the optimal parameters for lower hardness in the fusion zone and in the partially diluted zone.

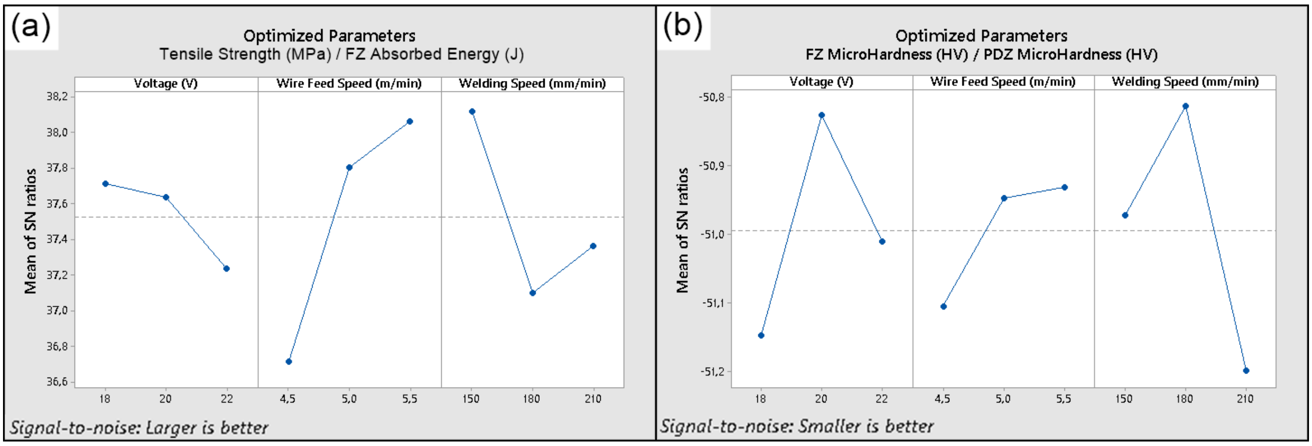

Figure 6: (a) Optimized welding parameters to obtain higher values of Tensile and Impact Strength. (b) Optimized welding parameters to obtain lower microhardness values in the Fusion Zone and in the Partially Diluted Zone.

CONCLUSIONS

It was possible to find, through the Taguchi DoE, which parameters were optimized for dissimilar welding of ASTM A36 and AISI 304 steels, obtaining conditions of higher tensile and impact strength and lower hardness for the Fusion Zone and Partially Diluted Zone.

It was observed that for higher Tensile Strength (Mpa) and energy absorption at impact (J) in the Fusion Zone, the experimental design pointed to optimized voltage parameters of 18(V), wire feed speed of 5.5(m/min) and welding speed of 150(mm/min).

With regard to obtaining optimized welding parameters for joints with lower microhardness (HV) in the Fusion Zone and in the Partially Diluted Zone, the experimental design pointed to a voltage of 18(V), wire feed speed of 4.5(m)/min) and welding speed of 210(mm/min).

Despite the existence of a Partially Diluted Zone in the fusion line between the ASTM A36 steel and the filler metal, no significant damage was found to the mechanical strength of the welded joints, as there was no rupture in the weld region in the tensile strength tests and the fractures in the impact strength tests had ductile behavior, showing Dimple fracture surfaces.

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