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EFFECT OF WELDING CURRENT INTENSITY ON TENSILE STRENGTH OF PRESSURE VESSEL STEEL SUBMERGED WELDED JOINTS

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Abstract: The quality of welded pressure vessels joints consists in using an optimal welding regime, a parameter that has a high influence in submerged arc welding is the welding current intensity. Increasing the welding current intensity correlated with an optimal welding speed and working voltage may result in increasing productivity. This paper deals with aspects of the effect of changing only the welding current intensity parameter within a welding regime that has the rest of the parameter's constant. The study presents how the welding current intensity affects the tensile strength of the welded joints from pressure vessel steel. The main aspects that are considered: the yield strength, breaking force and breaking stress occurred in stretching of the welded joints. The test specimens were created by using the welding process realized by using a semiautomatic industrial submerged arc welding machine. The base material used is a pressure vessel steel identified under the coding P355 N.

Keywords: welding, arc, parameter, stress, strain, intensity, amperage

INTRODUCTION

Pressure vessels are industrial machines that work in pneumatic or hydraulic circuits, a fact that requires the construction conditions of these products to ensure good tightness, resistance to high pressures and temperatures. As well the presence of mechanical fatigue must also be considered to which they can be subjected in exploitations with dynamic operating regimes, this means repeated pressure and temperature variations as well as sudden changes in the flow regimes of the fluids they store. [1]

In industrial applications that do not require a high standard of hygiene, such as the chemical or food industry, pressure vessels made of laminated steel sheets are used. The material of the semi–finished product is a carbon steel with a fine granular structure called pressure vessel steel, this material has good plastic properties and has a high mechanical resistance in high temperature conditions, also having a very good weldability. [2]

In order to ensure optimal operating conditions, it is essential that pressure vessels have welded joints that are as tight and durable as possible. The method used to assemble pressure vessels by submerged electric arc welding, the welding regime of this method is defined by a set of parameters that can be controlled by the welder operator. One of these parameters is the intensity of the welding current, which directly influences the strength of the welded seam, the geometry of the welded seams and their homogeneity. There are also several factors that are specific to welding processes that are influenced by this parameter such as:

- the degree of penetration of the additive material into the base material
- the size of the heat affected zone
- the deposition rate of the additive material

It is known that there are certain correlations between certain welding defects and parameters of the welding regime, which in the case of the intensity of the electric welding current can be found defects such as:

- cracks appeared during cooling welded seams
- over–elevation of welded seams due to too high a deposition rate
- pronounced thermally embrittled zone due to the too high temperatures developed in the area of the welding arc
- leaks at the root of the weld formed from the base material due to a high deposition rate and a high degree of dilution [3]

Regarding the submerged arc welding method, it should be mentioned that is used on a large scale for the mass production of pressure vessels. There are 2 consumables that are used during submerged arc welding processes such as: the electrode wire that is wound on a drum being similar to that of MIG/MAG welding and the flux layer which is a granular powder.

During the submerged arc welding process, the burning of the arc takes place under the layer of flux deposited over the welded seam, acting as a protective environment isolating the electric arc from the atmosphere and enriching the welding pool with beneficial alloying elements. Figure 1 shows the principle underlying the submerged electric arc welding process. [4]

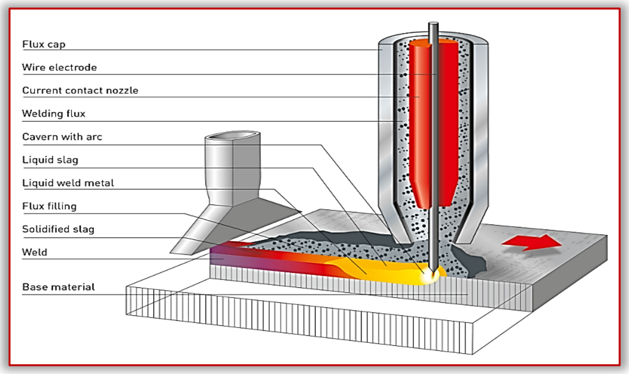

Figure 1. The process of submerged arc welding [5]

The method of depositing the flux can be through the electrode holder torch as in figure 1 or through a tube that deposits the flux layer in advance, later it is sucked by a flux collection system, it being recirculated to reduce losses of flow material.

The entire system of equipment used to make welds for pressure vessels is a complex one, there are auxiliary equipment for handling the cylindrical semi–finished product and auxiliary equipment for supporting the welding system. The connection and operation of the welding equipment is shown in figure 2, were also is exemplified the technique of external welding of a cylindrical vessel is presented. [6]

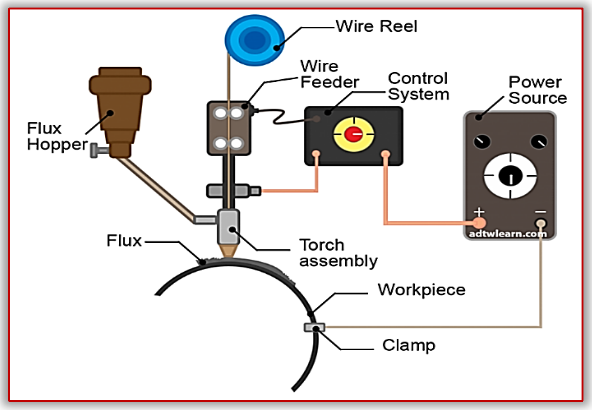

Figure 2. Submerged arc welding equipment [7]

In order to study the strength of welded joints with different intensities of the electric arc, a set of tensile test specimens was made for 3 different intensities of the welding arc current. Each set consisting of 4 specimens welded with the same regime. After testing the samples, stress–strain curves result, they provide a clear picture of the behaviour of welded joints during exploitation, the stretching being present during the operation of pressure vessels.

RESEARCH METHODOLOGY

The first stage of the experiments consisted in defining the welding process, for these the following welding process characteristics were established:

- Base Material: Carbon steel for pressure vessels P355 N (SR EN 10216–3:2003) [8]
- Filler material: Circular section wire 3.2 mm from molybdenum–alloyed copper for welding non–alloy and low–alloy steels under a flux layer, OK Autrod 12.24. [6]
- Protective environment of the electric arc: Flux the layer deposited in a layer with a thickness of 25 mm, OK flux 10.47 [6]
- Welding process feature:
  - Welding under flux with wire electrode (121), EN ISO 4063 [9]
  - Butt welding with full penetration (BW), SR EN 287–1
  - Welding with root support (mb), SR EN 287–1
  - One–pass welding (sl), SR EN 287–1 [10]
  - Horizontal (PA), SR EN ISO 6947:2011 [11]

Figure 4 shows the submerged welding process of two plate–type semi–finished products to create a welded sample, where it can be seen that the welding installation has a torch that has two roles: to manipulate the electrode and to deposit the flux layer in the welding area. The torch is followed by a system for collecting the flux left after welding. There is also a laser indicator that follows the welding direction for the correct orientation of the electrode.

Figure 4. Welding process of sample

From each welded sample, a set of 4 specimens were extracted for tensile testing in accordance with the standard BS EN 895:1995, having the main dimensions:

- sample length: 250 mm
- sample width: 37 mm
- the width in the breaking area: 25 mm
- the radius of passage between the brea king zone and the width of the sample: 26 mm
- sample thickness: 6 mm
- length in the grip area: 78 mm

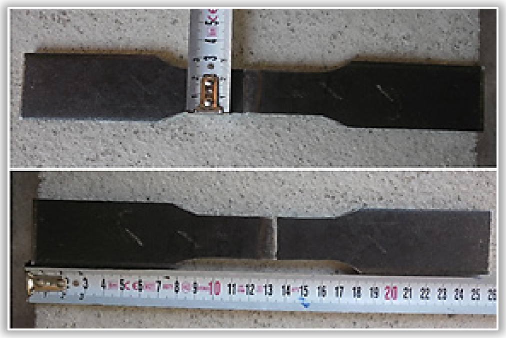

Figure 6. Tensile test specimen

The production of the specimens for the tensile test was carried out only by mechanical processing with cooling in order not to thermally influence the material, in figure 6 it can be observed the final tensile test specimen used.[12]

EXPERIMENTAL RESULTS

The obtained results are the stress–strain curves from which a series of strength indicators can be extracted for determination the strength of welded joints executed with welding regimes of 300A, 400A and 500A. Figure 8 shows the representative stress–strain curves for each set of specimens tested by applying a stretching force with progressive magnitude until the specimen completely breaks. The stretching speed at which the samples were tested is 50 MPa/s. [13]

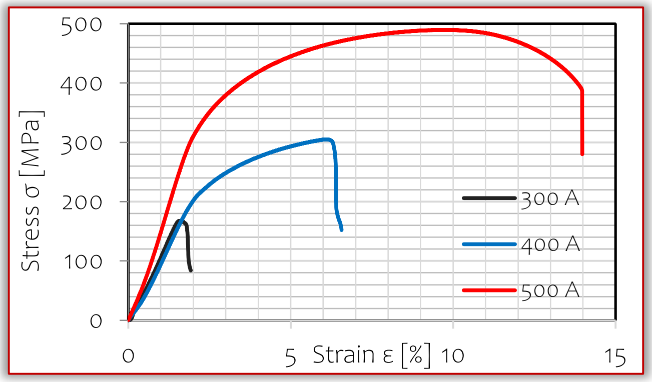

Figure 8. Stress–strain curves

A clear tendency to increase the resilience of welded joints is observed, directly proportional to the increase in the intensity of the welding current. The stress–strain curves increasing in gauge both on the tension axis and on the displacement axis denote the fact that the increase in the intensity of the welding current has a beneficial effect on the increase in the resistance of the welded seam. The ceiling of the increase in tensile strength of the welded joints occurs in the samples welded with 500 A where the sample fracture occurs through the base material. The other samples welded with lower amperages showed fractures through the weld bead, a fact that indicates poor penetration and a low deposition rate of the filler material.

Figure 9 shows graphs that reflect the evolution of the most important resistance indicators. An increasing evolution of both indicators is observed, the indicated values are averages of the data collected from the curves resulting from the test of the 12 specimens divided into three sets, 4 for each welding regime separately.

A more pronounced capping tendency is observed for the parameter average maximum stretching force compared to the average maximum stress, this predicts a fact that indicates that the existence of a set of samples executed with a more pronounced welding regime in terms of the intensity of the welding current would have presented a maximum stretching force not far from the value of 85.1 kN associated with the welding regime with 500 A.

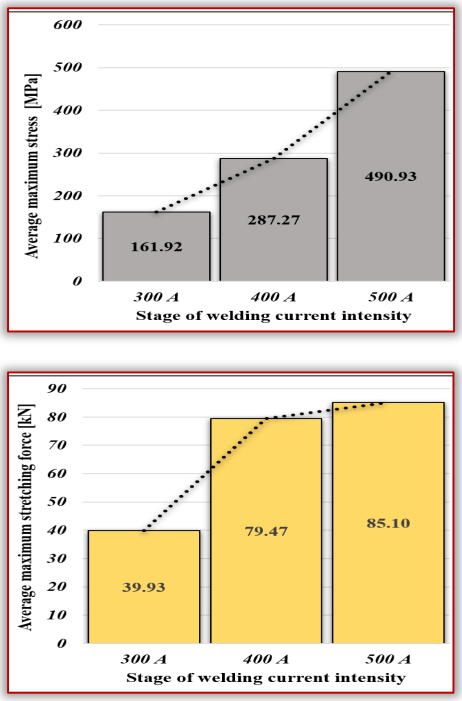

Figure 9. Stress–strain curves

Regarding the tendency of the stress increase in the breaking section of the samples, it can be mentioned that it increases by approximately 74% for each increase in the welding current by 100 A.

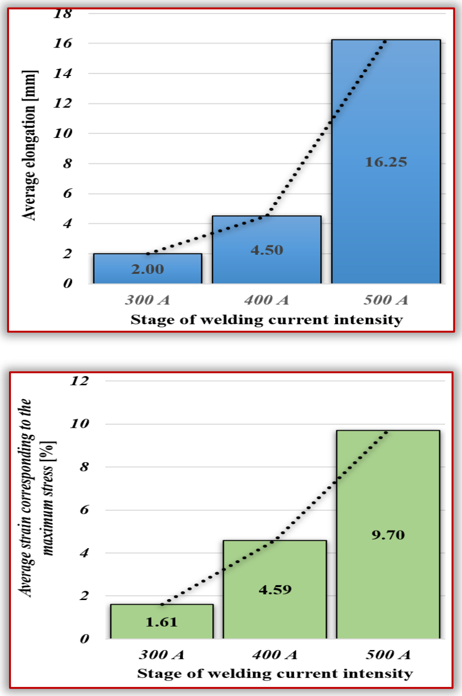

Figure 10. Stress–strain curves

Figure 10 shows graphs that reflect the situation of the indicators specific to the aspects that deal with the deformation of the welded joint under stretching loads. The average elongation chart presents a situation that indicates an increase in ductility for the welded joints by applying an increasing welding amperage. The samples welded with the lowest amperage of 300 A show a very high fragility when breaking and those welded by using with a current intensity of 500 A show a clear tendency to cap the ductility specific to an average elongation of 16.25 mm.

Regarding the average strain corresponding to the maximum stress this shows an increasing trend with the increase in the intensity of the welding current which respects a pattern of 148% increase for every 100A.

There are also other indicators resulting from the tests that can be analysed, they are presented in table 1, all the values are averages of the indicators and not all of them respect a clear increasing tendency with respect to the increasing of the welding current intensity.

Table 1. Average strength indicators resulted from strain test results.

Average strain test results	Welding current intensity			
	300 [A]	400 [A]	500 [A]	U.M.
Breaking stress	83.97	152.04	279.96	MPa
The strain corresponding to the breaking stress	1.92	6.56	13.97	%
Yield tensile stress	130.74	102.18	300.51	MPa
The strain corresponding to the yield tensile stress	1.2	1.08	1.9	%
Modulus of elasticity	105250	118550	314540	MPa
Strain energy	180.55	1416.34	5694.70	kJ

The indicators listed in table 1 that show a clear upward trend are:

- the breaking stress, with a constant average growth of 83% for every increase of the welding amperage with 100 A.
- The strain corresponding to the breaking stress, with a sudden increase of 241% followed by a lower increase of 112% indicating the capping trend.
- Modulus of elasticity, with an increase of 12,6% followed by a sudden increase of 165%.
- Strain energy, with a sudden increase of 684% followed by a lower increase of 320% indicating the capping trend.

CONCLUSIONS

After analysing the indicators resulting from the stress–strain curves obtained after testing the samples, it can be said that the increasing of welding current intensity has a benefice effect of increasing the mechanical properties of the pressure vessel steel welded joints. The main aspect observed is that with the increase in the intensity of the electric welding current there is a better penetration of the filler material into the base material, which favours the increase of the mechanical resistance of the welded joint. Also, the submerged electric arc welding process has a much more pronounced deposition and dilution rate of the filler material with the increase in the intensity of the welding current.

The strength indicators collected from the stress–strain curves, that show pronounced jumps with a clear ceiling trend are:

- The Strain energy, at the ceiling value of 5694,70 kJ
- The strain corresponding to the breaking stress, at the ceiling value of 13,97%
- The elongation, at the ceiling value of 16,25 mm
- The maximum stretching force, at the ceiling value of 85,1 kN

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