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

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Abstract: It is well known that in order to obtain a suitable quality of the products intended for industrial use, it is necessary to identify the critical points where wear defects may appear over time. In the case of pressure vessels that work under heat and pressure, these critical points are considered the welded joints of the various component elements that make up the functional assembly of the product. In most cases, pressure vessels for industrial, non–chemical and alimentary use are made of carbon steel with fine structures that are found in the form of sheet or pipe semi–finished products, they are processed by cutting and plastic deformation before being introduced into the frame welding processes carried out by submerged arc welding under a flux layer using semi–automatic or robotic equipment. In order to obtain optimal quality and productivity, it is necessary to adapt the welding regime by choosing the right values of the working parameters that define the welding regime. In this paper are treated aspects regarding the evolution of the tensile strength characteristics depending on the variation of the welding voltage parameter within the submerged arc welding processes of P355N pressure vessel low carbon steel.
Keywords: welding, arc, parameter, stress, strain, voltage

1. INTRODUCTION

Both in industry and in non–industrial organizations, which can be of a domestic nature, products such as pressure vessels are used in a way that can function as vessels for storing different types of fluids, parts of machines or boilers that manage fluids at high temperatures. Pressure vessels can be defined as tanks that develop large pressure differences inside them compared to atmospheric pressure, which can be maintained in safe conditions even in the case of high temperatures developing inside or outside the vessel. These machines can be found equipped with features such as:

- devices for measuring and controlling pressure, temperature, fluid flow and level;
- safety systems such as pressure valves, overflow drains, filters and sensors to detect fluid leaks;
- special holes such as: nozzles and manholes;
- features dedicated for handling, transport and fixing.

The body of a pressure vessel is made up of two distinct components on which some of the previously mentioned features can later be installed. The first being the cover of the container, which in most cases constitutes more than 50% of the body of the vessel, is the shell and it is made from a metal sheet processed by rolling in order to obtain a cylindrical shape that is joined by a longitudinal welded seam and is reinforced by welding internal or external reinforcement ring structures. The second component that makes up the body of the pressure vessel is the head of the vessel every pressure vessel body has 2 heads, and they can have different shapes depending on the functionality and strength conditions that are required, they can be: conical, tronconical, ellipsoidal, spherically dished and hemispherical. The pressure vessel body can be composed from a shell and to different or the same shape head ends all joined by welding.

Regarding the classification of these products as pressure vessels, they can be:

- considering the shape geometry: cylindrical, spherical and rectangular;
- considering the operating position: horizontal and vertical;
- considering the pressure and temperature regime: low, medium and high;
- considering the technological role that it serves: storage, heat exchanger, pressure expansion, environment for chemical processes [2]

Due to the high pressures and temperatures that can develop inside these containers, these machines present a very high hazard risk, their design, fabrication processes, verification and maintenance being very well regulated at the international level by technical standards and regulations. The main conditions that must be met by the pressure vessels are: ensuring good mechanical and corrosion resistance in high temperature conditions. It is also essential to ensure optimal tightness to prevent fluid leaks in the conditions of pressure and temperature present in the container. From the design phase, aspects regarding the subsequent maintenance of the product must be considered, the most important aspects being the use of interchangeable parts that are as standardized as possible and facilitating access as easily as possible to critical areas where interventions will be required. The materials used to make these machines are diverse, depending on factors such as: hygiene, corrosion, strength, fluid contamination, life span, manufacturing technology and safety.

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If we consider pressure vessels intended for industrial use that do not require special corrosion and hygiene conditions, we can make the body of pressure vessel steel intended for abbreviated as standard EN10025 with P followed by its tensile yield strength at room temperature. The system of pipes that communicate with the pressure vessel are usually constructed from steel for pipe and tube coded according to the same standard with the letter L. The last steel material that can be found in the pressure vessel construction is the structural steel that is used for creating peripheric supports and fixing elements. All these different steel materials have in common great plastic and weldability properties being categorized basically as low carbon steels. [3][4]

Practically, the critical points where disastrous effects can appear on the containers are the areas where there are welded joints. Pressure vessels are welded using arc welding technology, the most widespread method being the submerged electric arc welding (SAW). This welding technology involves the burning of an electric arc between an electrode wire and the welding joint, the electric arc is permanently covered by a layer of dust called flux, which plays the role of a protective environment. Due to the heat developed by the electric arc, the electrode wire and part of the base material are melted, creating a weld pool in the welding joint which, once cooled, creates a strong and sealed welded seam.[5]

It is well known that a significant share of the quality of welded seams is held by the welding regime used in the manufacturing processes. The welding regime in the case of submerged electric arc welding is composed of different variations of the following parameters:

- welding current voltage
- welding current intensity
- welding speed
- tilting the electrode

A first step towards the optimization of welding processes is to identify the effect of each individual parameter to observe how it affects the mechanical strength properties of the welded joints, also following the welding defects that are correlated with each of the specific parameters that compose the welding regime. By isolating each parameter of the regime so that it can be studied and optimized individually, specific conclusions can be drawn on each parameter and later by cumulating these conclusions, a complete overview can be obtained for the optimization of the entire welding regime.[6]

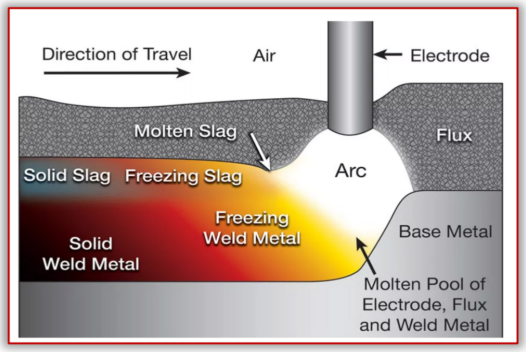

Figure 1. The process of submerged arc welding [7]

This paper will approach aspects regarding the behavior of the electric welding current voltage to see the effect that this parameter has on the mechanical tensile strength of welded seams using the technology of submerged arc welding presented in figure 1.

It is well known that the welding voltage has a pronounced influence on the geometry of the welded seam, in the sense that the increase in voltage causes a decrease in height and an increase in width of the welded seam. Other effects due to the maladjustment of the welding voltage in the sense of using a welding voltage that is too low is the increase in the difficulty in priming the electric arc and maintaining it.[8]

2. EXPERIMENTAL MATERIAL AND METHODS

To carry out the experiments, it was used as a base material from the pressure vessels steel family, consisting of a carbon steel with a fine grain metallic structure found under the name of P355 N according to the standard SR EN 10216–3:2003. The filler material used is an electrode wire found in commerce and industry under the name OK Autrod 12.24, has a diameter of 3.2 mm, being a wire specially designed for the execution of submerged arc welds, composed of material containing molybdenum–alloyed copper. To ensure the protective environment around the welding pool, flux granulated material was used, found under the name OK flux 10.47, being deposited in a layer of an approximate height of 25 mm. [4][9]

Regarding the aspect about the welding process, it was executed a butt welding with full penetration according to standard SR EN 287–1, welding under flux with wire electrode (121), EN ISO 4063, where this feature of the process can be found under coding BW. In the welding process it was used also a welding root support (mb) according to standard SR EN 287–1. The welding position is horizontal (PA) according to standard SR EN ISO 6947. It should also be mentioned that the joint was welded by one–pass welding on a single side of the probe.[10][11][12]

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Figure 2 shows images during the process of joining 2 plates using different welding regimes that consist of various welding voltage value while the rest of the welding regime parameters remain as constant.

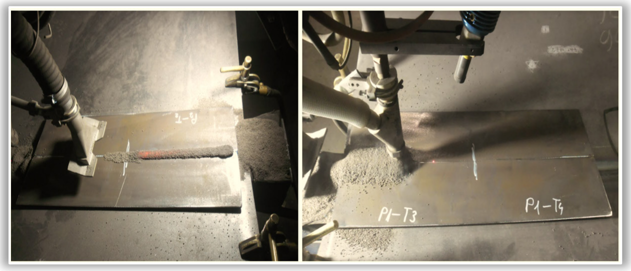

Figure 2. Welding process of sample

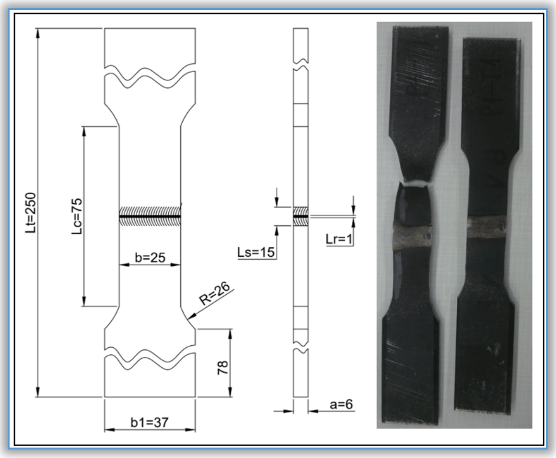

Figure 3. Tensile test specimen

The constants of the experiments that are found in every welding regime that were used to obtain the testing specimens are:

- welding current intensity 480 A;
- welding speed 60 cm/min;
- the tilt of the electrode 90 deg;

In the experiments, 3 welding voltage values were used 26V, 30V and 34V, for each of these voltages, a number of 4 tensile test specimens were elaborated according to standard BS EN 895:1995. From each set of specimens, a representative stress–strain curve was chosen to be compared with the other representative curves of the other sets representing other welding voltage values. Figure 3 represents the sketch according to which the samples were made, as well as a sample before and after the tensile test.[13]
Figure 3 shows aspects regarding the geometry and dimensions of the specimens which were used for tensile testing and an example of a specimen before and after testing.

3. DATA ANALYSIS AND INTERPRETATION

As a result of the tests, data was obtained which, through their processing, resulted in stress–strain curves. Figure 4 shows the 3 representative curves for each step variation of the welding voltage. It can be observed an increasing trend of the stress–strain curves correlated with the increase of the welding voltage both on the stress axis and on the axis representing the strain values.

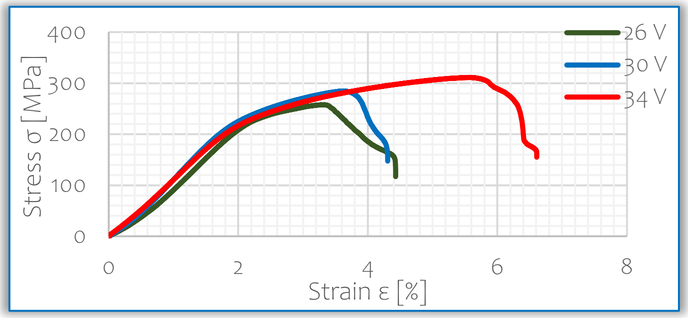

Figure 4. Stress-strain curves

The stress–strain curves allow us to extract a set of data from them which presents a relevant picture regarding the strength properties of the welded joints. Table 1 shows the numerical data collected from the stress–strain curves.[14]

The most relevant strength characteristics presented for determining the degree of increase in tensile strength of the welded seams are: the maximum stretching force, maximum stress developed in the breaking section of the welded joint, the yield tensile stress and the strain energy that it is needed to break the welded joint. All these characteristics present a clear increasing trend that is correlated with the increase of the welding regime voltage.

A clear picture of the simultaneous evolution of all the strength characteristics of the welded joints presented numerically in table 1 is shown graphically in figure 5. Where it can be seen that there is an exponential increase correlated with the increase in welding voltage in the area of the strain energy accumulated until breaking the welded joint and the strain corresponding to the maximum stress. As regards the maximum stress borne by the welded joint, it increases with small and constant steps of approximately 3%. The breaking stress presents a capping tendency.

The rest of the characteristics presented in the graph in figure 5 do not show a predictable trend of evolution nor controllable by the variation of the welding voltage. It can be mentioned that the best mechanical properties are presented by the welded joints made by using a high welding voltage.

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The greatest influence of the working voltage on the resistance characteristics collected from the stress–strain curves is observed on the accumulated strain energy until breaking, this highlights the fact that the welded joint has obtained an increase in ductility with the increase of the welding voltage, the samples showing the fracture section through the welded seam, making a brittle fracture with a high elongation of the tested specimens due to the stretching of the base material. Presenting the situation of a hard weld seam and an elastic base material resulting in a welded assembly with high tenacity and elasticity linked by a strong bond.

Table 1. Strength characteristics collected from stress-strain curves

Parameters	26 V	30 V	34 V	U.M.
Maximum stretching force	62.31	66.97	79.74	kN
Maximum stress	257.77	284.69	311.25	MPa
The strain corresponding to the maximum stress	3.31	3.62	5.58	%
Breaking stress	116.95	147.35	155.03	MPa
The strain corresponding to the breaking stress	4.42	4.30	6.60	%
Yield tensile stress	42.13	207.33	220.49	MPa
The strain corresponding to the yield tensile stress	0.55	1.77	2.03	%
Modulus of elasticity	122580	154170	102990	MPa
Strain energy	476.74	812.25	1491.49	KJ

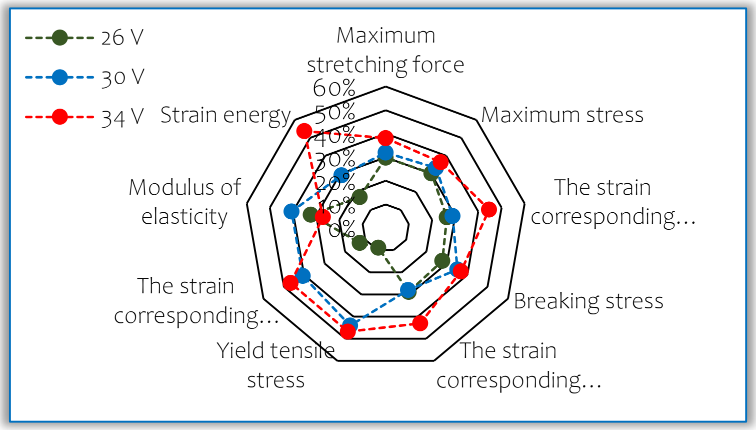

Figure 5. Evolution of strength characteristics collected from stress-strain curves

Theoretically, considering the analysed situation, an optimization of the welding process can be achieved by increasing the working voltage in order to influence part of the strength characteristics of the welded joint. The main characteristics that can be controlled and improved by increasing the welding voltage being: the maximum stress, the breaking stress and the maximum stretching force. It seems that the following rules can be considered in optimizing the characteristics that can be controlled by varying the welding voltage:

- by increasing with 1 V the welding voltage results an increasing of the maximum stress with 0.75%;
- by increasing with 1 V the voltage results an increasing of the breaking stress with approximately 3%;
- by increasing with one volt the welding voltage results an increasing of the maximum stretching force with approximately 2.5%.

4. CONCLUSIONS

It can be said that the welding voltage has a directly proportional effect on most of the mechanical tensile strength characteristics, some showing an exponential evolution trend and others an evolution trend with regular steps. It is also possible to make a prediction in order to optimize the tensile strength of welded joints for strength characteristics such as: the maximum stress, the breaking stress and the maximum stretching force. It was concluded that the ductility of the welded joint is provided by the elasticity of the base material, the ruptures of the specimens rupture occurs entirely by the welded seam, which denotes a characteristic of higher hardness of the weld seam, a fact that makes the joint brittle, being not suitable for exploitation in regimes of where are present dynamic loads.

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