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Variation of the Physical Properties in the Weld Bead of the Submerged Arc Welding of Low-Carbon Alloy Steel

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This paper presents an experimental study, which is performed on weld bead of the gas-tank element made of the low-alloy steel with the following chemical composition (% wt.): (C: 0.20, Si: 0.0079, Mn: 0.778, P: 0.0156, S: 0.058, Cr: 0.021, Al: 0.035, Cu: 0.012, Ni: 0.0075), and 3.3 mm of thick. This manufacturing process ends with a normalized annealing heat treatment at temperature of 920 ± 10°C. The purpose of this work is to study the effect of important parameter—the electrical voltage *V*. This welding is submerged arc welding under submerged arc-welding particle flux. The principle of the characterization taken into account consists in varying both the electrical voltage *V*, which is between 31 V and 36 V. As shown, this physical parameter directly influences the carbon content in the weld bead, the structural components and the mechanical properties (σ and $HV_{0.3}$) of the steel under study.

Key words: gas tanks, submerged arc welding, electric voltage, low-alloy steel, ferrite, pearlite.

У статті представлено результати експериментальних досліджень, виконаних на зварному шві елемента паливного баку, виготовленого з низько-

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леґованої криці з хемічним складом (% мас.): (C: 0,20, Si: 0,0079, Mn: 0,778, P: 0,0156, S: 0,058, Cr: 0,021, Al: 0,035, Cu: 0,012, Ni: 0,0075) і товщиною у 3,3 мм. Процес виробництва завершувався термообробленням (нормалізованим відпалом) за температури у 920 ± 10°C. Метою даної роботи було дослідження впливу важливого параметра — електричної напруги V. В роботі розглянуто дугове зварювання під флюсом з використанням потоку частинок флюсу. Для характеризації було враховано зміну електричної напруги V, яка знаходилася в межах від 31 В до 36 В. Показано, що цей фізичний параметер безпосередньо впливає на вміст Карбону в натопленому шві, структурні компоненти та механічні властивості (σ і $HV_{0,3}$) досліджуваної криці.

Ключові слова: паливні баки, дугове зварювання під флюсом, електрична напруга, низьколеґована криця, ферит, перліт.

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1. INTRODUCTION

Submerged arc welding (SAW) is an arc welding process of which the latter is covered with a fusible granulated flux surface, the melted amount of which turns into slag, the rest of supporting materials recycle and can reuse later [1–3]. This process is widely used for the welding of cylindrical and spherical tanks, even for thick sheets, as well, for their high productivity and the quality of the welded joints, thanks to the protection provided by the flux in particles [4]. In this assembly method, the welding arc is maintained between the part to be welded and the filler metal. A motor controls the advancement of weld wire; the weld bead is impacted by many parameters such as, the voltage, the current intensity. The welding speed and the distance between the filler metal and the part to be welded [5]. To this end, the control and mastery of the main submerged arc welding parameters will lead to adequate welds [6]. The welding operation generates linear energy or heat input, the latter causing changes in the properties of the heat-affected zone (HAZ) and the fusion zone (FZ) [7]. During welding of mild, low alloy steels, the austenitic transformation into ferrite, impacted by the chemical composition and the decreasing cooling rate, caused the formation of structural constituents such as grain boundary ferrite, polygonal ferrite, Widmanstätten ferrite, acicular ferrite, upper bainite and lower bainite, martensite [8].

The cooling of steels with a low carbon content (hypoeutectoid), will cause the formation of proeutectoid ferrite, this structural constituent, can appear in elongated grain, called ferrite of Widmanstätten caused by transformation of austenite into ferrite [9]. The structural constituent whose acicular ferrite plays a key role in increasing the mechanical characteristics (tensile strength) of steels [10].

The pearlite aggregate ($\alpha + Fe_3C$) appears in a similar way in steels whose silicon (Si) is 0.4 to 0.7%, which explains the behaviour of the alloying elements with regard to their distributions and their diffusivities in cementite and ferrite, this specification becomes more moderate for the case of Mn, Cr and Co in low concentrations [9]. The thermal cycles (heating, melting and cooling) generated by the welding operation will greatly modify the properties of the different zones of the steel weld bead [11]. Z. Boumerzoug *et al.* showed that FZ and HAZ of the weld bead of the low carbon steel (0.19% wt.) present the maximum values of the hardness's measured [12].

The purpose of this work is to vary the electrical voltage V of the submerged arc welding process of the steel 0.2% wt. C and determine their influence on the carbon content, the structural constituents and the mechanical characteristics (σ and $HV_{0.3}$).

2. EXPERIMENTAL STUDY

The experimental study is based on welding an LPG gas tank element (Fig. 1). This is performed by means of LINCOLN CWP 2.0 SAW type welder that uses the submerged arc welding process under particulate flux (Fig. 2, *a*) and with low carbon steel materials (Table 1). The use of the tensile test is to determine the mechanical resistance of the materials [13] (Fig. 2, *b*). The characterization of the samples under study is based on the microscopic analysis SEM (Fig. 2, *c*). Then, complete the tests by the microhardness ($HV_{0.3}$) (Fig. 2, *d*) of the different welding zones: HAZ, weld interface (WI) and FZ.

When welding the gas tank element, we varied the electric voltage V from 31 V to 36 V. The microstructure of LPG gas tank steel is composed of ferrite (α) and pearlite ($\alpha + Fe_3C$) (Fig. 3).

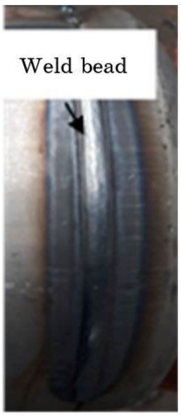

Fig. 1. Element of the gas tank under study.

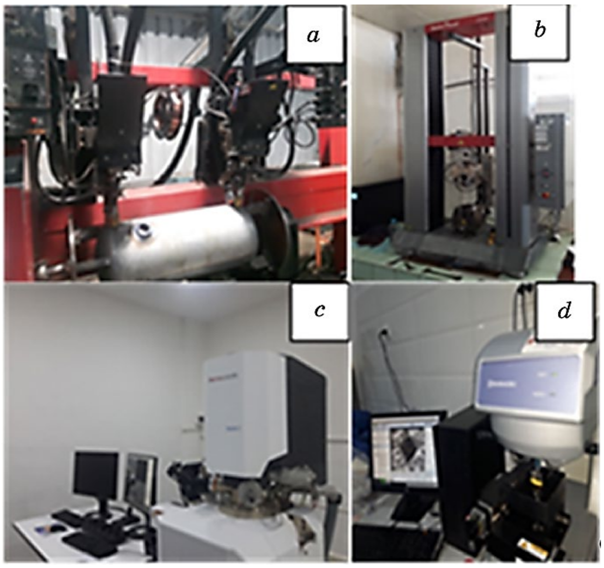

Fig. 2. Equipment used for characterization: welder Lincoln (*a*), tensile testing machine (*b*), SEM (*c*) and microhardness testing machine (*d*).

TABLE 1. Chemical composition of gas tank steel (% wt.).

Elements	C	Si	Mn	P	S	Cr	Al	Cu	Ni
% wt.	0.20	0.0079	0.778	0.0156	0.058	0.021	0.035	0.012	0.0075

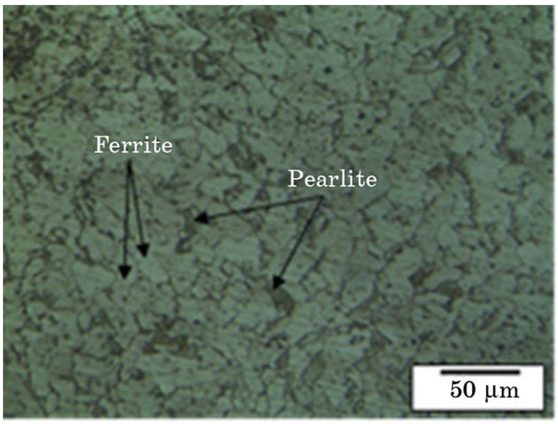

Fig. 3. Steel microstructure 0.20% wt. C normalized annealing at temperature 910 ± 10°C (4% Nital).

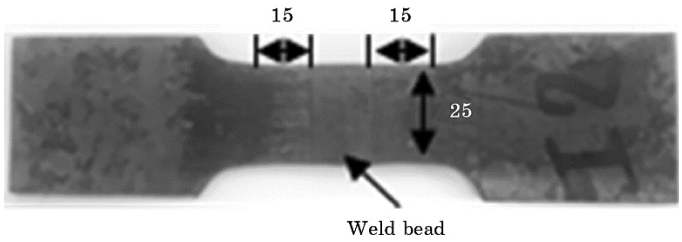

Fig. 4. Tensile specimen under study.

The tensile specimen was prepared in accordance with standard NF EN 1442-2017. The dimensions are indicated in (Fig. 4).

3. RESULTS AND DISCUSSIONS

3.1. Carbon Concentration

During the submerged arc welding operation, the carbon concentration in the weld bead was reduced from 0.350% wt. to 0.163% wt. respectively with a variation of the electrical voltage from 31 V to 36 V (Table 2).

The values of the carbon element recorded from the weld beads are presented in the curves (Fig. 5).

3.2. Micrographic Analysis

According to the SEM microscopic analysis of the different samples of the steel under study and by varying the electrical voltage *V*, two main structural components were revealed in the weld bead, due to the type of steel, the thermal energy and the cooling rate during the welding operation [7].

3.2.1. Electric tension

The microstructures observed, when the variation of the electric voltage *V* from 31 V to 36 V, comprise two structural components, which

TABLE 2. Content of carbon in the weld bead as function parameter electric voltage *V*.

Electric voltage *V*	C, % wt.
31	0.350
33	0.173
36	0.163

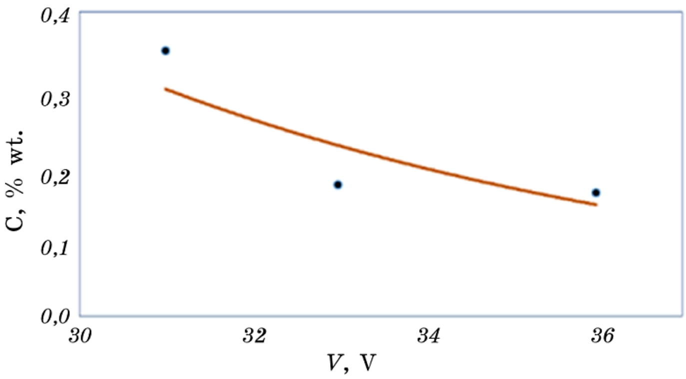

Fig. 5. Variation of carbon (% wt.) as a function of the electric voltage *V*.

are ferrite (α) and colonies of pearlite ($\alpha + Fe_3C$). The grain of pearlite at 31 V in HAZ has a dimension, inter-lamellar spaces and quantity greater than FZ. FZ, whose interlamellar space is reduced, caused by the cooling speed and the high concentration of the element carbon that plays an important role in the formation of pearlite (Fig. 6, *a*). On the other hand, the grain of the ferrite becomes coarser when we sweep from HAZ towards FZ zone (Fig. 6, *b*).

At the electric voltage *V* of the orders of 33 and 36 V we observed a reduction in the pearlite aggregate ($\alpha + Fe_3C$) in the intermediate zone WI (Fig. 7) and FZ. The pearlite is located entirely at the boundaries of the grains of the ferrite (α), whose inter-lamellar space is almost zero and very close to that of the weld bead at 31 V. This phenomenon on is due to the lowering of the carbon content in the welded joints, the concentrations of which decreased by 0.350% wt. and 0.163% wt.

The grain of the solid solution (α), coarsens with the increase in parameter *V* in HAZ and WI zones (Fig. 8), impacted by the enrichment,

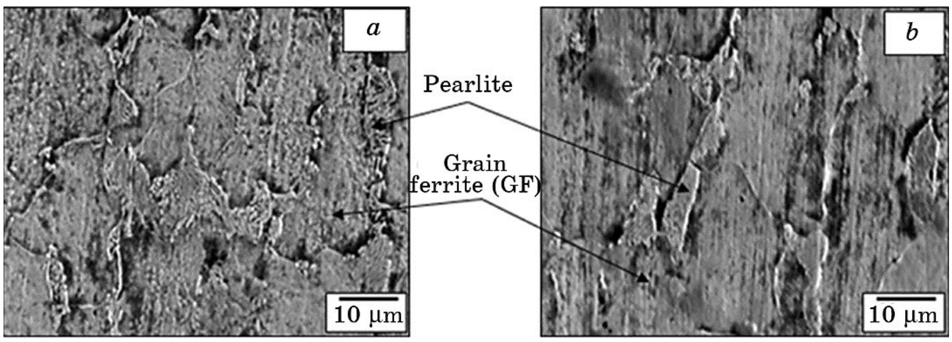

Fig. 6. SEM/electric voltage microstructures (4% Nital), $V = 31$ V: HAZ (*a*) and FZ (*b*).

and the impoverishment of the structural constituents (ferrite and pearlite) in carbon element, thus the cooling speed of the welded joint influenced by the thermal cycle of welding.

3.3. Tensile Strength

The results of the tensile strength of the weld of the LPG tank element under study, shown in (Table 3), lead to an inversely proportional rela-

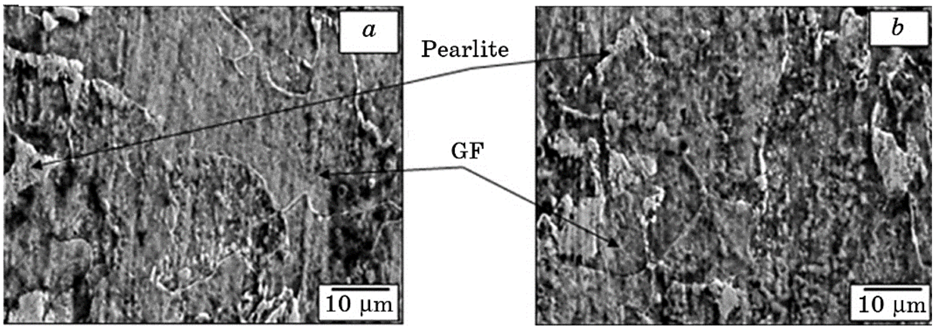

Fig. 7. SEM/electric voltage microstructures (4% Nital), $V = 33$ V: WI (*a*) and FZ (*b*).

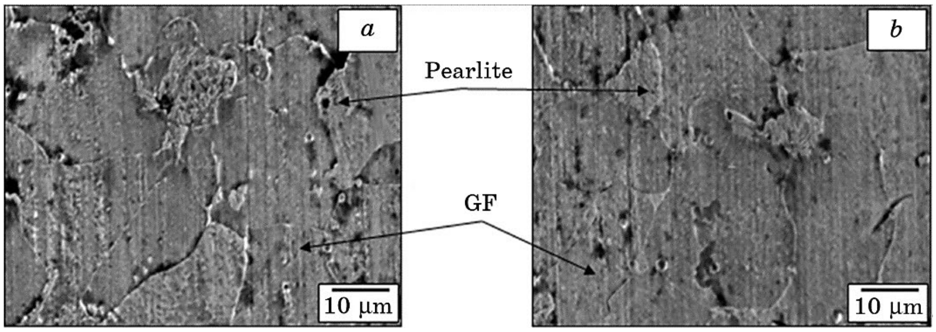

Fig. 8. SEM/electric voltage microstructures (4% Nital), $V = 36$ V: HAZ (*a*) and WI (*b*).

TABLE 3. Variation of the tensile strength as a function of the electric voltage *V*.

Electric voltage *V*	Tensile strength σ, MPa
31	473
33	470
36	459

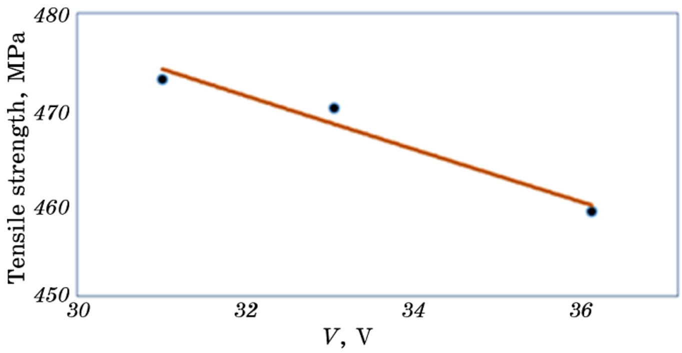

Fig. 9. Variation of the tensile strength as a function of the electrical voltage V.

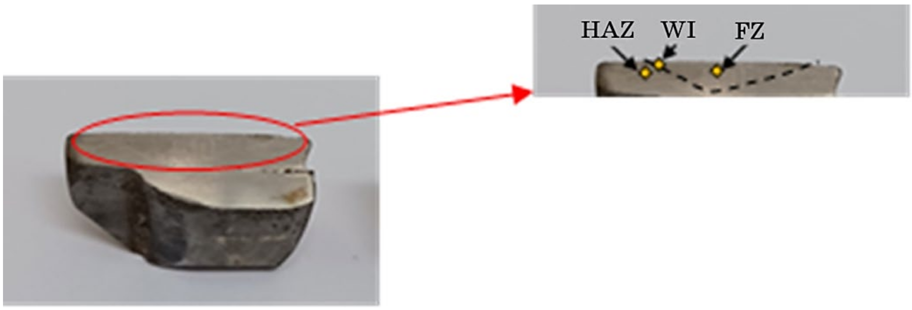

Fig. 10. Sampling areas for the microhardness tests.

tionship for the case of a variation of the electrical voltage parameter V. The lowering of the value 473 MPa to value 459 MPa (Fig. 9) is due to the types of structural components (ferrite and pearlite) and their proportions in the microstructures.

The increase in the carbon element in steels promotes the formation of carbides, which leads to an increase in resistance, on the one hand, a decrease in ductility and weld ability on the other hand [14, 15].

3.4. Microhardness

The microhardness tests were carried out on the three zones of the weld (HAZ, WI and FZ) (Fig. 10.) with a force of 2.942 N ($HV_{0.3}$). The results obtained are shown on Table 4.

The microhardness test results shown in the curves (Fig. 11, *a*, *b* and *c*) show the actual values determined for the three areas of the weld (HAZ, WI and FZ). These results show, the evolution of the microhardness, moving from HAZ towards FZ, where it was recorded the

TABLE 4. Variations of microhardness respectively with electric voltage V.

Microhardness areas	Electric voltage, V		
	31	33	36
	Microhardness values ($HV_{0.3}$)		
HAZ	171 172 174 181	165 166 170 174	156 169 169 171
WI	162 165 170	166 177 181	164 163 168
FZ	175 189 209	188 200 205	184 194 197

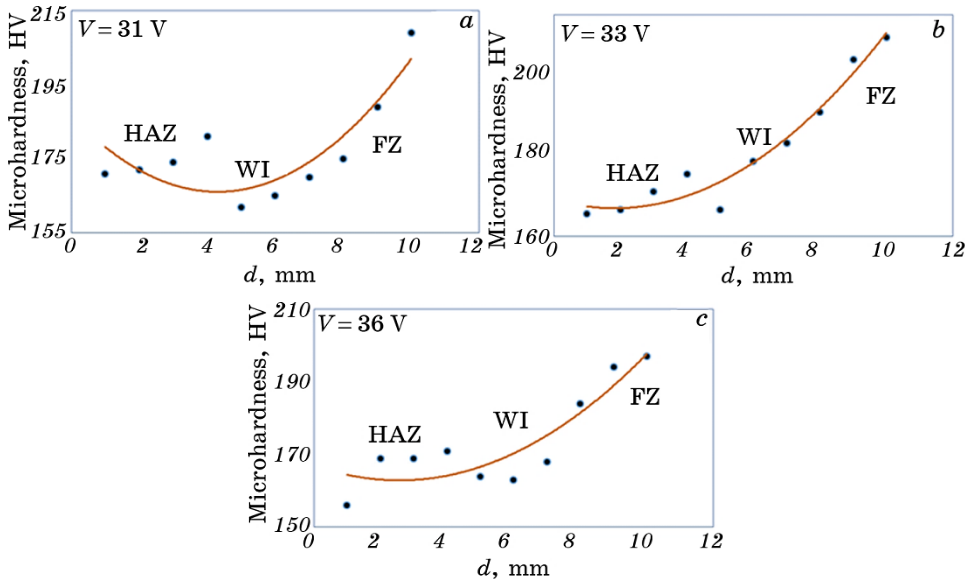

Fig. 11. Variation of the weld microhardness as a function of the electric voltage V: $V = 31$ V (*a*), $V = 33$ V (*b*), and $V = 36$ V (*c*).

maximum value, which is 209 $HV_{0.3}$ for the electric voltage $V = 31$ V.

4. CONCLUSION

In this study, the variation of the electrical voltage V parameter of submerged arc welding under particle flux, have a remarkable impact on the weld beads of the LPG tank element, the results obtained are as follows.

1. Change in the carbon content compared to the change in the electrical welding parameter.
2. The presence of the ferrite and perlite colonies in microstructures, and, the inter-lamellar space of the perlite aggregate, varies according to the electrical voltage.
3. The tensile strength of the weld decreased from 473 MPa to 459 MPa, increasing the electrical voltage from 31 V to 36 V.
4. The microhardness increases by 53 units, while the electrical voltage increases from 31 V to 36 V.

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