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**INFLUENCE OF TiO<sub>2</sub> NANOPARTICLE ADDITION ON SUBMERGED  
ARC WELDING PROCESSES ON CARBON STEEL**

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**Abstract.** *Submerged arc welding (SAW) is a metal bonding process which involves an electric arc between the base metal and a consumable wire electrode, under a layer of granular flux. The purpose of applying the flux is forming the electric arc, protecting the arc region from atmospheric contamination, reducing spatter, forming slag and, eventually, adding alloying elements to the weld. This is a widely used process for joining thick plates, and it can also be applied to deposit large coating areas, due to the possibility of using multiple wires and inserting other materials, even on the nanoscale, which provide differentiated electrical and mechanical characteristics to the weld bead. In this regard, the present study aims to investigate the influence of ceramic nanoparticles (NPs) addition on welds beads deposited by submerged arc welding process. The filler metal used was carbon steel wire, AWS A5.17 class EM12K, 2,4 mm diameter and the wire flux combination used was AWS F48A2-EM12K. Ceramic TiO<sub>2</sub> nanoparticles were mixed with isopropyl alcohol in a solution, which was deposited on half of a 250 x 75 x 16 mm<sup>3</sup> ASTM A 36 plate, allowing for the deposition of the weld bead in regions with and without nanoparticles using the same welding parameters. The weld beads were characterized by stereoscopy, X-ray fluorescence (XRF), and Vickers microhardness (HV0.3) tests. The chemical analysis of slags showed a successfully added of TiO<sub>2</sub> nanoparticles to the weld beads during welding. The addition of NPs did not influence the stability and dilution of the process welding; however, they increased the width and penetration of the weld bead and reduced the microhardness of the weld. It is suggested that the lower thermal conductivity of the nanoparticles reduced the solidification speed of the bead, resulting in an increase in the width of the bead weld and coarse grains.*

**Keywords:** *Ceramic nanoparticles, Weld pool, Inclusions, Slag, SAW, Titanium dioxide*

## 1. INTRODUCTION

Submerged arc welding (SAW) is a metal bonding process which involves an electric arc between the base metal and a consumable wire electrode, under a layer of granular flux. The purpose of applying the flux is forming the electric arc, protecting the arc region from atmospheric contamination, reducing spatter, forming slag and, eventually, adding alloying elements to the weld. This is a widely used process for joining thick plates, and it can also be applied to deposit large coating areas, due to the possibility of using multiple wires and inserting other materials, even on the nanoscale, which provide differentiated electrical and mechanical characteristics to the weld bead (ASM Metals Handbook, 1995).

Nanotechnology has contributed to the development of several areas of knowledge through the study and application of nanomaterials. These are defined as ultrafine particles, in nanometer scale, having diameters ranging from 1 to 100 nm (Naito et al., 2018). Nanotechnology is a broad interdisciplinary area of research and development, that involves different types of materials (polymers, ceramics, metals, composites, etc) structured in form of nanoparticles, nanotubes, and nanofibers (Fortunato, 2005). Due to their small size, nanoparticles tend to present different properties from the material in micrometric scale, such as morphological and structural, thermal, electromagnetic, optical, and mechanical properties, which provides a great highlight for its applications in different industries (Chen et al., 2014).

In engineering, the application of nanotechnology in the welding process is prominent. The addition of nanoparticles in welding process aims to refine the microstructure and improve the weld's mechanical properties, such as hardness, toughness, mechanical resistance, etc. The addition can occur through the fluxes, filler materials, coating of coated electrodes, furthermore, being deposited directly on the base material. In low carbon steels, the addition of TiO<sub>2</sub> nanoparticles in the coating of AWS E6010 coated electrode, improves the toughness and mechanical resistance of the weld bead (Fattahi, et al. 2011), also the addition of tungsten carbide NPs directly in the weld pool by the twin-wire SAW process (Aleshin, et al. 2019). In aluminums, the addition of Al<sub>2</sub>O<sub>3</sub> nanoparticles in the filler material of TIG process caused refinement in the grain size, that caused an increase in hardness of the weld metal (Kianezhad and Raouf, 2019).

In the submerged arc welding process of steels, the addition of TiO<sub>2</sub> nanoparticles increases the level of Ti in the weld bead, which favors the increase of the amount and average diameter of non-metallic inclusions, that act as potential heterogeneous nucleation sites, collaborating with the raise of the formation of acicular ferrite in the weld bead (Jiménez, et al. 2019a). The presence of this type of ferrite in a weld bead represents an improvement in its mechanical resistance, toughness, and decrease in the hardness of the material, due to the acicular ferrite's aleatory metallographic orientation, which restricts the propagation of cleavage fractures in the material (Xing, et al. 2015).

In this regard, the present study aims to investigate the influence of the addition of TiO<sub>2</sub> nanoparticles in submerged arc welding of carbon steel in the process stability, geometry characteristics and hardness of the weld beads.

## 2. MATERIALS AND METHODS

To study the influence of nanoparticles on weld beads, a solution of TiO<sub>2</sub> nanoparticles in absolute ethyl alcohol was made and pre-deposited on carbon steel plates for subsequent submerged arc welding.

The solution of nanoparticles powder with absolute ethyl alcohol was composed of 14 g of TiO<sub>2</sub> nanoparticles of 21 nm in 24 ml of ethyl alcohol, carried out in an IKA-RW 20 digital propeller mechanical stirrer, in which powder was added in small amounts, with a spatula, in the beaker with alcohol, with rotation varying between 500 rpm and 1500 rpm. Finally, with the NPs added, the solution was taken to an ultrasonic shaker with amplitude adjusted to 20% for 1 minute, while being cooled in a container with ice, because the process generates heat. After the solution was ready, it was homogeneously distributed, in half of the specimen, in a 75 mm thick layer on the surface of a steel plate, as shown in Figure 1.



Figure 1. Pre-deposited solution of TiO<sub>2</sub> nanoparticles in absolute ethyl alcohol.

With the solution deposited on the surface of the sample, the welding process was performed according to the parameters in Table 1, on an ASTM A36 plate measuring 250 x 75 x 16 mm<sup>3</sup>, using the wire-flux set AWS F48A2-EM12K (wire diameter 2.4 mm and aluminate-rutile slag) according to Table 2. Residues and oxidation points were removed from the steel plate, before the welding process, using a flap disc. The welding process started in the side without nanoparticles toward the side with, as shown in Figure 1, and the electrical signals were measured and treated by SAP (Portable Data Acquisition System).

Table 1. Welding parameters.

Defined Parameters			Measured Parameters	
Voltage (V)	Welding speed (cm/min)	Wire speed (m/min)	Voltage (V)	Current (A)
30	30	2.4	26.7	211

Table 2. Chemical composition<sup>(1)</sup> of the welding materials (% weight).

Material	C	Mn	P	S	Si	Cu
Base Material	0.26	0.75	≤ 0.04	≤ 0.05	≤ 0.40	-
Wire-Flux Set	≤ 0.10	0.80	≤ 0.03	≤ 0.03	0.07	≤ 0.35

<sup>(1)</sup> Chemical compositions according to supplier quality certificates

The weld beads cross sections were cut and metallographic prepared with emery papers up to 600 polishing with alumina up to 0.3 μm in micro cloth and finally etched with 2% Nital. Hardness measurements were performed along the cross-section with a distance between indentations of 0.30 mm on the x and y axes, with a load of 0.3 kgf, according to the ASTM E-92. Therefore, maps and hardness profiles were generated in the weld beads with and without nanoparticles. The geometric characteristics analyzes were the bead width (W), reinforcement (R) and penetration (P), as shown in Figure 2 and the dilution (D%) by the area method Equation (1), based on Figure 3, using the Laica Application Suit X software. The slags obtained in the welding process was collected and grounded to analyze its chemical composition by X-ray fluorescence, to identify whether there was loss of nanoparticles towards the slag during the solidification process.

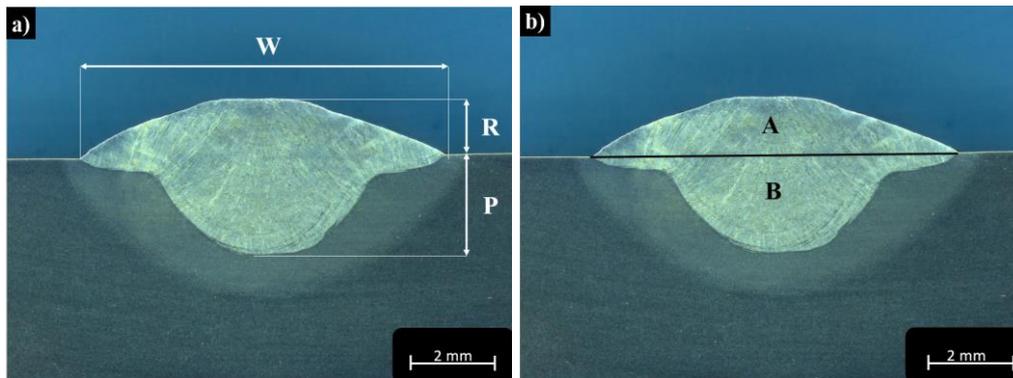


Figure 2. a) Geometry characteristics of the weld beads and b) Areas of the weld to calculate the dilution.

$$D(\%) = \frac{Area\ B}{Area\ A + Area\ B} \times 100 \quad (1)$$

### 3. RESULTS AND DISCUSSION

#### 3.1 Electrical Signals

To assess the stability of the welding process, the voltage and the current can be presented though cyclograms. According to Suban and Tusek (2003), cyclograms are a simple and practical interpretation tool to evaluate process stability. The more concentrated and closer to overlapping the lines of the same cycle region, the more stable the process is, while the presence of dispersed lines shows an unstable operating condition (Díaz, et al. 2018). The electrical signals of the weld bead did not show differences in behavior in the side with and without nanoparticles. Therefore, the addition on NPs did not change the stability of the welding process (Figure 3).

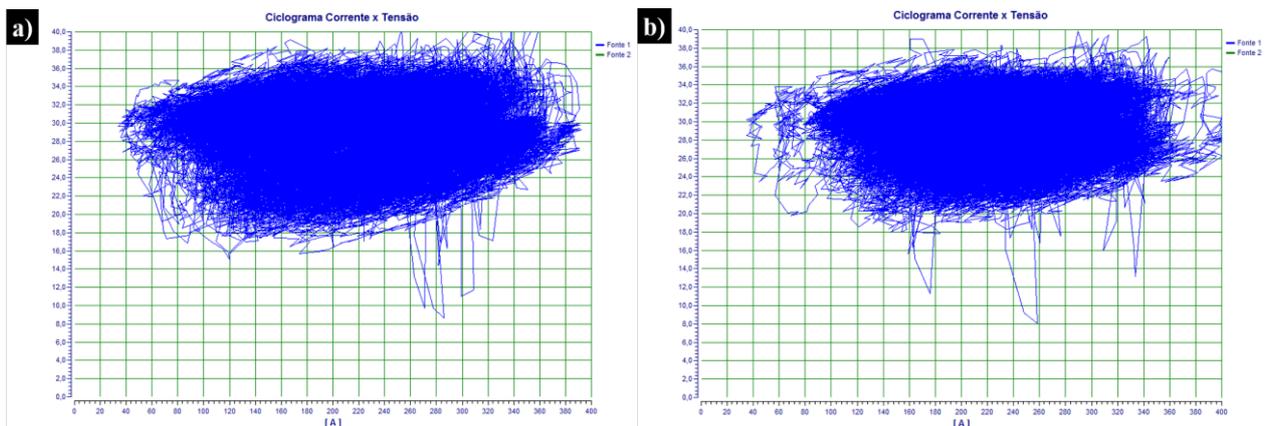


Figure 3. Current x voltage cyclograms of the weld bead: a) without nanoparticles and b) with nanoparticles.

#### 3.2 Chemical Composition of Slag

The analysis of the chemical composition of the slag, formed in the welding process, indicated an increase of 2.18% in the Ti content in the slag of the weld bead with the addition of TiO<sub>2</sub> nanoparticles. According to Jiménez et al (2019a) and Jiménez et al (2019b), increases greater than 1.2% of Ti characterize loss of a portion of nanoparticles towards the

slag. However, as the TiO<sub>2</sub> NPs were completely covered by flow during the welding process, it is suggested that a large amount of Ti was deposited in the bead, which will influence the microstructure, geometric characteristics and hardness of the bead.

Table 3. Chemical composition (% weight) of slag formed by FRX.

Sample	Al	Si	Mn	Ti	Ca	Mg	Fe	P
Slag Without NPs	47.32	15.60	11.90	7.57	5.62	4.84	4.06	1.18
Slag With NPs	34.44	12.32	18.09	9.75	7.06	5.45	5.75	0.75

### 3.3 Geometric Characteristics of the Weld Beads

The weld bead geometry characteristics were measured in both weld beads, with and without nanoparticles, as shown in Figure 4. There was an increase by 7% in weld bead width and penetration. The suggested mechanism which could explain this increasing could be the lower thermal conductivity of the TiO<sub>2</sub> nanoparticles reduced the solidification speed of the bead.

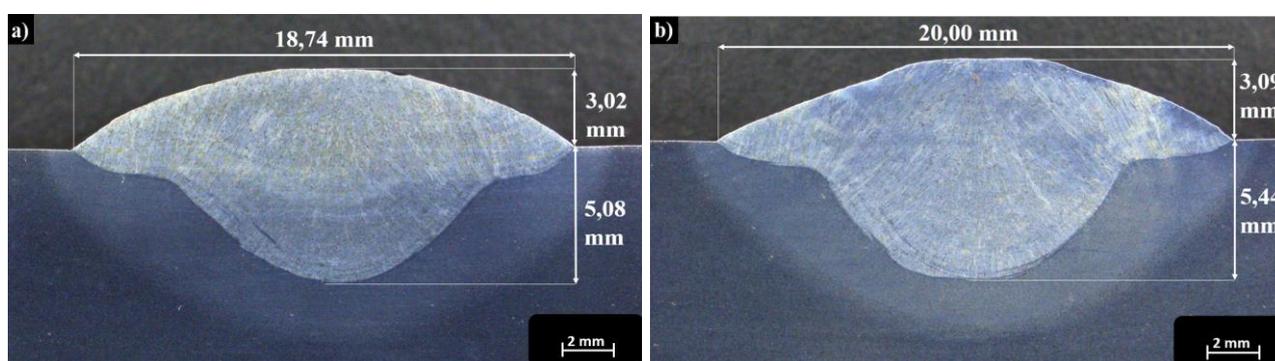


Figure 4. Geometry Characteristics of the Weld Beads: a) Without Nanoparticles and b) With Nanoparticles.

The dilution (%) of the weld beads was calculated and are presented in Table 4. The areas of the weld beads present a proportional increasing, which did not affect the dilution significantly. Although, according to Aghakhani and Naderian (2015), the adding of ceramic nanoparticles in SAW process changes the Marangoni convection mode of the fluid flow in the weld pool to inward which resulted in an increase in the percentage dilution, with a narrow weld and deep penetration.

Table 4. Area values and dilution of the weld beads with and without nanoparticles.

Sample	Area A (mm <sup>2</sup> )	Area B (mm <sup>2</sup> )	Dilution (%)
Weld Bead Without NPs	38.8	50.5	56.6
Weld Bead With NPs	41.5	53.6	56.4

### 3.4 Vickers Microhardness

The Vickers microhardness (HV) was determined on the cross sections of the weld beads with and without nanoparticles, as shown in the hardness maps (Figure 5). The weld bead without nanoparticles has a hardness profile with higher values compared to the corresponding values in the bead with nanoparticles (Figure 6). According to Jiménez, et al (2019a), the decrease of hardness suggests a decrease in the fragility of the weld metal with the addition of TiO<sub>2</sub> nanoparticles during the SAW process. The decrease of hardness values in the bead with nanoparticles can also be correlated with the greater presence of acicular ferrite, formed from the introduction of ceramic nanoparticles during the welding process (Xing et al, 2015). Furthermore, the addition of TiO<sub>2</sub> NPs may have reduced the speed of solidification of the weld bead, since they have lower thermal conductivity than steel, resulting in coarse grains and decreased hardness (Aghakhani, et al. 2013).

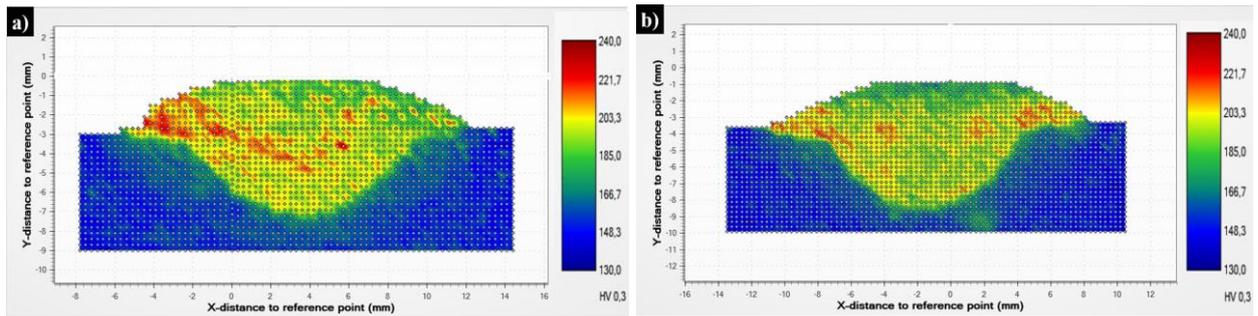


Figure 5. Microhardness maps in the cross-section of the weld beads: a) without nanoparticles and b) with TiO<sub>2</sub> nanoparticles.

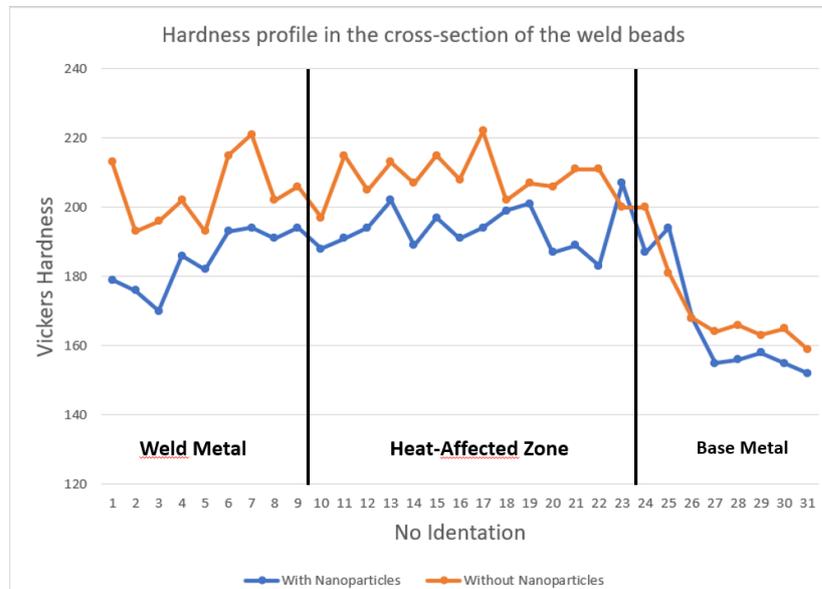


Figure 6. Hardness profile in the cross-section of the weld beads: a) without TiO<sub>2</sub> nanoparticles and b) with TiO<sub>2</sub> nanoparticles.

#### 4. CONCLUSIONS

The chemical analysis of slags showed that we successfully added TiO<sub>2</sub> nanoparticles to the weld beads during welding. The addition of NPs did not influence the stability and dilution of the process welding; however, they increased the width and penetration of the weld bead and reduced the microhardness of the area weld. It is suggested that the lower thermal conductivity of the TiO<sub>2</sub> nanoparticles reduced the solidification speed of the bead, resulting in an increase in the width of the bead weld and coarse grains.

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## 7. RESPONSIBILITY NOTES

The author(s) is (are) the only responsible for the printed material included in this paper.