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RESEARCH ARTICLE

PROPERTIES AND PARAMETERS OF APPLICATION OF THE SAE 310 STEEL COATINGS OVER ON SAE 1020 STEEL SUBSTRATE, USING COATED ELECTRODE WELDING PROCESSES

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ABSTRACT

The objective of this work was to analyze the coating performance embedded in a SAE 1020 steel deposited with SAE 310 steel using the coated electrode welding process. The coating was applied at 110 and 130 A of current, without and with of the specimen inclined in 20° from the horizontal. The purpose was to determine the deposition efficiency, where dilution, reinforcement, bead width and depth of penetration were evaluated under different conditions. It was observed that with the increase of the current and of the inclination of the piece the dilution and the penetration of the bread deposition metal increased, with subsequent decrease of the amount of metal deposited and reinforcement, since the width of the bead decreased with the increase of the welding current and grew with the increase of the angle of inclination of the piece. Therefore, the microhardness results were slightly better in the fusion zone and the lower dilution and penetration were obtained in the current condition of 110 amps and with angle of inclination of 0º.

INTRODUCTION

The coatings may be defined as the deposition of a metal alloy on a surface to achieve desired properties or dimensions, so as to provide protection of the desired surface in its working environment. Austenitic stainless steels have stood out against their good resistance to cavitation and corrosion, as their performance is related to both the mechanical properties and their good performance against oxidation, since corrosion acts as an accelerator of erosion that leads to cavitation (Lambert *et al.,* 1987). One of the materials most used in the coatings for this purpose are stainless steels, as they also have easy weldability and important use at high temperatures. In the case of austenitic steels of line SAE 310, as in their chemical composition they have chromium, nickel and molybdenum, they provide the coating an excellent corrosion resistance when compared to carbon steels, which shows a very important innovation in relation to maintenance coatings (Pradeep *et al.,* 2010). However, when measuring the geometric profile of the welding by coating, what is sought is an increase of width and reinforcement, so that it has the smallest possible number of passes in the welding, reducing the time, cost and also the adequate amount of metal used in welding.

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The main objective of this research is to obtain a deposition with the smallest possible dilution, small penetration, greater width and adequate reinforcement for a better yield of the process. Corrosion prevention is important although it can't be completely eliminated but reduced to some extent, and corrosion-resistant layers of protection on a less resistant substrate are a technique used to improve the life of engineering components and also reduce cost of maintenance and general (Gerhardus *et al.,* 2001). There are several processes for coating metal surfaces, and among them the electric arc welding with coated electrode (SMAW) -MIG / MAG may be one of several applied. To regulate and control welding coating techniques, it requires knowledge about the effects of welding process parameters, overlap percentage, temperature between passes and dilution to adapt the properties of the coating deposits (Senthilkumar *et al.,* 2015). Weld coating techniques are widely used to impart corrosion and wear resistance characteristics of low carbon steel on substrates. By the conventional consumable electrode coating process, the welding parameters have a direct influence on the bead geometry, the hardness distribution and the corrosion behavior. In addition, welding parameters can be primary and secondary based on their influence on the heat input, and are directly connected to welding current and arc voltage mainly.

The main difference of the welding of coating in relation to the conventional applications of welding concerns the geometry of the weld bead. Unlike conventional applications, where high penetration is desired to ensure the strength of the welded joint in the coating weld, the desired geometric profile is summarized as large bead widths, high reinforcements, low penetrations and low percentages of dilution (Kannan and Murugan, 2006).To regulate and control welding coating techniques, it requires knowledge about the effects of welding process parameters, overlap percentage, temperature between passes and dilution to adapt the properties of the coating deposits (Senthilkumar *et al.,* 2015). have equal heat dissipation rates on both sides of the bead. The E310-16 electrodes were developed for the welding of type 310 stainless steel for weld deposit will exhibit the same chemical analysis and oxidation resistance as the base plate metal. It is considered a general purpose electrode for welding almost every analysis of carbon and alloy steel, where with preheating to 150 to 250ºC produces strong crack-free welds in dissimilar steels as shows in Table 1.

Table 1. AWS Chemical Composition Requirements

Element	C	Cr	Ni	Mo	Cu	Si	P	S	Mn
%wt	0.08-0.20	25-28	20.0 – 22.5	0.75	0.75	0.75	0.03	0.03	1.0-2.5

The Advanced Submerged Arc Welding process, due to its certain merits over conventional. Submerged Arc Welding process, is used for cladding AISI 308L stainless steel on mild steel plate. A mathematical model has been developed to study the effect of ASAW process parameters on weld penetration shape factor (WPSF). Weld penetration shape factor is defined as the ratio of bead width and depth of penetration. It is also called the coefficient of internal shape (Om and Pandey, 2014). Mathematically, WPSF can be represented as $WPSF = W/P$, where W and P are the Bead Width and Depth of Penetration respectively as shown in Figure 1. They studied the linear relationship between the arc intensity and the welding current in the GMAW process, which can control the fusion. On the other hand, the relationship between welding stress and arc length in the conventional process was investigated, and was shown with a higher arc length in this process (Om and Pandey, 2014).

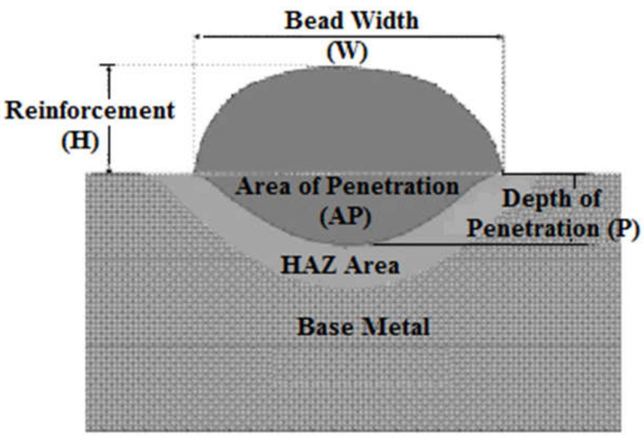

Figure 1. Weld bead geometry [Aghakhani *et al.*, 2011]

A modified Taguchi method has been adopted to analyze the effect of each welding process parameter consist of arc gap, flow rate, welding current and travel speed on the weld pool geometry and then determined the TIG welding process parameters combination associated with the optimal weld pool geometry (Fan *et al.,* 2013)

MATERIALS AND METHODS

Materials

A 'single bead on plate' technique was adopted for deposit beads in E310-16 stainless steel single bare wire electrode of 4.76 mm of diameter on 150 mm x 50 mm x 6.35 mm mild steel plates SAE 1020 as shown in Table 1, with deposition at 0º and 20º of inclination and 30V de voltage. The bead was deposited at the centre of each plate along its length in order to

The substrates underwent the recommended process to obtain the surface roughness necessary for the adherence of the coating with cleaning by the abrasive blasting that guaranteed the Sa3 grade cleaning according to the NACE Standard NR - 01/70. The pieces, after being properly prepared, were coated by the coated electrode welding process (SMAW) (American Welding Society, 2015) with the deposition only a weld bead. These high-chromium stainless alloys were selected because they tend to favor the formation and precipitation of chromium carbides in grain contours, and that in these cases, due to the carbon content, it does not happen.

Welding

The conventional welding processes were TIG with continuous direct current (CCPD) and for the realization of the weld beads the BAMBOZZI PICCOLA 400T coated electrode welding equipment was used. To perform the optical analysis of the metallographic profile of the bead the Auto-Cad drawing tool was used, in which the areas and dimensions are automatically found in millimeters, through photos and using as reference the thickness of the plate that is of 6.35 mm according to Figure 2.

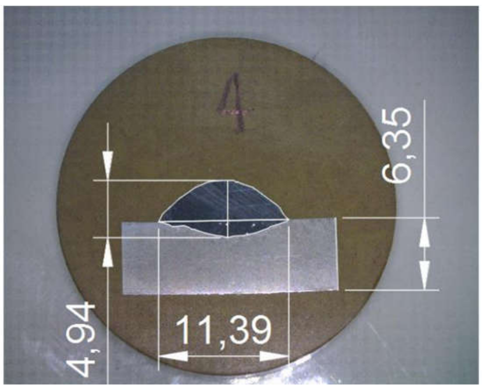

Figure 2. Measurement in millimeters of the morphology of the weld bead

Parameters

The influence variables of this work are two being the welding current and the slope of the work piece in the longitudinal direction. Only one weld bead was deposited and the levels of the variables are presented in Table 2 and 3, where the samples used are identified.

Table 2. Parameters and variables in welding and their levels

Parameters	Level -1	Level +1
Current (A)	110	130
Angle of the piece (º)	0	20

Table 3. Identification of the samples for the experiments

Piece	Current(A)	Angle of the Piece(º)
B01	110	20
B02	110	0
B03	130	20
B04	130	0

Metallographic Analyzes

Metallographic tests are procedures used to reveal macro or microstructures optics, which were performed to complement the influence information of the variables used during welding, and analyzes were carried out with a magnification of 200 times.

Microhardness Tests

The test was performed on the cross section of the weld bead of the samples, in the region of any deposition zone. The method used to measure the microhardness was Vickers, in microhardness equipment REICHERTER BRIVISOR, with application load of 300 gf for 15 seconds. The measurements were made in the cross section of the weld bead, with a distance of 5 mm below the surface line of the specimen, aligned in the horizontal direction, spaced apart by 0.3 mm and comprised between the base metal, the thermally affected zone and molten zone. The penetrator used was the diamond pyramid with a square base and a 136 ° angle, and a distance between indentations of at least 2.5 times the diagonal of the prism formed by penetration of the penetrator following the orientation of ASTM E384 and ASTM E 92 (2003).
Two columns of microhardness indentations with five measurements were performed in each region of the weld bead (FZ), Thermally Affected Zone (HAZ) and Base Metal (BM)) and after 9 vertical measurements, 3 in each of the zones, with the removal of the mean of the parallel points horizontally.

EXPERIMENT AND RESULTS

In coating welding, it is advisable to obtain as little dilution as possible (Yu *et al.,* 2014) so that the addition metal mixes as little as possible with the base metal, but we should not ignore the other important parameters, such as width, reinforcement, penetration, melting and deposition rate. Table 4 presents the results of the mass deposited (grams) in each test, noting that the current increased, the angle remained fixed and the deposited mass decreased. Also when current was fixed, and increased the angle of the piece the amount of mass deposited had the same behavior. This behavior probably occurred due to the instability of the electric arc occurred with increasing current and angle, causing a greater amount of splash to form and a smaller amount of material to be deposited.

Table 4. Characteristics of the parameters and physics of the deposited material

Piece	1	2	3	4
Ângle (º)	20	0	20	0
Current (A)	110	130	110	130
Piece weight before welding (g)	366.64	366.84	364.69	366.80
Piece weight after welding (g)	384.51	385.66	378.06	382.55
Weight of deposit of material (g)	17.87	18.82	13.37	15.75

This behavior probably occurred due to the instability of the electric arc occurred with increasing current and angle, causing a greater amount of splash to form and a smaller amount of material to be deposited. Table 5 presents the results of weld bead morphology (width, reinforcement, penetration, penetration area, reinforcement area and dilution). It was observed that with the increase of the current there was a growth of the width, penetration, area of the penetration and dilution. This fact is related to the reason that with the greater current there is an increase of the heat applied at the tip of the electrode due to the Joule effect, causing these results also to rise. Reverse behavior can be observed by the reinforcement and reinforcement area, being proved by the increase in penetration and area of penetration, causing the volume of the deposited metal to decrease in the reinforcement and to move for penetration.

Table 5. Results of the morphology of the weld bead

Ângle (º)	20	0	20	0
Current (A)	110	130	110	130
Wigth (mm)	11,16	11,39	11,63	9,71
Penetration (mm)	2,15	1,45	2,96	1,99
Reinforcement (mm)	3,16	3,49	2,10	2,10
Reinforcement area (mm^2)	20,94	27,15	14,16	14,09
Penetration area (mm^2)	13,32	9,40	19,48	12,53
Total area (mm^2)	34,26	36,55	34,09	26,62
Dilution (%)	39	26	57	47

The change in the magnetic arc reduces the tendency of cracks, grain sizes in the deposits and the penetration (American Welding Society, 2005), because Tables 4 and 5 show the results plotted according to TAGUCHI method and Figures 2 to 6 reinforce the visualization of the behavior of the deposit. It can be observed that the penetration sensitivity is more prominent for the changes in the welding current, while the changes of the dilution and the width of the deposit cord depend on the distance to the part (Sreeraj *et al.,* 2013). In Figure 3, referring to the amount of deposited material, and in Figure 4 referring to the reinforcement of the cord, the welding current and the inclination angle of the part are the same, that is, with the increase of the current from 110 to 130A and from the angle of inclination from 0 to 20º the results provided less deposited material, in turn less reinforcement.

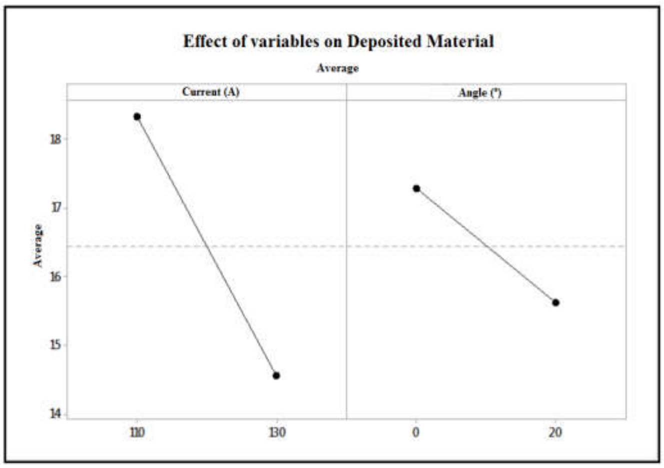

Figure 3. Effect of variables on Deposited Material

Possibly with the increase of the variables there was an increase of the electric arc instability, making the amount of material deposited smaller, reproducing this fact also for the reinforcement, although the smaller current influenced more significantly these variables.

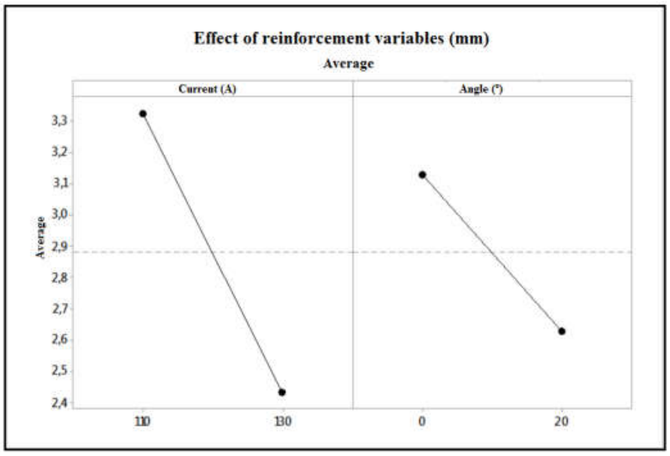

Figure 4. Effect of reinforcement variables (mm)

It was found that the amount of material deposited by increasing the current from 110 A to 130 A decreased by 26%, which affects the reinforcement of the deposit. However, in Figure 5 where we have the effect of the variables in the penetration, the increase of the current and the slope of the piece show a growth of the layer penetrated by 39% for the current increase and 47% because exactly the inclination of the piece.

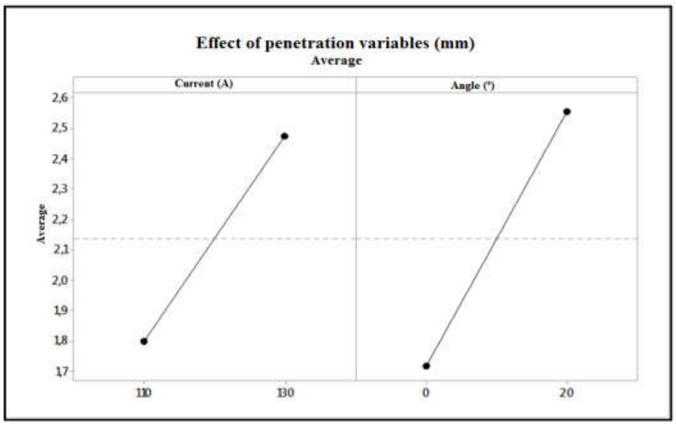

Figure 5. Effect of variables on Penetration

In Figure 6, with increasing current, a higher increase in dilution it happened, due to the increase of the Joule effect at the tip of the electrode which generates a larger amount of material to be deposited, but with very little influence due to the inclination of the piece.

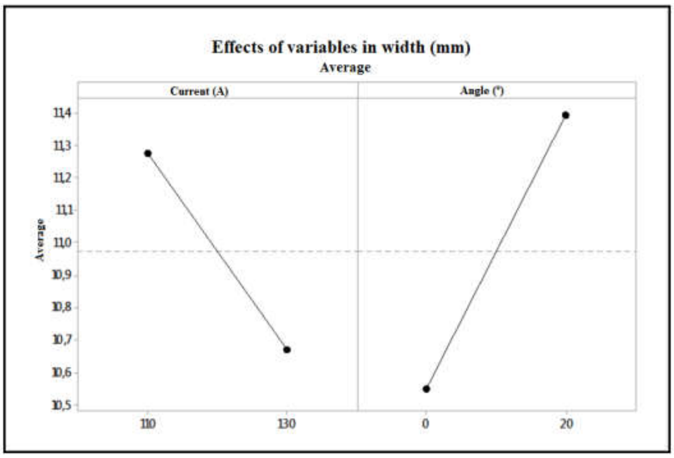

Figure 6. Effect of variables on Dilution (%)

Figure 7 shows the effects of the variables in the width, where we observed that with the increase of the current the width of the cord diminishes and with the growth of the angle of inclination of the piece the behavior was inversed. This decrease in width with increasing current is due to the fact that part of the molten metal has been dilute in the penetration zone.

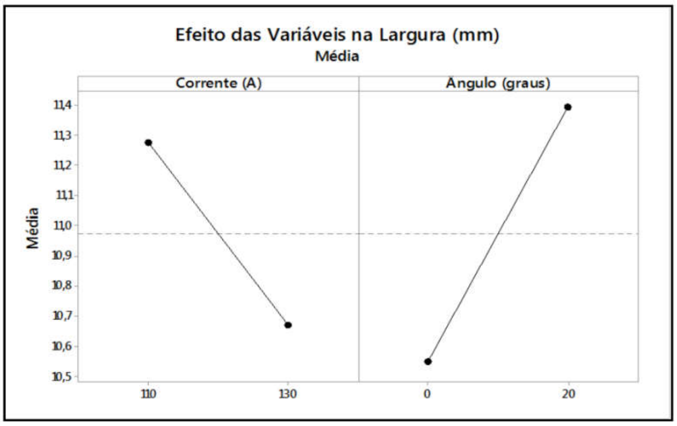

Figure 7. Effect of variables on width

On the other hand the increase in width with the growth of the part angle from 0 to 20° possibly is due to the fact that there was a lateral displacement of the melting pool due to the force of gravity, causing the width to increase. Therefore for the coating process of carbon steels with stainless steels, in particular austenitic steels, with the dilution increasing, there will be a reduction of the original alloying elements and thereby increase the carbon content in the coated layer, while reducing corrosion resistance properties (Shahi and Pandey, 2008).

Optical macroscopy

The macrographs of the beads were made and revealed, showing their real morphology, as Figure 8, where the deposit was well characterized. In this Figure 8 we can observe that the most well distributed deposition profile is that of sample B02, whose morphology stands out for the distribution of parameters, width, penetration, reinforcement and the microhardness showed a little higher in the fusion zone. In order to diagnose the hardness profile, 9 indices of Vickers microhardness of each specimen were executed, with 3 values of the fusion zone (FZ), 3 values of the Heat Affected Zone (HAZ) and 3 values of the Base Metal (BM). Table 7 shows the results obtained from the test specimens under study and plot them graphically in Figure 8 where we can verify more clearly the distribution of these micro indentations.

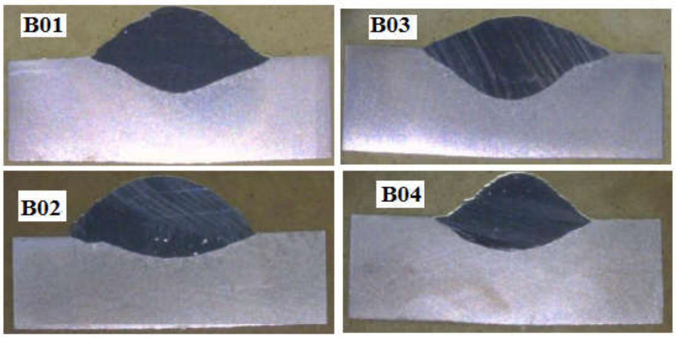

Figure 7. Morphology of weld beads studied

Table 6. Microhardness results as a function of string parameters and region

Inclination angle (º)		20	0	20	0
Averege current (A)		110	130	110	130
Measure	Region	B01	B02	B03	B04
1	FZ	175.8	187.3	178.3	209.8
2	FZ	170.7	196.2	182.2	202.8
3	FZ	189.9	204.8	179.4	222.5
4	HAZ	169.7	189.9	182.2	175.8
5	HAZ	177.4	189	158.5	175.8
6	HAZ	168.3	179	171.2	172.7
7	MB	144,.1	145.3	161.9	166.1
8	BM	141.8	165.4	141.8	158.5
9	BM	143	155.2	150.1	155.8

Table 7. Results of the mean microhardness values in the bead regions

Tests	B01	B02	B03	B04
Base Metal	142.97	155.30	151.27	160.13
HAZ	171.80	185.97	170.63	174.77
Fusion Zone	178.80	196.10	179.97	211.70

The microhardness results of the specimens are presented in Tables 7 and 8 and plotted in the graph of Figure 8, show that the deposition zone was the one that presented better performance, certainly due to the segregation of chromium and nickel associated to the carbon that favor the formation of complex carbides that aid in the increase of hardness. On the other hand, the processes of fusion welding are characterized by the use of an intense heat source, whose concentrated energy generates regions with high temperatures, high thermal gradients (Midha *et al.,* 2001 and Gomes *et al.,* 2012) and extensive variations of microstructure and properties, in small volume of material, known as thermally affected zone (HAZ).At a point just beyond the HAZ of the weld pool edge temperature rises rapidly to a level near the weld pool and also producing an effect rapidly decreases as the semi tempering. (Chotěborský *et al.,* 2011).

Conclusion

The purpose of this work is to determine the morphology and its characteristics of weld beads in a SAE 310 austenitic stainless steel with high chrome and nickel, varying the current and the inclination of the test pieces in the welding, we can conclude that: With the increase of the current and the inclination of the piece, there was a growth of penetration and dilution; The amount of deposited metal and reinforcement decreased with increasing current and slope of the piece; The width decreased with increasing welding current and increased with increasing the angle of inclination of the piece; The results of microhardnes showed that the deposition layer presented the best average (186 HV) which besides the good corrosion resistance of the alloy, the hardness also favors certain conditions of not very intense wear; The lowest average of dilution and penetration were obtained in the condition of lower current, 110 amps and without angle of inclination of the piece.

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