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Arc Stability Characterization of Double Coated Electrodes for Hardfacing

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ABSTRACT

The aim of this work is to establish the influence of the relative position of the alloy charge C-Cr-Mn in the structure of the coating of rutile electrodes for hardfacing, on the operational behavior (arc stability). For this, three variants of electrodes with similar chemical composition are elaborated in the metallic core and the coating, differentiating only in the relative position that occupies the alloy charge (C-Cr-Mn) in the structure of the coating: internal, external and homogeneous. For the development of the research, a completely random design is used. The operative characterization of the electrodes is performed in terms of the arc stability. In conclusion, it can be seen that the position of the alloy load influences the operation behavior (stability of the arc). The variant of internal alloy charge in the coating presents the better arc stability performance.

1. Introduction

The evolution of the use of arc welding processes in recent years is well known^[1]. In Latin American countries this trend has been less marked, being used for 40% of the metal deposited in countries such as Argentina. In China and India, accompanying the remarkable growth of steel production, there has been a marked increase in the use of coated electrodes. Everything seems to indicate that the

use of coated electrodes will stabilize around 30% of the weld metal deposited worldwide^[2].

Wear is part of the production process, since metals suffer the effects of abrasive particles that cause sensitive losses in them. The action of these particles in the wear mechanism depends on multiple factors, in addition to the characteristics of the worn material. Research on new materials for hardfacing is one of the fields of greatest potential to face phenomena such as the wear of parts and components^[3,4].

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The proper study of the mechanisms of wear contributes in great percentage to make the selection of the appropriate consumable. In some cases, the piece may be subject to several factors. There is no consumable that resists all the previous conditions, but, in practice, an appropriate solution can always be found^[5].

Among the factors to be considered in the material deposited to deal with abrasive wear is the hardness of the phases that compose it separately, although this is a much more complex problem. In fact, the hardness is not always the only parameter to take into account in the wear resistance. For example, for the same hardness values of the metal, in martensite and other martensite and carbide compositions, the second will have more wear resistance^[6].

The use of welding for hard facing offers unique advantages over other systems for these purposes; a metallurgical union that is not susceptible to detachment and can be applied relatively easily^[7, 8]. Deposits applied by welding can be used with a thickness greater than most other techniques, typically in the range of 3 to 10 mm.

Within the techniques of hard facing by welding, the manual hard facing by electric arc is very used and, often, the only possible solution in the restoration of pieces, even when it is recognized as an unproductive process. Generally, the configurations of the pieces or their dimensions do not allow to use another process, with some degree of automation. The need to perform short welds and use electrode oscillation techniques also influences. In addition, the simplicity of the equipment and the possibility of profitably manufacturing a specific consumable, in small batches, for a given application are valued, making it the most economical and versatile method^[9, 10].

To achieve the functionality characteristics of the electrodes, they must have a certain coating composition. The coating, in the case of the electrodes destined to the recovery of pieces, must be composed of a matrix and an alloy charge. The coated electrodes are the consumables that allow reaching the highest transfer levels because of the potentialities of the coating in terms of alloy input^[11, 12].

Some of these required characteristics of the electrodes may be incompatible and, therefore, compromises and balances between them must be observed when designing the coating.

The chemical composition of the alloy charge significantly affects the chemical composition of the deposited metal and its mechanical properties. The loss of the alloying elements can be replaced by the addition of some ferroalloy. By doing so, the transfer of alloying elements could be greater, that is, the percentage of the element that is transferred from the electrode to the weld metal^[13]. The introduction of metallic elements in an alloy based on iron

and high carbon content will fulfill two functions^[14]: On the one hand, the elements forming carbides participate in the formation of this phase; on the other side, the alloying elements influence the properties of the alloy matrix.

The solid electrodes destined to the recharge, whose nuclei are formed from steel with low carbon content and without alloys, have an alloy charge in the coating, whose function is to transform the core metal into a special alloy^[15].

For this purpose, are added special substances and compounds to the coating, whose functions could compete with others designed to guarantee adequate operating properties of the electrode^[16]. The way to obtain the combination between these coating compounds is vital to achieve efficiency in the transfer process^[17]. In conventional electrodes for hard facing, it is not common to use high alloy cores. In these cases, the codes restrict the current values to avoid the overheating of the core and reduce the values of the caloric contribution in the welding bath.

The homogeneous mixtures of the alloy charge and the electrode coating may not lead to solutions that favor the use of the entire alloy charge of the solid electrodes destined for hard facing.

The homogeneous mixture of the alloy filler with an oxidizing silicone matrix and the use of binders in conventional electrodes for the recharge presuppose a considerable loss of the alloy charge during the transfer, from the coating of the electrodes, to the welding bath. The result of intensive oxidation processes of ferroalloys in the arc column, depending on the affinity of the metal element for the oxygen contained in the materials, which make up the coating, which decreases the percentage of alloy elements that reaches the deposit^[18].

Hardfacing electrodes must fulfill their main function: to achieve the incorporation of elements of alloy, which allows reaching the special characteristics to face certain wear mechanism^[19].

Established a classification of the electrodes in terms of the constructive structure of the electrode coverings. Thus, classified the electrodes in terms of the thickness of the coating and the structure of the coating. As for the thickness, the coatings are classified as fine, medium, thick and extra-thick^[20]; as for the structure of the coatings, the electrodes can be single-coated and double-coated^[21]. To this last aspect, given for several years more interest for potential to improve the technological properties of the process^[20].

Currently, manufactured double-coated electrodes with great success in several developed countries^[22]. It has achieved high stability of the arc and a metallic transfer of fine droplet, from locating the fluoride in the outer layer and the elements of low ionization potential (CaCO_3) in the interior.

The use of electrodes with double coating also makes

it possible to increase the stability indicators of the arc, when welding with alternating current, using transformers with low vacuum voltages [23]. However, identified the position of the alloy charge to achieve adequate performance in the operational behavior of the electrodes and the transfer of alloying elements to the deposits. Valuations on these aspects, in electrodes with a double coating structure applied in the hard facing, have not found explicitly in the consulted literature.

2. Materials and Methods

2.1 Materials

To obtain the coatings of a double layer electrode it was necessary to prepare two charges of raw materials, one for each layer. One layer, to guarantee the operating parameters of the electrode, constituted by 70% of the dry mass of the commercial composition, manufactured for the coating of a rutile electrode E6012.

Designed another layer (30% of the dry mass) to provide the alloy charge. The proportions of 70 and 30% are assumed, according to recommendations in the literature [22] and seeking to ensure that the stability of the process does not become an independent variable.

Manufactured three types of electrodes with the same chemical composition for the metallic core and the alloy charge (Table 1). Likewise, the same coating was used (Table 2), similar to that of an E6012 electrode [2]. Where: D_1 is the first layer diameter, D_{ex} is the external diameter and d is core diameter.

The coating of the alloy charge for each type of electrode occupied the same cross-sectional area of the coating and therefore the same measurement in the total volume of the coating, in the same way that of E6012 is used. Where: A_1 is alloy charge section area and A_2 is electrode coating E6012 area. The binder used was also common for all electrodes: sodium silicate, with a density of 1.44 to 1.48 g / cm³, occupying between 28% and 30% of the total mass of the coating.

Table 1. Chemical composition of the raw materials used in the preparation of the electrodes

Electrode component	Percent, in mass, of the chemical element in each component of the electrode						
		Cr	C	Si	Ti	Fe	
Wire		0.48	0.11	0.11	0.4	0.002	Balance
Alloy-Charge	Ferro-chrome	0.00	75.00	0.10	2.00	0.00	Balance
	Ferro-chrome-manganese	59.02	19.45	0.11	2.17	0.00	Balance
	Graphite	0.00	0.00	99.50	0.00	0.00	Others

Table 2. Chemical composition of electrode coating E6012

Chem. composition en %	SiO ₂	Al ₂ O ₃	TiO ₂	NaO	CaCO ₃	FeMn	C ₆ H ₁₀ O ₅
E6012	16	6	52	2.5	2.5	14	7

For the research, established the formulation of three prototypes of electrodes as a comparative strategy, whose differences were not in their composition, but in the position occupied by the alloy charge and the matrix in the structure of the electrode coating (Figure 1).

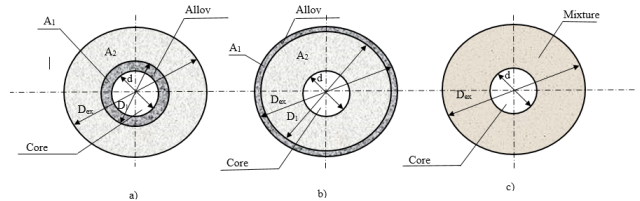


Figure 1. Geometric diagrams of the conformation of the coatings on the electrodes

a) doubly coated (internal alloy charge) b) doubly coated (external alloy charge) c) simply coated (alloy charge homogeneously distributed)

The alloy coating and masses involved in each electrode variant were guaranteed equal, from the consideration of the mass product and the density of each component.

As a result, obtained the dimensions of the different coatings for each developed electrode variant (Table 3).

Table 3. Electrodes dimensions

Electrode type	Diameter (mm)			Weight(*) (g)
	Core (d)	Internal-layer (D_i)	External-layer (D_{ex})	
Internal alloy charge	3.0	4.5	6.5	22.764
External alloy charge	3.0	5.8	6.5	22.766
Simply coated	3.0	-	6.5	22.763

* Electrode length: 250 mm

2.2 Methods

Established the experimental planning was to satisfy the objective of the work in relation to the evaluation of the effect of the position that occupies the alloy charge (C-Cr-Mn) in the structure of the coating of an electrode for the recharge. The position of the alloy charge in the lining structure was taken as an independent factor

Due to the characteristics of the experiment, it was convenient to use a completely randomized design (CRD) [24, 25].

The set of hypotheses to be tested when applying the ANOVA test to the data, according to the CRD, was [24].

Ho: The means of the treatments are the same ($\mu_1 = \mu_2 = \mu_3$)

H1: Some pair of means of the treatments differ ($\mu_i \neq \mu_j$ for some $i \neq j$; $i = 1, 2, 3$)

We used the Statgraphics Centurion XV software as a tool for the study [26].

Among the dependent factors, the stability of the arc was considered.

The acquisition of data on the electrical behavior allows differentiating the operational electrical stability of homologous electrodes [16], then, it can be used to identify differences between the behaviors of electrodes manufactured with different position of the alloy charge in the structure of the coating during the recharge process.

The use of alternating current allows evaluating the behavior of the electrodes in both polarities. The evaluation of its use, presupposes to estimate with which of the two polarities would behave better, from the point of view of the stability of the arc, in the case that both half cycles of current and voltage are asymmetric.

The installation for the acquisition of the signals was composed by a welding station, which includes the alternating current source, a signal conditioner, a shunt, a computer and a digital oscilloscope Tektronix DPO 3014; the latter captured and saved the data obtained, which were processed with the MatLab software [26]. The alternating current source used was an Airco transformer, 200 A, AC / DC Heliwelder Model: 2A / DDR- AC, maximum vacuum voltage 80 V, 200 A with a duty cycle of 60%. The electrodes used to obtain the deposits were dried before the test, between 90 and 120 °C, for 2 hours, in a "Conterm" model stove. Carried out the maintenance of the electrodes in a portable thermo (HydroGuard), from Lincoln Electric.

The data collected constituted samples of peak voltages of re-ignition of the arc, welding voltage and maximum current in each half-cycle, at a frequency of 12000 Hz, above 5000, recommended in the specialized literature [16], according to the theorem of Nyquist-Shannon sampling [27].

As a criterion to measure the stability of the arc (Equation 1), the average rate of increase in electrical conductivity in the arc column during the period of re-ignition in the positive half-cycle (B^+) was taken [2]. Which is directly proportional to the average re-ignition peak current (I_r^+) and inversely proportional to the product of the average re-ignition voltage (V_r^+) with the average re-ignition peak time (t_r^+), all measured in the positive half-cycle.

$$B^+ = \frac{I_r^+}{V_r^+ \cdot t_r^+} \cdot 1000 \quad (\text{Equation 1})$$

3. Analysis and Discussion

From the census, conditioning, recording and digital processing of the current and voltage signals taken during the operational tests, are constructed the graphs (Figure 2) to compare the performances of the electrodes evaluated. Considering a mean welding time of 40 seconds for each variant, a total of more than 10^6 samples were counted during the study of each electrode, which allowed obtaining the current and voltage oscillograms (Figure 2) and the subsequent analysis of the behavior of the main electrical parameters (voltage, current and re-ignition peak voltage). These readings were sufficient to make the statistical comparisons.

In accordance with the criteria published in the literature [16], robust comparison parameters in the current and voltage oscillograms of the welding arc are recognized at the re-ignition peak voltages, the welding voltages and the maximum current.

The values of the welding current (Table 4) oscillate by more than 1% in the case of the positive half cycle, while approximately 5% in the negative half cycle. This refers to more stability in one cycle than the other, with the negative half cycle being the most suitable for comparing the electrodes, since this is where the greatest differences in their behaviors can be observed.

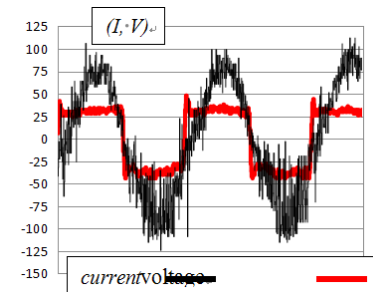


Figure 2a. Fragments of current (I) and voltage (U) oscillograms, obtained during the operational test of the electrodes evaluated (sampling time 0.042 s)

a) Electrode with internal alloy charge

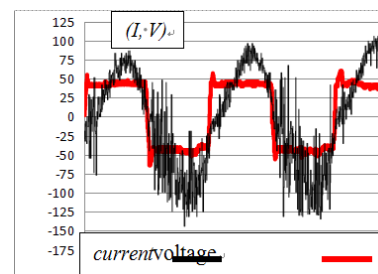


Figure 2b. Fragments of current (I) and voltage (U) oscillograms, obtained during the operational test of the electrodes evaluated (sampling time 0.042 s)

b) Electrode with external alloy charge

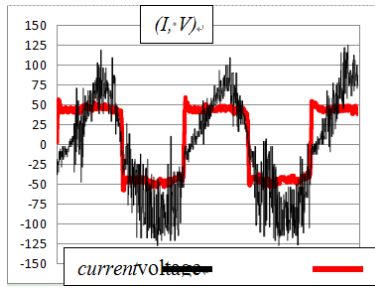


Figure 2c. Fragments of current (I) and voltage (U) oscillograms, obtained during the operational test of the electrodes evaluated (sampling time 0.042 s)
c) Electrode with homogeneous coating

The values of voltage registered for the performance of electrodes with internal alloy charge (32 V and -34 V) present differences of about ten volts with respect to the values obtained for the electrodes with external alloy charge and alloy charge homogeneously distributed (43 V and -46 V). This agrees with the values obtained by Vornovitsky et al. for rutile coating electrodes and alloy core [28].

The voltage value is associated with the magnitude of the arc length: result of the sum of the anodic, cathodic and arc column lengths; the first two are practically constant for the same coating compositions and the same metal core material [29].

Then, in this case, the length of the arc depends on the length of the column, which, in turn, the depth influenced the coating cup. French [30] supports the same criterion. Therefore, the arc length may be influencing the differences (Figure 2) of the voltage values between the electrodes with internal alloy charge (32 V and -34 V) and the electrodes presented by the external alloy charge and homogeneously distributed alloy charge (43 V and -46 V).

Table 4. Electrical indicators. Average values

Parameters	Units	Position of the alloy charge		
		inter- nal	external	homogeneous
Average maximum current				
Maximum average current (Imax+)	Ampere	112.4	113.1	114.3
Maximum average current (Imax-)	Ampere	-138.3	-147.7	-150.5
Average current of re-ignition peak (Ir+)	Ampere	9.67	11.33	11.67
Average re-ignition voltage (Vr+)	Volt	42.7	53.1	53.6
Average re-ignition voltage (Vr-)	Volt	-43.6	-52.5	-50.9
Average welding voltage (Vs+)	Volt	32.7	43.9	43.1
Average welding voltage (Vs-)	Volt	-34.1	-46.3	-42.1
Average re-start peak time (tr+)	Second ⁻³	0.76	0.86	0.75

(+) in the positive half-cycle; (-) in the negative half cycle.

The thermo-physical properties in a zone of the coating, composed of silicates, are different to that composed of metallic components, due to the thermal conductivity of the materials that compose it. In electrodes with an internal alloy charge, which has greater thermal and electrical conductivity, than the rest of the coating, it will melt first (because of the aforementioned and because it is closer to the area of higher arc temperature). Then, practically in unison with the metallic core and the ordinary coating layer, it will then melt. This process induces the participation of a greater number of conductive elements in the column, to the process of conduction in the arc and, therefore, to the reduction of its voltage, being able to generate a smaller coating cup. When the alloy layer is located at the periphery of the coating (externally), the ordinary coating layer functions as a physical barrier. This leads to the outer alloy layer being less exposed to high arc temperatures. Then, the position of the alloy charge in the electrode coating structure produces differences in arc conductivity and is exposed to the different melting temperatures.

All the previous analyzes have no meaning if they do not contribute to differentiating the stability of the welding process. Therefore, the stability of the arc is determined B^+ (Equation 1), from the voltage, current and re-ignition time values obtained, determining the value of B^+ (Figure 3) for each variant studied.

The values of B^+ indicate satisfactory stability values for all variants, being slightly better for the variants with internal alloy charge ($371.21 \Omega^{-1} \cdot s^{-1}$) and homogeneous ($309.39 \Omega^{-1} \cdot s^{-1}$). The values of B^+ obtained in the work are higher than those obtained by the aforementioned authors [31] and since the coatings used have SiO_2 , TiO_2 and graphite in sufficient quantities (Table 1), they could be responsible for this behavior.

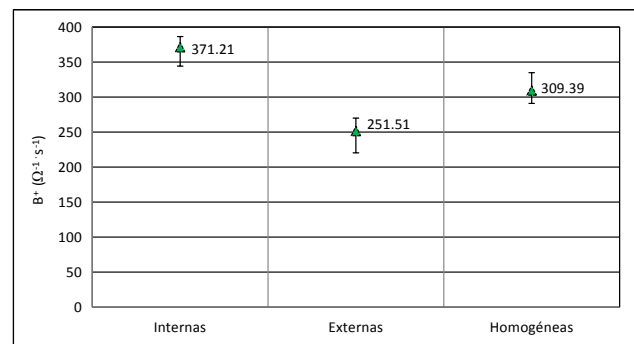


Figure 3. Arc stability indicator B^+

The ionization potential and the inverted energy in the dissociation and ionization processes, which make up the column of the arc, determine the stable functioning of the arc [14]. It is argued by Pokhodnya [20] that TiO_2 has an effect of stabilizing the arc, reaching values of $400 \Omega^{-1} \cdot s^{-1}$.

s^{-1} for 100% of rutile in the coating. In addition, the presence of elements with lower ionization potential (sodium present in the binder), considerably increases the stability of the arc [2]. Both aspects guarantee an electrical stability (B^+) suitable for the realization of the process; however, it is more effective in the case of the electrode with the internal alloy charge, due to its more active participation within the arc column.

4. Conclusions

The tests for the determination of the electrical stability make it possible to establish criteria that allow differentiating the operative behavior of the electrodes evaluated with different position of the alloy charge in the coating structure.

The relative high percentage of elements with low ionization potential and metallic elements, which characterizes the alloy charge, produces differences in the behavior of the average rate of increase in electrical conductivity in the arc column during the re-ignition period (B^+), inversely proportional to the value of the average re-ignition voltage (Vr^+). Therefore, the position of the alloy charge in the coating structure defines the behavior of the electrical stability of the process, resulting in the best performance ($B^+ = 371.21 \Omega^{-1} \cdot s^{-1}$) in the electrode with internal alloy charge.

The results of the experiments carried out establish that the relative position of the alloy charge C-Cr-Mn in the coating structure of rutile electrodes (E6012) significantly influences the operational behavior (stability of the arc) in the hardfacing process.

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