Evaluation of the Specific Electric Behaviour of Covered Electrodes in Welding

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***Abstract*- The present work is directed to the evaluation of the electric behaviour of covered electrodes and its main objective is to communicate to the international scientific community a novel methodology developed with this purpose. Methods of digital processing of the welding voltage and current signals and statistical methods based on non-parametric technical were used for the evaluation of the electric conduct of the process, using a feed by gravity dispositive for the elimination of the operator influence, in comparison with the process using standard electrodes. The proposed methodology allows the detection of destabilization events in anyone of the well-known transfer modes, in periods of arc and short circuit as well as during the re-ignition picks; and to evaluate the grade of the general electric stability of feed by gravity covered electrodes, proposing a novel index combining 5 parameters not referred before as stability criterion. A new index for the stability of the metallic transfer and another new index for evaluating the stability in the load transfer during the arc re-ignition were proposed. For validation of the developed methodology results obtained by means of metallographic technical, of visual inspection and of determination of the consumption indexes were analyzed, overcoming the well-known previous methods and allowing the evaluation of the electric behaviour in all types of covered electrodes and other welding processes, such as SAW, GMAW and GTAW.**

Keywords- Specific Electric Behaviour; Coated Electrodes; Feed by Gravity

I. INTRODUCTION

According to bulletin of the American Bureau of Shipping (ABS), in 2005 there were more than 1500 different manufacturers of covered electrodes at world level, for welding of ferrous and non-ferrous metals, contained in different classifications [1]. In 2006, the welding world metal consumption oscillated around 4.5 million metric tons, while approximately about two million metric tons were wasted in employing electrodes, which accounted for 44.44% of the world metal consumption [2]. The same source forecast maintaining this proportion was almost constant for the year 2010, with tendency to a slight decrease for 2013.

The Shielded Metal Arc Welding (SMAW) stays among the main welding processes at world level, being irreplaceable in diverse applications of different branches of the developed countries industry and of the third world too. In the last years the operative characteristics of the covered electrodes have been continuously improved, contributing to minimize the metallic losses for splash [3] and studying the behaviour of the arc under the welding conditions [4].

The covered electrodes are classified according to specifications that respond to different norms, among which the specifications of the American Welding Society (AWS) are important references. Electrodes for welding of carbon steels, low alloy and stainless steels, are specified according to the norms AWS-A.5.1, AWS-A.5.5 and AWS-A.5.4, respectively.

Some years ago the knowledge about the rutile electrodes of the classification E6013 became more important every day for the possibility of using them in the wet sub-aquatic welding, of deepening in the study of the slag rutile system and of obtaining more economic formulations, without sacrificing the excellent typical operative characteristics of these electrodes, satisfying the requirements of Grade 3 of the Unified Classification Societies (ABS, BV, DnV) for the naval industry. For these reasons, in Latin America, a combined program of investigation on the covered electrode AWS - type A.5.1-91 E6013 began [5].

In the field of the wet sub-aquatic welding Cuban scientists took part in international projects [6-9] directed to the development of electrodes for the recharges of hard surfaces [10-14], and in the topic of the determination of the electrodes efficiency [15, 16], without considering the energy consumptions [17]. Although there are some works on the diagnosis and evaluation of consumables [18-20], in Cuba a methodology of evaluation of the electric stability for the different types of employed consumables has not been even established scientifically.

During the manual feeding of the covered electrode, their specific electric behaviour is modified. To avoid the influence of the operator, devices of automatic feeding are based on the employment of electric motors commanded by control knots, and sensitive to the variations of the arc longitude produced by the consumable fusion process and the dynamic answer of the welding source [22, 23]. The characteristics of the dynamic answer of the automatic system of feeding modify the electrode specific electric behaviour too [24]. Feed by gravity devices have been used to weld with electrodes of carbon in the practice [25] and with covered electrodes in applications of the naval industry, as well as for the simulation of the wet sub-aquatic welding [26-29], however, the study of the specific electric characteristic of covered electrodes feed by gravity has not been reported explicitly in the specialized literature [30].

Modes of metallic transfer reported during the SMAW welding, have been identified as explosive, short circuits, globular and spray [31, 32], presenting different transition currents in dependence of the physical-chemical properties of the consumable, the type of polarity and current of the welding source, and operability conditions and others. The reported methodologies for the evaluation of stability in the metallic transfer, assume that the fundamental mode of transfer is that of short circuits, rejecting the short circuits of durations smaller than 2 ms [5, 11, 33]. The metal proportion contributed by each mode and its effect in the signals of voltage and welding current, is in some cases even unknown, being required the development of new methods of determination of the general electric stability [30].

In the analysis of the literature the procedure of determination of the characteristic parameters from the short circuits metallic transfer and in the transference of electric charge during the re-ignition of the arc is not detailed. It is assumed in some cases that the parameters have an empiric distribution near a normal distribution [33-34] but this is not always correct. In other cases the description of the methodology for the statistical processing of each parameter is omitted and one inadequate estimator of dispersion was used [5, 33, 34].

II. DEVELOPMENT

From the analysis of the literature [31, 35] and the experimentation results [30] it was possible to determinate some knowledge about the arc electrical nature with rutile and other types of electrodes like double coated for hard facing and E7018 type electrodes. By the physic of the electric arc, the electric charge transport has similar nature on all types of coated electrodes and the phenomenon of metal transference has the same principal modes also in other welding process. Important parameters of the waves of voltage and welding current have been identified. These parameters are representatives of the stability of the processes of electric charge and metal transfer through the arc.

It is recognized that the rutile electrodes are those that present a better electric behaviour, for this reason a methodology that allows differentiating the electric operability of feed by gravity homologous rutile electrodes, should allow the determination of operative differences among electrodes of worse electric behaviours. The rutile electrodes have a very high grade of applicability on the SMAW welding and the E6013 specification is one of the more represented on different manufactures at world level.

A. Materials

In this paper two different electrode types were studied, one type of electrode manufactured in Cuba, ACINOX-E6013 with a diameter of 4 mm, referred to as the C letter in this paper, again another type of electrode WURTH-E6013 (Spain) with a diameter of 4 mm named E type. Both types of electrodes are certified for the norm ANSI/AWS 5.1/91, guaranteeing similar mechanical and chemical properties ranges. An appropriate characterization of the coating and nucleus of the electrodes, and the metal of the test plate was carried out (Tables 1-4).

TABLE 1 CHEMICAL ANALYSIS OF THE COMPOSITION OF THE COATING

Oxide	E Electrode	C Electrode
	(%)	
SiO_2	28,63	31,95
Al_2O_3	0,63	0,63
Fe_2O_3	3,3	3,32
TiO_2	38,34	30,3
CaO	6,23	8,63
MgO	0,24	0,19
Na_2O	0,18	0,96
K_2O	4,37	5,52
P_2O_5	0,04	0,03
MnO	5,34	3,07
SO_3	0,13	0,13
PPI	10,10	12,04
Total	97,53	96,77

TABLE 2 MINERALOGICAL ANALYSIS OF THE COATING

E Electrode	(%)	C Electrode	(%)
Rutile	30	Rutile	25
Carbonate	39	Carbonate	39
Others (miscellanea)	30	Others (miscellanea)	35

TABLE 3 CHEMICAL COMPOSITION OF THE PLATE METAL

Element	C	Si	Mn	P	S
%	0,136	0,01	0,979	0,05	0,001

TABLE 4 CHEMICAL COMPOSITION OF THE ELECTRODE CORE

Sample	C	Mn	Si	S	P
E Electrode	0,09	0,30	0,10	0,03	0,03
C Electrode	0,1	0,32	0,10	0,03	0,03

B. Methods

For the direct experimentation of the covered electrodes electric behaviour, two experimental designs of simple factorial type are planned. In the first factorial design, the welding current factor (regime) has three levels (125, 140 and 160A), while in the second simple factorial design, the composition of the coating is a two-level variable. One original and two replicas in each regime are carried out with each electrode type (in total 18 experiments). The samples were selected from commercial packets, weighted, measured, marked and characterized individually guaranteeing an adequate process of identification of the sample with the obtained results.

For the experimentation by gravity feed device was employed, suppressing the operator influence on the electric signals. The electrical behaviour was studied for about 1 minute during the execution of each covered electrode welding process when the 18 different and independent electrodes were tested and the voltage and current signals were digitized exactly at 5000 samples by second with a professional data acquisition card [36]. More than 10,000,000 of samples were recollected, statistically analyzed and digitally processed with the module of Digital Processing of Signs of Matlab 10.0. The developed C++ code programs for extraction of the parameters of duration and frequency of short circuits and the electrical conductivity of the reignition picks [37], were prepared and proven in the own environment of Matlab and programmed in executable code based on Delphi technology. The statistical processing of the signals was carried out with functions of Matlab and of the specialized in statistical program STATGRAPHICS CENTURION XV15.1.0.2.

Each experimental sample (burned electrode) gave two signals of voltage and current synchronized in time. The information extracted from these electrical signals was very important for the evaluation of the electric behaviour of the process. The occurrence of one short circuit is evident on the signals of the first derived of the Electrical Power and in the own Electrical Power signal obtained from the voltage and current digital processing. With the occurrence of one short circuit ((2) short circuit zone) the electrical power falls down while the first derived is zero. Just at the moment of the reignition pick the first derived rice suddenly (Fig. 1).

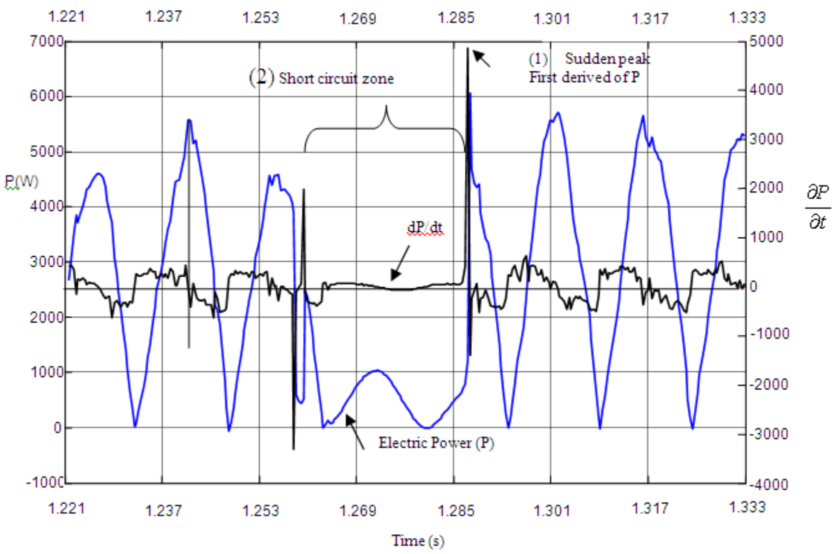

Fig. 1 The digitized first derived of the electrical power and the electrical power during one short circuit occurrence

Other news parameters like the welding circuit resistance, the phase difference between current and voltage, the conductivity of the reignition picks were analysed respect on the traditional indexes based on the frequency and duration of the short circuits. The statistical analysis was based on an analysis "free of distribution" inside and among the groups of the evaluated electrodes. In the parameters: "duration and frequency of short circuits" and "conductivity during the reignition picks", the Kolmogorov-Smirnov's test is used for determining if the empirical distributions come closer to the distributions of well-known models or the normal distribution, in all cases it is demonstrated that the empiric distributions cannot approach to a normal model.

The result of the regime study denotes a high reproducibility and repeatability grade of the results, being determined that the most stable regime is that of 160A in alternate current. For the study of comparison of both groups of electrodes the non-parametric Mood ́s median tests are used for the analysis among groups (Tables 5-7) and that of Kruskal-Wallis ́test for making studies inside the evaluated groups, in each work regime (Tables 8, 9). In the Mood's test if the P-value for the Chi-squared proof is less than 0.05 the medians of the samples are significantly different with a level of confidence of 95 %. Similarly in the Kruskal Wallis test if the P-value is more than or equal to 0.05 it can be assumed that there are no significant differences between the medians of the sampled groups.

Like measure of dispersion the MAD (Median Absolute Deviation) estimator was employed considering the median of the absolute values of the deviation of the data respect on the general median of the data (median (abs(X-median (X)))) and like measure of central tendency the median was considered.

TABLE 5 MOOD'S MEDIAN TEST, GROUPS E AND C (160A) "DURATION OF SHORT CIRCUITS"
N = 1540 MEDIUM GRAND = 24.0, TEST STATISTIC = 5.46365, P-VALUED = 0.361948

Experiment	Muestra	n ≤	n >	M	LI	LS	M(ms)
E1(22)	279	172	107	23.0	22.0	25.0	4.6
E2(23)	259	163	96	22.0	20.0	25.0	4.4
E3(33)	252	148	104	23.5	21.0	26.0	4.7
Average							4.56
C1(22)	243	116	127	25.0	24.0	27.0	5
C2(23)	287	138	149	25.0	23.0	26.616	5
C3(33)	275	143	132	24.0	22.0	26.0	4.8
Average							4.93
Difference (%)							7.50

Note: M is median (units of count and time (ms)); LI and LS are respectively the limits inferior and superior (certainty of 95%).

TABLE 6 MOOD'S MEDIAN TEST, TOTAL SAMPLES N = 1578, MEDIUM GRAND = 52.9, GROUPS C AND E (160A) "FREQUENCY OF SHORT CIRCUITS"

Experiment	Sample	n<=	n>	M (ms)	LI (ms)	LS (ms)	F (Hz)
C1(22)	242	109	133	50.20	45.05	68.35	19.92
C2(23)	286	145	141	51.50	41.00	59.80	19.42
C3(33)	274	138	136	52.00	40.50	66.15	19.23
F-Average							19.52
E1(22)	278	147	131	50.90	33.40	60.20	19.64
E2(23)	258	130	128	52.40	34.40	62.04	19.08
E3(33)	240	120	120	51.70	35.69	65.29	19.34
F-Average							19.36
Difference							< 1 %

Test statistic = 3.38708 P-Value = 0.640539

Note: M is the median; LI and LS: Limit inferior and superior respectively (95%); F is the frequency (1/M)

TABLE 7 MOOD'S MEDIAN TEST GROUPS C AND E (160A) "ELECTRICAL CONDUCTIVITY".
TEST STATISTIC = 38.1215, P-VALUE = 3.567E-7

Experiment	Sample	n<=	n>	M ($S.s^{-1}.10^3$)	LI ($S.s^{-1}.10^3$)	LS ($S.s^{-1}.10^3$)
C1(22)	224	93	131	2220.65	1873.52	2726.41
C2(23)	203	81	122	2079.50	1850.70	2760.79
C3(33)	207	96	111	1883.90	1700.21	2324.35
	Average			2061.35		
E1(22)	237	117	120	1836.70	1646.23	2100.01
E2(23)	233	130	103	1593.60	1500.02	1816.75
E3(33)	256	163	93	1868.20	1664.74	2185.57
	Average			1766.16	**Difference (%)**	14.32

Note: M is the median; LI and LS: Limit inferior and superior respectively (95%).

TABLE 8 KRUSKAL-WALLIS`S TEST, INSIDE GROUPS E AND C (160A) "DURATION OF SHORT CIRCUITS" TEST STATISTIC = 8.095168, P-VALUED = 0.1510690

Experiment	Sample	Average
C1(22)	243	817.93
C2(23)	287	798.064
C3(33)	275	774.798

E1(22)	279	756.495
E2(23)	259	717.388
E3(33)	252	755.5

TABLE 9 KRUSKAL-WALLIS´S TEST AMONG GROUPS OF ELECTRODES C AND E (160A) "ELECTRICAL CONDUCTIVITY"

Experiment	Range	E.Test	P-Value
C1(22)	321.67		
C2(23)	324.62	1.2387	0.5383
C3(33)	306.00		
E1(22)	375.00		
E2(23)	344.17	2.9751	0.2259
E3(33)	370.40		

The estimator of central tendency employed in all the cases is the median and the MAD (Absolute Deviation of the Median) it is valued like dispersion estimator [37] (Tables 10-12).

TABLE 10 MAD FOR THE "DURATION OF SHORT CIRCUITS" GROUPS C AND E (160A)

Experiment	C1(22)	C1(23)	C1(33)	E1(22)	E1(23)	E1(33)
MAD(ms)	1.4	1.8	1.6	1.4	1.4	1.6
Average	1.6			1.46		
Difference (%)	8.33					

TABLE 11 MAD OF THE "PERIOD OF SHORT CIRCUITS" GROUPS C AND E (160A)

Experiment	C1(22)	C2(23)	C3(33)	E1(22)	E2(23)	E3(33)
MAD(ms)	48.40	42.00	43.00	38.10	43.20	39.70
Average	44.46			40.33		
Difference (%)	9.29 %					

TABLE 12 MAD OF THE "ELECTRICAL CONDUCTIVITY" ELECTRODES C AND E (160A)

Experiment	C1(22)	C2(23)	C3(33)	E1(22)	E2(23)	E3(33)
MAD(U)	1022.75	979.50	812.40	683.50	515	739.20
Average	938.22			645.90		
Difference (%)	31.16 %					

Note: $U= S.s^{-1}.10^{3}$

The behaviour of the traditional parameters, denotes bigger uncertainty in the processes of transfer of electric charge and of metal in the C group of electrodes, however, these parameters do not allow the realization of a complete evaluation of the destabilization events; being necessary to analyse the behaviour of new parameters like: power, current and resistance of the welding circuit, difference of voltage-current phase and the derived of the power regarding the time.

The empiric distributions of these parameters present an evident abnormality, for this reason they were processed by means of non-parametric methods. The median was used as central tendency estimator, and the Range Interquartile (IQR) and the MAD for evaluating the dispersion grade. From this new analysis a coherent result respect the traditional method was obtained, being verified that the group of electrodes type C was manifested in a more unstable way electrically speaking.

III. METHODOLOGY

The methodology of electrical evaluation (Fig. 2) is based on the employment of an experimental installation (1) able to weld using a by gravity feed device and digitizing the welding voltage and current signals, produced by carefully selected homologous electrodes (2) according the experimental plan (3). The electric signals are submitted to a detection, processing and evaluation process, by means of a parametric-comparative study regarding the reference electrode (4) that allows to evaluate the processes of electric charge transference during the reignition picks (5) and the metal transfer process in short circuit mode (6).

A novel index of general electric stability (7) constitutes a more complete measure of stability accounting all of the metallic transfer modes, and types of picks taken place in the arc periods and to the entrance and the exit of the short circuits.

The relative unstability of the process is expressed (Eq. 1) in terms of three fundamental components.

$$Dt(\%) \approx \frac{k1 \cdot D_{Tcc}(\%) + k2 \cdot D_{reign}(\%) + k3 \cdot D_{Arc}(\%)}{3} \quad (1)$$

Where $k1$, $k2$ and $k3$ are constants for calibration, representative of the contribution of each parameter to the process general stability; Dt (%) is the relative perceptual difference of the total dispersion of the process; D_{Tcc} (%) is the relative perceptual difference of the dispersion of the metallic transfer in short circuit mode; D_{reign} (%) is the relative perceptual difference of dispersion relative to the conductivity during the arc reignition; D_{Arc} (%) is the relative perceptual difference of the dispersion, product of the electric charge and metallic transfer.

The perceptual differential dispersion of the transfer in short circuit mode (Eq. 2) is in function of the unstability in the duration of the short circuit (*dmTc*) and of the unstability of the short circuit frequency (*dmFc*).

$$D_{Tcc}(\%) = \frac{dmTc(\%) + dmFc(\%)}{2} \tag{2}$$

This constitutes a new index of stability of the metallic transfer for short circuit mode that constitutes part of the scientific novelty of the work (Fig. 3).

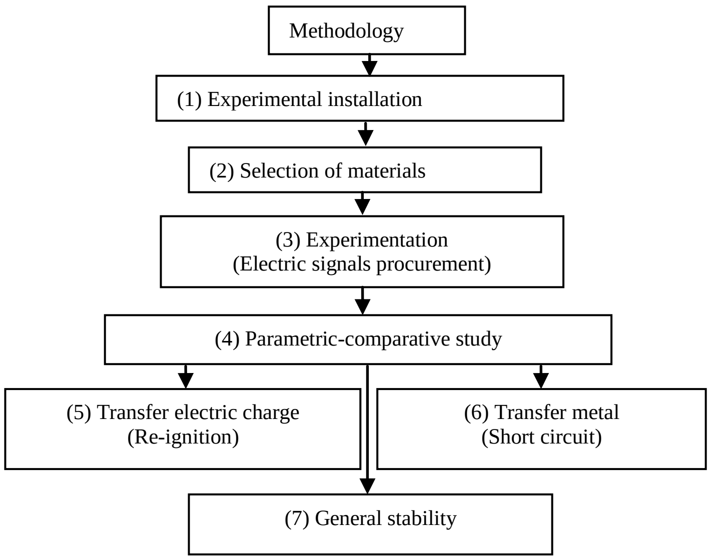

Fig. 2 General scheme of the methodology

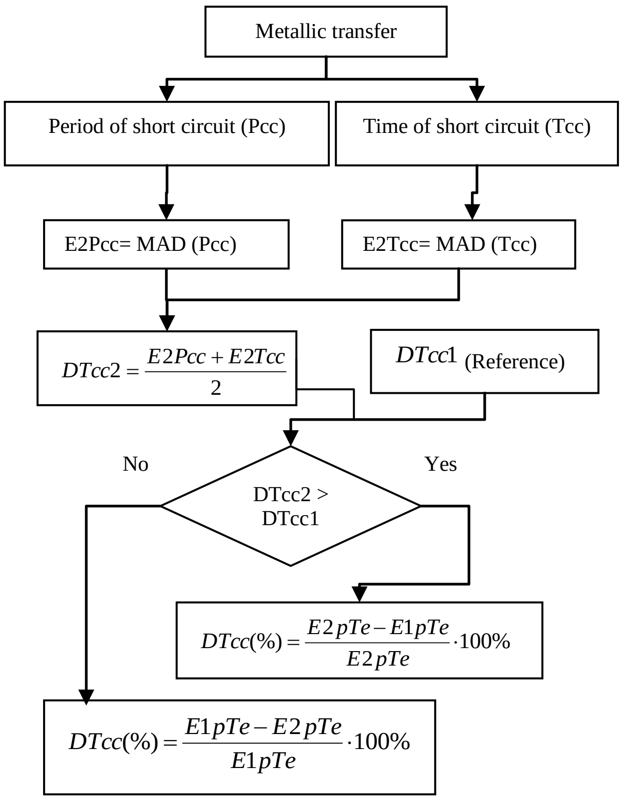

Fig. 3 Perceptual differential dispersion of the transfer in short circuit mode

The specific dispersion of the conductivity during the reignition (Eq. 3) of a certain electrode is calculated:

$$BE = \frac{mB}{mB_{all}} \cdot \quad (3)$$

Where *BE*, is the index of specific variation of the conductivity during all reignition picks; *mB*, is the MAD of the conductivity during the severe picks of reignition; mB_{all}, is the MAD of the conductivity in all the picks including the severe ones.

Keeping in mind the Eq. 3 is defined D_{reign} (Fig. 3), according to Eq.4

$$D_{reign}(\%) = dBE \cdot \quad (4)$$

Where *dBE* is the relative perceptual difference of the *BE* parameter between both groups. This constitutes a novel index result of the application of a new physical conception of the stability in the electric charge transfer that overcomes the previous indexes (Fig. 4).

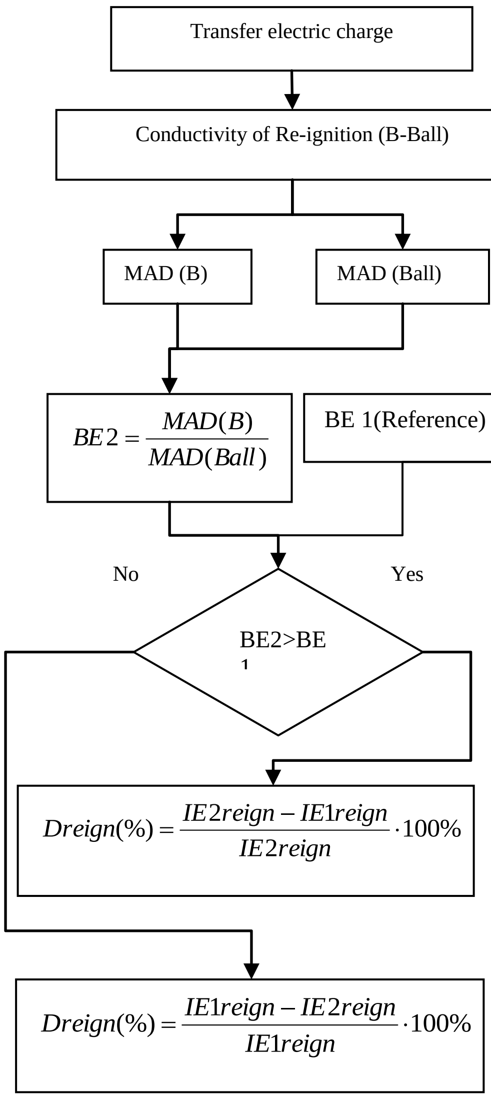

Fig. 4 Perceptual differential dispersion of the specific variation of the conductivity during the arc reignition

The general electric stability of the process is expressed according to the relative perceptual difference of the total dispersion of the process (Eq. 5).

$$Dt(\%) = \left(\frac{dmR + dmV + dF + ddP/dt + dmP}{5} \right) \quad (5)$$

Where *dmR* is the perceptual relative difference of MAD of the arc resistance; *dmV* is the perceptual relative difference of MAD of the welding voltage; *dF* is the perceptual relative difference of the welding voltage-current phase; *ddP/dt* is the perceptual relative difference of the second derived of the welding electrical power and *dmP* is the perceptual relative difference of MAD of the welding electrical power.

This index accounts for the unstabilization events occurred in any mode of metallic transfer and during the arc reignition period. It uses five new parameters of proved physical relationship permitting to corroborate among them the validity of the results (Fig. 5).

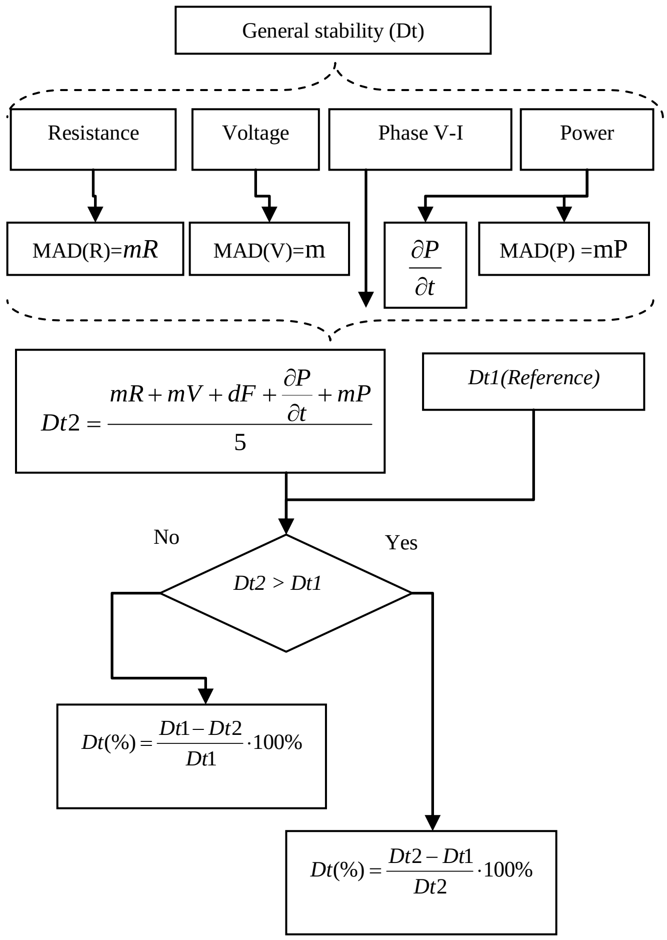

Fig. 5 Scheme of determination of the perceptual index of general stability

The Table 13 shows the value of the calculated index for case of the evaluated groups of electrodes:

TABLE 13 CHARACTERIZATION OF THE ELECTRIC BEHAVIOUR

D_{Tcc}(%)	D_{Reenc}(%)	Dt(%)
8.8^{C}	39.20^{C}	6.84^{C}

Note: The super index C indicates that the difference is on favor of the C group of electrodes

The result of the application of this methodology indicates that the group of the C type electrodes is more unstable than the E group.

IV. VALIDATION

In the present investigation, by means of the control of variables and the employment of a feed by gravity device, it has been made to depend on the electric stability of the process, of the chemical and physical properties of the evaluated consumables. The electric stability, reflect of the general stability of the welding process, it is strongly conditioned to the nature of the component substances of the coating, necessary for the plasma establishment, sustaining the high temperatures of the arc and transporting part of the energy necessary for the fusion of the metals to joint, impacting the form of the welding deposit and the quality of the welded union.

A. Chemical Composition of the Coating

The enthalpy of the gas in the exothermic reaction will be higher or majors in mixtures with more concentration of elements of high potential of ionization and less in mixtures with less concentration of elements of high potential of ionization, being necessary the established an agreement guaranteeing an appropriate process of ignition and maintenance of the arc and a high efficiency in the transport of heat [31]. Knowing that the temperature in an iron arc in the air is approximately 6000 K [38], and that the grade of ionization of the substances varies in function of the temperature (Fig. 6), it is possible to calculate the consumed energy for the ionization of the mixtures components of the E and C coatings for unit of time to determinate temperature.

Results of chemical analysis express the percentage of the component oxides of the coating in a quantity of 100 g. Calculating the quantity of coating consumed per second, and multiplying it for the fraction of each oxide and for the gravimetric constant of the element regarding their oxide, the weight of the atoms of the present element can be obtained in that quantity. Considering the weight of 1 mol of the element, whose quantity is wanted to determine inside the oxide, is possible to obtain the molar fraction that allows to determine, knowing the relationship of 1 mol with the number of Avogadro, the quantity of electrons and ions that can be formed when taking place the complete ionization of the element that multiplied by the ionization grade of each element it constitutes the quantity of ionized electrons that really contributes each element to a certain temperature, in this case 6000 K.

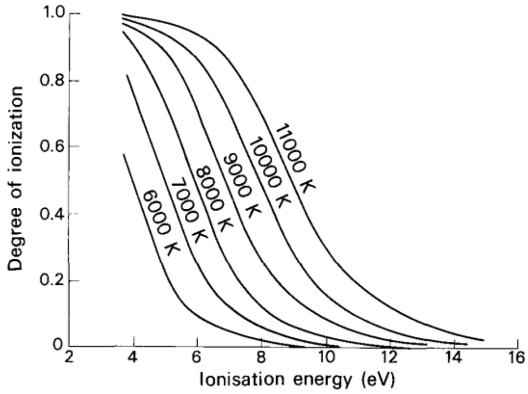

Fig. 6 Ionization grade like function of the ionization energy for different temperatures
Taken of the book "The Physics of Welding". Lancaster JF. Page 139

The invested energy by unit of time in the ionization of the coating of the E type electrodes, according to the carried out calculations, was 149, 64 J, while the energy invested in the ionization of the C coating was 149, 86 J. As it can be appreciated, there exists no practically difference in the consumed energy by both mixtures in your initial ionization. The general enthalpy of ionization of the gas does not justify energetic differences between both processes. However, the energy absorbed for ionizing by the atoms of Calcium, Sodium and Potassium in the E coating was just 39.98 J, while the same energy in the same elements in the C coating was 56,50 J, taking account the concentrations of its atoms and the ionization grades to the temperature of 6000 K.

The consumed energy for ionizing of these elements of low potential of ionization in the C group was bigger (29%), evidencing a bigger difficulty in the ignition of the arc. The intense heat of the arc melt the tip of the electrode while the coating, less thermal and electrically conductive and more far from the source of heat, goes forming a cup modelled by the isothermal distribution of the arc, where the electrode is backing when it is fed by gravity. The depth of the cup has an effect in the energy consumption and the electric stability, constituting an important property of the consumable.

The arc longitude is on function of the depth of the cup and of the penetration of the melted metal in the deposit. The penetration is bigger in the deposits obtained with C type of electrodes. The fusion temperature distribution, in function of the concentration of the CaO-SiO_2-TiO_2 system, it has been studied [39]. This diagram of state of three components shows a study of the different phases formed starting from mixtures of different concentrations of the elements studied to different temperatures. Considering that the coating is compounded alone by CaO, SiO_2 and TiO_2, starting from the compositions of the mixtures of the coating, a possible cristobalite phase is identified for the C coating at 1550^0C, of concentration CaO = 12.8%, SiO_2 = 45.07% and TiO_2 = 42.75% and, another phase of rutile of concentration CaO = 8.50%, SiO_2 = 39.16% and TiO_2 = 52.34% at 1600^0C for the E coating. Because the point of fusion of the C type mixture is smaller than that of the E, the smallest longitude in the cup in C is justified, requiring less energy to melt under similar energy conditions.

B. Properties of the Deposit

For the comparison in the 160A regime a total of 6 deposits of welding in metal plates with alternating current were carried out. The deposits were meticulously studied. The metallographic analysis was based on the measurement of the distance among solidification fronts, wide and reinforcement height, the penetration and the affected by heat zone, using an optical microscope. The statistical processing of the results of the measurement threw bigger stability in the case of the deposits obtained with E type electrodes (Tables 14-16), that which coincides with the obtained results of the electrical characterization.

TABLE 14 LONGITUDE AMONG SOLIDIFICATION FRONTS AVERAGE (E AND C)

Experiment	Average Mean (mm)	Standard Deviation (mm)
E1(22)	0.40122	0.135779

E2(23)	0.36375	0.105604
E3(33)	0.35125	0.128346
Average	0.37	0.123243
C1(22)	0.382927	0.168114
C2(23)	0.41375	0.146755
C3(33)	0.363415	0.141432
Average	0.39	0.1521
Difference	0.02	0.029
%	5.13	18.97

TABLE 15 WIDE OF THE DEPOSIT AND THE HEIGHT OF REINFORCEMENT (E AND C)

Experiment	Wide (mm)	D-Std (mm)	Reinforcement (mm)	D-Std (mm)
E1(22)	10.505	0.362	2.94	0.161
E2(23)	10.87	0.355	3.03	0.160
E3(33)	10.335	0.329	3.04	0.107
Average	10.57	0.349	3.003	0.142
C1(22)	10.165	0.504	3.19	0.172
C2(23)	10.145	0.257	3.165	0.135
C3(33)	10.465	0.442	3.025	0.188
Average	10.258	0.401	3.126	0.165
Difference	0.31	0.05	0.12	0.012
%	2.95	13.03	3.94	13.204

Note: D-Std is the standard deviation

TABLE 16 PENETRATION AND AFFECTED FOR THE HEAT ZONE (AHS). (E AND C) ELECTRODES

Groups	AHZ(mm)	D-Std (mm)	Penetración(mm)	D-Std (mm)
E1(22)	3.585657371	0.165	1.235059761	0.115
E2(23)	3.884462151	0.19	0.996015936	0.127
E3(33)	3.556514511	0.185	1.115537849	0.116
Average	3.67	0.18	1.12	0.12
C1(22)	3.685258964	0.191	1.513944223	0.122
C2(23)	4.083665339	0.193	1.235059761	0.119
C3(33)	3.784860558	0.189	1.494023904	0.13
Average	3.85	0.191	1.41	0.1236
Difference (%)	4.67	5.76	20.56	7.69

Note: D-Std is the standard deviation

The analysis of non-metallic inclusions in the deposited metal reports the existence of inclusions of "globular oxides" type, Series 1, Type D (ASTM E 45-51), in low quantity in both types of electrode deposits. The obtained structure in the deposit of welding for both groups of electrodes is typical of the deposits with electrodes E6013. This result suggests that the maximum temperature and the cooling speed do not differ considerably [40]. The chemical composition of the deposits is similar: 0.1% of carbon and 0.15% of silicon; confirming that differences in the composition of the coating of homologous electrodes do not have significant influence in the properties of the deposits. Consistently the hardness average determined with a load of 10 kg during 10 s is 143 HV in the E group and 145 HV in the C group, in agreement with that specified by the norms [41] for this type of electrodes.

In the E group, the slag was removed practically without the use of pickaxe, delaying about 10 s to clean totally the welding deposit; however, in the deposit of the C group the average time employee for removing the slag oscillates around 60 s with the employment of the pickaxe.

The compound with more probabilities of being formed in the slag presents a high cristobalite content when C type electrodes are used, this species of volcanic stone is in black colour and it adheres strongly to the metal of the welding deposit, which evidences the formation of spinel probability from the compound Fe_3O_4. The spinel is a very strong structure coupled to the metal of the deposit by structural compatibility.

C. Consumption Parameters

The behaviour of the consumption parameters (Table 17) indicates that the C group presents bigger values in the indexes: αf, Fusion coefficient; αd, Deposit coefficient; P, Productivity of the process; Ed, Efficiency of the deposit; Et - total

Efficiency of the electrode. However, C type electrodes are slightly bigger than the coefficient of losses (ψ) that quantifies the metal losses that take place during the welding because of evaporation, losses in slag and losses for splashes, while the index E (Deposit Efficiency, referred to as the nucleus of the electrode) expresses the relationship between the mass of deposited metal and the fused net mass, it is inferior in the C type electrodes, which is characteristic of the manifest unstability in the form parameters (Tables 14-16), evidencing a bigger quantity of losses for evaporation and splashes, product of a bigger unstability of the process with C type electrodes [42].

TABLE 17 RESULTS OF THE CALCULATION OF THE CONSUMPTION PARAMETERS FOR E AND C GROUPS (160A)

Index	αf **(g/A-h)**	αd **(g/A-h)**	***P*** **(Kg/h)**	ψ **(%)**
E	9.825658385	8.721223915	1.418119266	11.24031008
C	10.10463335	8.952013574	1.465579499	11.40684411
Difference	0.278974963	0.230789659	0.047460233	0.166534029
%	2.760861809	2.578075393	3.238325393	1.481578602
Index	***E (%)***	***ED (%)***	***Et (%)***	
E	88.75968992	64.93383743	51.15413254	
C	88.59315589	66.76217765	53.3180778	
Difference	0.166534029	1.828340221	2.163945264	
%	0.187976179	2.738586855	4.058558285	

Where: αf (Fusion coefficient), αd (Deposit Coefficient), P - (Productivity of the process), ψ - (Coefficient of losses), E - (Deposit efficiency referred to the nucleus of the electrode), Ed-(Efficiency of the deposit), Et - (Total Efficiency of the electrode).

D. Analysis of Results

The fact that starting from analytic calculations the chemical composition of the coating can be esteemed the difference of energy in the phenomena implied in the ionization and ignition of the arc; and this calculation evidences that the C type electrodes need more energy during the process of arc ignition, is related to the fact that its electric behaviour is more unstable than in the case of the E type electrodes. In a similar way, the analysis of the properties of the deposit throws that exists bigger stability in all the parameters obtained in the deposits with E type electrodes.

The grades of hardness, sanity and chemical composition of the metallic deposit are practically equal as establishing the accepted classification norms. The chemical and mechanical properties of the deposit stay in the established ranges for electrodes of the same classification.

Differences were reported in the productivity of the electrodes and the cost of the coating of both groups of electrodes, due to the difference of 5% in the content of titanium of both mixtures, which constitute important data for the selection and the design of new electrodes to weld.

V. CONCLUSIONS

The developed and evaluated experimental installation allows obtaining a stable process of welding, in exclusive function of the physical-chemical characteristics of the evaluated consumables, reaching an appropriate grade of repeatability and reproducibility of the results of the electric characterization, of the indexes of consumption of the electrodes and of the analysis of deposits form parameters and metallurgical considerations.

The proposed methodology allows to detect events of unstabilization in anyone in the well-known transfer ways, in the periods of arc and short circuit, as well as during the reignition picks; and to evaluate the grade of general electric stability of covered electrodes feed by gravity, proposing a novel index that combines 5 parameters before not referred to as approach of stability, a new index for the stability of the metallic transference and another new index to evaluate the stability in the electric charge transference during the reignition of the arc.

The approaches obtained by means of metallographic technical, of visual inspection and of determination of the consumption indexes, allow to validate the developed methodology for the evaluation of the electric behaviour, overcoming the previous methodologies and allowing their application for the valuation of the electric behaviour in all types of covered electrodes and welding processes, such as SAW, GMAW and GTAW.

It is endowed to the scientific community of an alternative methodology for the evaluation of the electric behaviour of covered electrodes to weld that allows the selection, inside groups of homologous electrodes, of the electrode of better operative electric behaviour

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