Impermeable Covered Electrodes - The Next Generation of EXX18 electrodes

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Abstract

This paper evaluates the weld metal microstructure and properties of low hydrogen covered electrodes where the usual binders (potassium and sodium silicates) were replaced by polymers. This new electrode has a moisture resistant coating. The new technology promotes gains on the production and use. Production cost reduction is obtained by drying elimination. Elimination of special storage conditions, re-drying, storage in holding oven and electrically-heated quivers before use are possible with it. The impermeable covered electrode was produced using the E7018 formula. Preliminary tests with different polymers and formulation changes were realized to meet the satisfactory weldability. The best covered electrode at the first stage was evaluated at the second stage. Weld metal diffusible hydrogen, microstructure and mechanical properties were evaluated and compared with traditional low hydrogen covered electrodes. The impermeable covered electrode diffusible hydrogen content was less than 4ml/100g of weld metal. This is very low if compared to conventional low hydrogen covered electrodes. Additional hydrogen tests were made after covered electrode moisture exposure under several conditions and confirm the coating resistance. The impermeable covered electrode weld metal showed the same morphology and typical microstructure of weld metal produced by the E7018 low hydrogen covered electrode. However, the acicular ferrite volume was significantly higher when compared with E7018 covered electrode. Weld metal tensile and yield strength, elongation and toughness (Charpy V notch test) overcome the E7018 low hydrogen covered electrodes properties. The slag analysis showed the strongly polymer influence.

Key words: Covered electrodes, polymers, hydrogen, acicular ferrite.

1 INTRODUCTION

In 1904, Oscar Kjellberg (Figure 1) invented the coated stick electrode in his search for a practical method for repairing leaks in ships' steam boilers. The joining is obtained by electrical arc established between consumable covered electrode and work piece.

Figure 1 - Picture of Mr. Oscar Kjellberg the covered electrode inventor [1]

Since the beginning the coating was fixed on the wire using silicates as a binder. There is no information available of what formulation was the first, but for sure the way the coating was fixed was by immersion. Figure 2 shows two ladies works in coating several electrodes.

Figure 2 - Ladies coating the electrodes by immersion [1]

In a working description, which Oscar Kjellberg wrote around the same time as he received his first patent, there are very detailed instructions on how to hold the electrode in the left hand in order to be able to hold the hammer in the right hand. These instructions titled "Working method for electrical welding, including material and how it is handled", dated 1 October 1904, are preserved in the original. The 8-pages of instructions are handwritten; there is not one spelling mistake, not one correction – typical of his methodical approach and attention to detail.

One of Kjellberg´s strengths was his own practical experience of the problems with which a chief engineer on a steamship had to grapple. Marine boilers were riveted and, without exception, they began to leak after a time. This was a serious problem, as pressure could not be maintained, which resulted in reduced power from the engine. Therefore, leaks had to be sealed as quickly as possible. Normal practice was to force a wedgeshaped nail, followed by flax and hemp, into the leaking joint. This was a very difficult task under the worst conditions imaginable. The boiler had to be cooled down so that workers could endure working on it. Also leaks would sometimes occur on the underside of the boiler, making access difficult.

The big breakthrough came with the invention that was granted a patent on 29 June 1907. The patent is called "Procedure for electric welding including the electrode intended for this purpose." Its revolutionary property was that Kjellberg had coated the welding electrode with non-conductive material, which gave many advantages. Firstly, the coating generated a protective gas (CO_2) when it melted. This gas prevented the formation of iron oxides in the hot melt and it became possible to weld longer pieces, up to a whole electrode length, without needing to interrupt the welding. Welding could therefore be more continuous. Moreover the patent described how to build up a weld with several beads. Secondly, Oscar Kjellberg sought a solution to the problems associated with difficult welding positions, particularly overhead welding. When he formulated a 'recipe' for the coating that melted at exactly the same rate as the welding metal rod, he found that a crater was formed at the tip of the weld electrode. This crater directed the flow of molten metal and after many experiments with different coating compositions he was able to find one that enabled overhead welding.

Even as a lower productivity welding process, compared to others welding process, covered electrode welding or SMAW still remains as an interesting alternative in manufacturing operations and maintenance. This fact is associated mainly to its versatility. The electrodes can be classified according to the materials used in coating, as: rutile, cellulosic, basic or oxidizing agents. In welds where it is necessary to ensure high levels of health of the weld metal, ie, high "responsibility", it is recommended the use of electrodes type basic. Its use provides to obtain welds characterized by different mechanical properties and low diffusible hydrogen levels (around 8ml/100g weld metal). However, the hygroscopic nature of some components of the coating (limestone and fluorite), requires the adoption of special care before using it in order to avoid incorporation of hydrogen into the weld metal. These precautions include storage under controlled conditions, drying and maintenance in greenhouses [2].

Recent studies by Ivan et al. [3] indicated the technical feasibility of using in wet underwater welding, rutile electrodes where the traditional binder was replaced by "polymers". Using this new technology allowed the production of electrodes with water-resistant coating. The electrodes were tested and the results were fantastic. Acicular ferrite was observed in all welds produced with this new technology. Figure 3 and 4 show a mosaic of microestructures of a weld produced with one of the electrodes tested. Another interesting finding was the reduction or total elimination of drying during manufacture of these electrodes (shown in Figure 4) that also allowed a reduction in production cost.

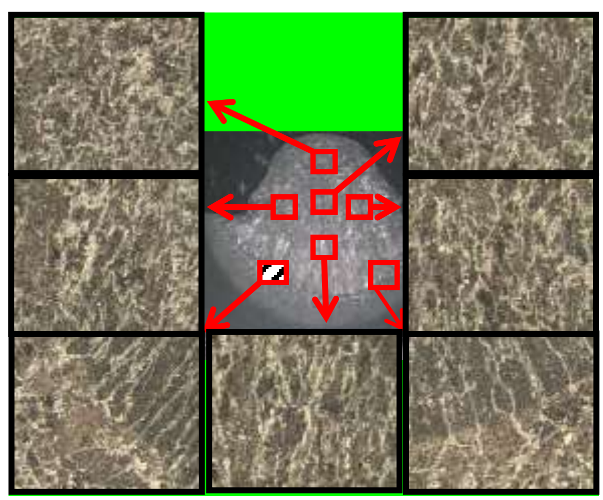


Figure 3 - Mosaic of underwater wet weld produced with an experimental E6013 electrode using polymer as binder. Depth: 0,5mm, polarity: DCEN; Electrode welding angle: 70°; welding current: 150 A; Chemical attach: Nital 2%; 100X.

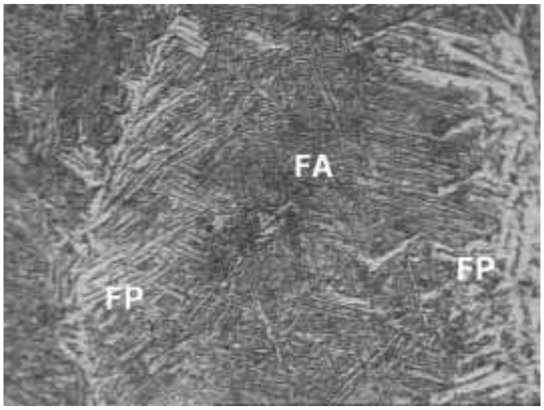


Figure 4 - Detail of the diagonal pattern region on Figure 3. Despite the Primary Ferrite (PF), common in this type of weld metal, it is possible to observe the presence of a large amount of Acicular Ferrite.

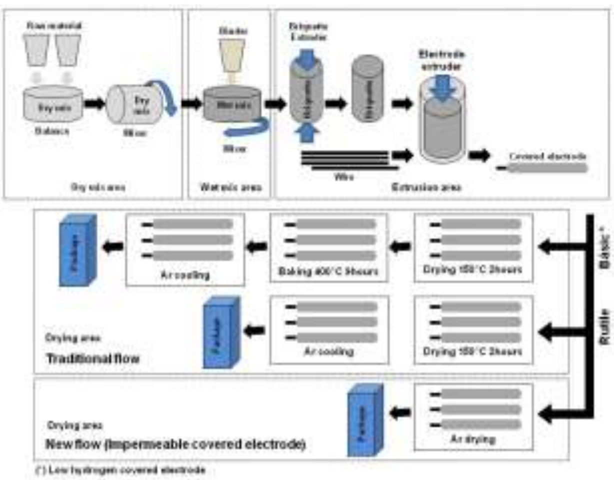


Figure 5 - Traditional and impermeable covered electrodes production flow chart

The satisfactory results obtained underwater motivated the development of impermeable basic electrodes for conventional welding. In this application, to eliminate a major source of hydrogen, it is necessary to ensure that the coating of the electrodes has low moisture content [4].

Vaz et al [5] developed in laboratory scale (Figure 6), a waterproof low hydrogen coated electrode. As a starting point, the formula of the conventional class SMAW E7018 was adopted. Adjustments were made in the formula in order to obtain a consumable with minimum operational characteristics necessary for its application. The preliminary metallographic analysis of the weld metal microstructure showed usual morphology and constituents. However, a higher volume fraction of acicular ferrite that usually is observed in the weld metal deposited by E7018 class electrodes was also observed.

The aim of this work was to evaluate the weld metal deposited by the coated electrode with better performance formulation in the study of Vaz et al [5]. The weld metal produced was subjected to chemical and metallographic analysis, diffusible hydrogen test, tensile test (to determine yield strength, ultimate strength and elongation) and impact toughness (Charpy - V notch test). Additionally, fumes produced during welding were analyzed using ion chromatography and slag produced was analyzed by x-ray diffraction.

(a)

(b)

Figure 6 – (a) Laboratory device to produce very small amount of experimental electrode, (b) Exeprimental electrodes produced in laboratory

2 EXPERIMENTAL PROCEDURE

To evaluate the structure and properties of the weld metal, impermeable coated electrodes using the formulation of better performance in the study of Vaz et al [4] were produced on an industrial scale. The weld metal deposition, to determine the chemical composition, was performed as proposed by the AWS A5.1 specification [1]. The analysis of the content of chemical elements was performed by optical emission spectrometry.

For the metallographic analysis, transverse sections, at the center of the welds, were performed and samples were taken. These were sanded, polished, attacked with Nital 2%, and observed in an optical microscope and photographed with magnification up to 1000 times. Quantitative metallography was performed in order to determine the percentage of acicular ferrite in weld metal deposited in accordance with the methodology proposed by IIW Doc IX-1533-88 [5]. The hardness of the weld metal was done using the Vickers method with a load of 100g.

Test plates for removal of specimens for tensile and impact test of the weld metal were welded as proposed by the AWS A5.1 specification [2] (Figure 7).

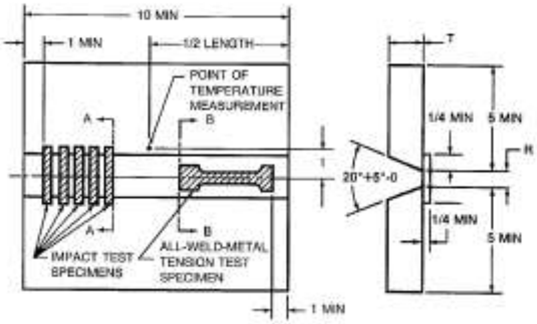


Figure 7. Plate for removal of specimens for tensile and impact test of the weld metal. (dimensions in inches). [2]

The content of diffusible hydrogen in weld metal was determined by gas chromatography according to AWS A4.3 [7]. Tests were performed with electrodes obtained right after production and after exposure to the atmosphere for a period of 30 days. Since the relative humidity was not monitored during the exposure period, the hydrogen in weld metal deposited by electrodes E7018 was determined immediately after the drying operation, as recommended by the manufacturer, and after 30 days of exposure under the same weather conditions of the impermeable electrode.

The slag obtained in the welding with the impermeable and conventional electrodes were collected, milled and subsequently analyzed by x-ray diffraction. To allow identification of likely compounds and the evaluation of the formulation of the electrodes was performed semiquantitative analysis of the slag by EDS.

3 RESULTS

Table 1 shows the results of chemical analysis of weld metal deposited by the impermeable electrode. Also presented are values specified for the class E7018 electrodes, established by standards

Table 1. Impermeable covered electrode weld metal chemical composition.

Chemical element	Impermeable electrode	E7018 class specification*
C	0,16	0,15
Si	0,67	0,75
Mn	1,29	1,6
P	0,03	0,035
S	0,01	0,035
Cr	0,03	0,2
Ni	0,01	0,3
Mo	0,01	0,3
V	0,01	0,08
Cr+V+Ni+Mo	1,35	1,75

* Maximum values.

Figure 8 shows the visual appearance of the weld deposited with the impermeable electrode and the conventional electrode base class E7018. Both welds were produced by the same welder in the same conditions for both types of welding electrodes.

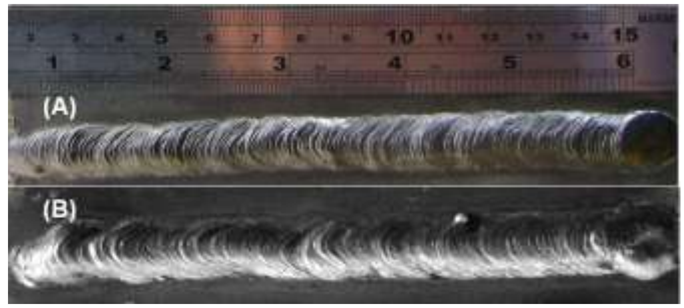


Figure 8. Visual appearance of the bead on plate weld deposited with impermeable electrode (A) and conventional E7018 electrode (B).

Figure 9 shows the Macrography cross section of a bead on plate deposited with the impermeable electrode. In this figure the areas where microstructural analysis was performed are indicated. In Figure 10 are presented, with magnification of 100, 200, 500 and 1000 times the corresponding microstructures.

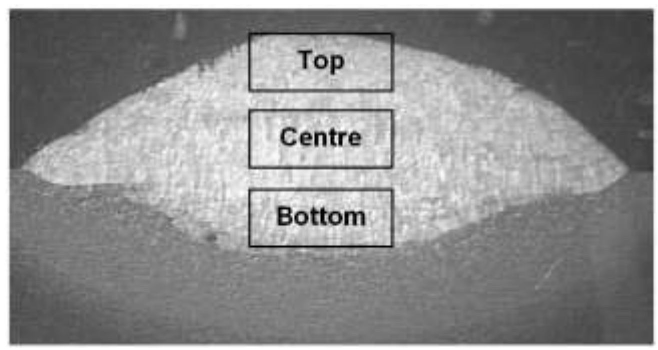


Figure 9 - Macrography of the weld metal

The volume fraction of acicular ferrite in different regions of weld metal is shown in Figure 11 and Table 2 presents the measurements of Vickers hardness (HV100) of that constituent.

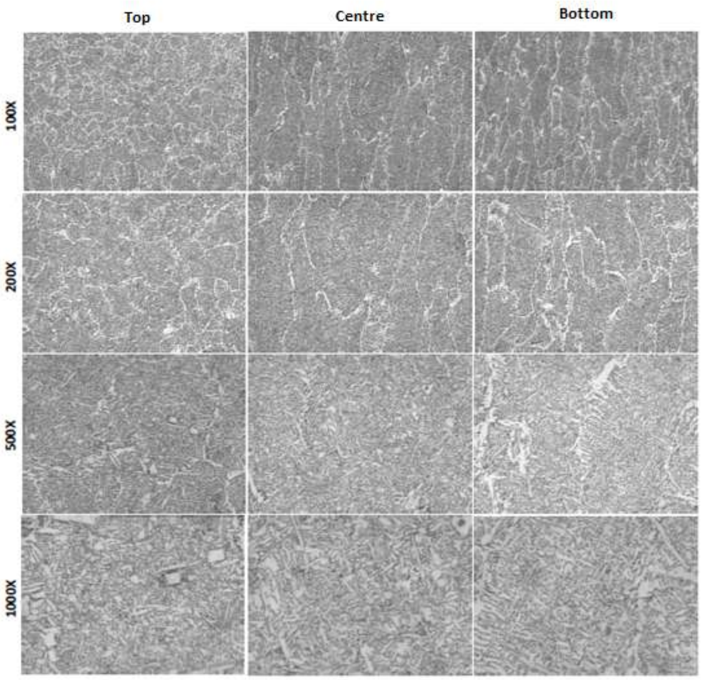


Figure 10 - Microstructure of the weld metal deposited with the impermeable electrode. Magnifications: 100, 200, 500 e 1000x.

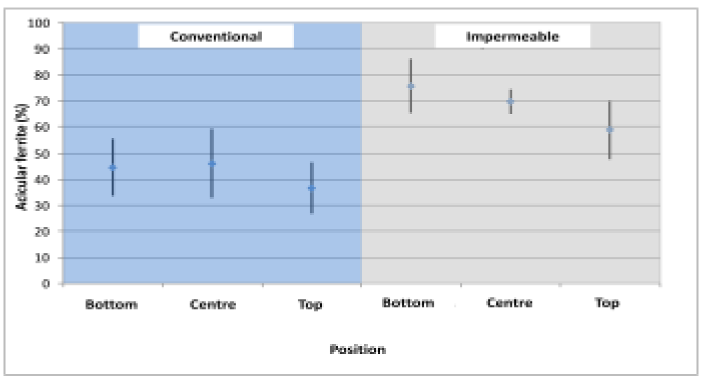


Figure 11 - Acicular ferrite content (Impermeable and conventional covered electrodes).

Tabela 2. Acicular ferrite hardness (HV100)

1	2	3	4	5	6	7	8	9	10	11	12	Average
274	269	261	255	251	285	274	275	27				

Table 3 presents the results of mechanical properties of weld metal deposited with the impermeable electrode (yield strength, tensile strength, elongation, area reduction and impact toughness). The fractured surfaces of specimens of Charpy tested at -29°C and -45°C are shown in Figure 12.

Tabela 3. Weld metal mechanical properties (yield strength, tensile strength, elongation and impact toughness (Charpy-V notch).

Tension test				
Tensile strength	678 Mpa			
Yield strength	554 Mpa			
Elongation	29 %			
Area reuction	67 %			
Impact toughness (Charpy – V notch)				
(-30°C)	56	62	74	64*
(-45°C)	30	48	52	43*

(*) Average

Figure 12. Impact fractured surfaced (Charpy – V notch).

Figure 13 presents the values of diffusible hydrogen in weld metal of conventional and impermeable electrodes just after manufacture and after thirty days of exposure to the atmosphere under the same conditions of temperature and relative humidity.

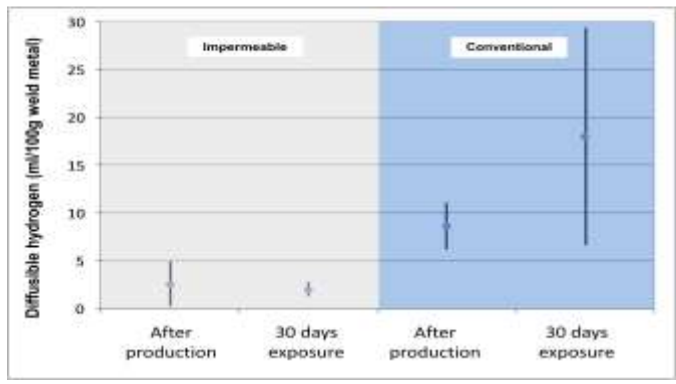
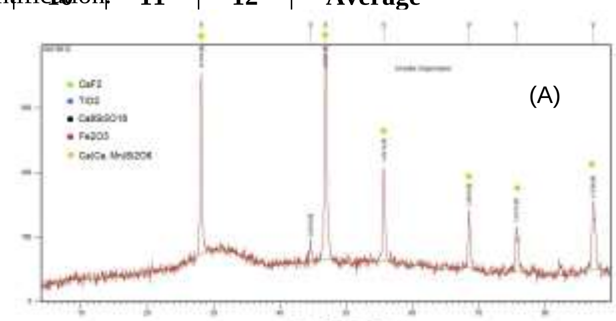


Figure 13. Weld metal diffusible hydrogen (impermeable and conventional covered electrodes).

Figure 14 shows the XRD patterns obtained from the analysis of slag and conventional impermeable electrode. The identification of the probable components present in the slag was carried out by comparison with cards available at the ICDD database. The survey of raw materials present in the coating of the electrodes, the chemical analysis of the weld metal and chemical analysis of slag by EDS were used in this identification.



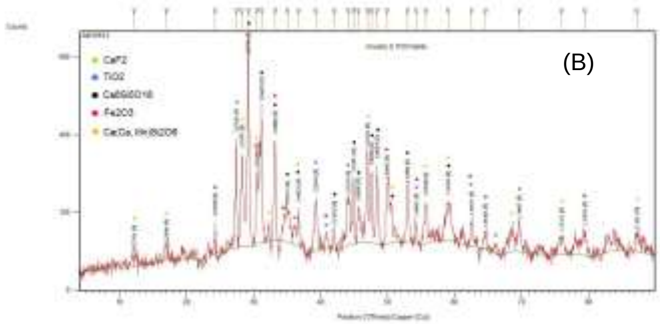


Figure 14 - diffraction patterns of the slag obtained in the welding with impermeable (A) and conventional (B) class E7018 electrodes.

FUMES

4 DISCUSSION

It can be observed by analyzing the results presented in Table 1 that the chemical composition of weld metal deposited with electrodes are inside the limits specified for Class E7018 electrode.

Analyzing Figure 3 it can be seen that the visual appearance of the weld deposited by the impermeable electrode is similar to the conventional E7018 class electrode. However, during welding, it was observed that the opening and maintenance of the arc with impermeable electrodes were easier for the welder when compared with the convectional electrode. This is probably due the plastic characteristic of the coating at the tip that allows the tip of the wire touch the piece without breaking, burning and easily ionizing.

It has been very well reported that the microstructure of a weld bead deposited by electrodes coated basic type E7018 is mainly composed by: acicular ferrite – AF, grain boundary ferrite PF(G) and second phase aligned ferrite - FS(A) [7]. The analysis of Figure 6 shows that the volume fraction of acicular ferrite in weld metal deposited by the impermeable electrode is superior to equivalent regions of the weld metal deposited with conventional compared to the conventional electrode E7018. As a main result, one can observe a reduction in volume fraction of the remaining constituents in the weld metal deposited by the impermeable electrode The presence of acicular ferrite in welds is always desirable, since this phase is associated with increased toughness. Vickers hardness measurements carried out in regions where the weld metal was observed the occurrence of acicular ferrite indicated consistent with those obtained by Babu [7].
The yield strength and resistance of the weld metal deposited with the impermeable electrode are well above the specified minimum for class E70XX electrodes (400 MPa and 490 MPa, respectively). However, there was noticeable reduction in elongation. Evaluating the chemical composition of the weld metal could associate the temperature with silicon content of weld metal. The average energy absorbed in impact tests at-30^{o}C was 64J and 43J was -45^{o}C. These results are significantly better than the expected for a weld metal produced by conventional E7018 electrodes.

It is observed that the levels of diffusible hydrogen found in the weld metal produced with impermeable electrode in both tests, immediately after manufacture and after 30 days of exposure to the atmosphere, are similar and much lower than those found in the weld metal produced with conventional E7018 electrodes, especially after exposure to the environment. The values obtained for the impermeable electrodes in both conditions (below 4ml/100g weld metal) are considered exceptionally low compared to the classic basic electrodes (generally below 8ml/100g weld metal). It must be also emphasized that these low results of diffusible hydrogen were obtaine with impermeable electrodes that do not require drying ovens and maintenance in those greenhouses before its application.

The analysis of the diffraction patterns in Figure 9, showed the presence of some amount of amorphous compounds in both slags. The XRD pattern of slag of conventional electrode showed a typical morphology of conventional slag, ie, large amount of peaks indicating the presence of many crystalline compounds. On the other hand, the XRD pattern of slag of the impermeable electrode showed an unsual morphology. The few peaks observed in XRD pattern can be associated, according to a survey conducted, to the compound CaF_2. In understanding the phenomena responsible for this fact is necessary to conduct additional studies but with the new coating all the ingredients used are working leaving fluorine free to react with hydrogen. This can be related to the low hydrogen obtained in the weld metaland as commented, needs further evaluation.

5 CONCLUSIONS

The results showed that:

• The composition of weld metal deposited with the impermeable electrodes is within the limits specified for Class E7018 electrodes;
• There is a trend, that should be better understood, to obtain microstructures with higher amount of acicular ferrite (above 25%) compared to the conventional electrode grade E7018;
• The content of diffusible hydrogen in weld metal produced with impermeable electrodes are extremely low, being below those found in the weld metal deposited by conventional Class E7018 electrodes;
• Exposure of the impermeable electrodes for periods relatively long (30 days), under adverse conditions, did not increased the content of diffusible hydrogen in weld metal as observed in the case of conventional class E7018 electrode.
• Mechanical properties of weld metal deposited by the impermeable electrode were satisfactory when compared to the minimum required for the class E7018 electrodes;
• The energy absorbed in impact tests is consistent with the microstructure of the weld metal;
• The polymers used in impermeable coating has a strong influence on the composition of the slag.

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