Journal of Materials Research and Technology

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Journal of Materials Research and Technology

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ORIGINAL ARTICLE

Impermeable Low Hydrogen Covered Electrodes: Weld Metal, Slag, and Fumes Evaluation

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Manuscript received November 29, 2011; in revised form June 19, 2012

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. The impermeable covered electrode was produced using the commercial E7018 formula. Preliminary tests with different polymers and formulation changes were realized to meet the satisfactory weld ability. 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. In addition, it were made tests to evaluate the slag and fumes generated during the welding. The impermeable covered electrode diffusible hydrogen content was less than 4 mL/100 g 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: Electrodes; Polymers; Hydrogen; Acicular ferrite.

1. Introduction

In 1907, Oscar Kjellberg patented the welding process using cover electrodes[1]. Since the beginning the coating has been made using silicates as a binder. There is no information available of what was the first formulation, but for sure the way the coating was fixed was by immersion[1]. Latter, production process improvements were reached by substituting it to extrusion. Since then, significant technological improvements were observed only on the formulation field. However, this scenario changed on the last decades, mainly because most productive welding processes were the research focus.

Even as a lower productivity welding process when compared to others, covered electrode welding or SMAW is still 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

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of health of the weld metal, i.e., 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 8 mL/100 g weld metal)[2]. 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 ovens[2].

Recent studies by Fichel *et al.*[3] indicated the technical feasibility of rutile electrodes agglomerated with "polymers" in wet underwater welding. This new technology allowed the production of electrodes with water-resistant coating. The electrodes were tested and acicular ferrite was observed in all welds. Figs. 1 and 2 show a mosaic of microstructures of a weld produced with one of the electrodes tested underwater. Another interesting finding was the reduction or total elimination of drying during manufacture of these electrodes (Fig. 3). These findings motivated impermeable basic electrodes development for conventional (dry) welding. In this application, to eliminate a major source of hydrogen it is necessary to ensure a low moisture content coating[4].

Vaz *et al.*[5] developed in laboratory scale, using the device shown in Fig. 4, a waterproof low hydrogen coated electrode. As a starting point, conventional class SMAW E7018 formula 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 in comparison with conventional E7018 weld metal was observed.

The aim of this work was to evaluate the weld metal deposited, slag, and fumes generated by the coated electrode with better performance formulation in the study of Vaz *et al.*[5]. It is a first step for understanding the polymer influence. To reach the proposed objectives the weld metal produced was subjected to chemical and metallographic analysis, diffusible hydrogen test, tensile test (to determine yield strength, strength, and elongation), and impact toughness (Charpy V-notch test). In addition, fumes produced during welding were analyzed using ion chromatography and slag produced was analyzed by X-ray diffraction.

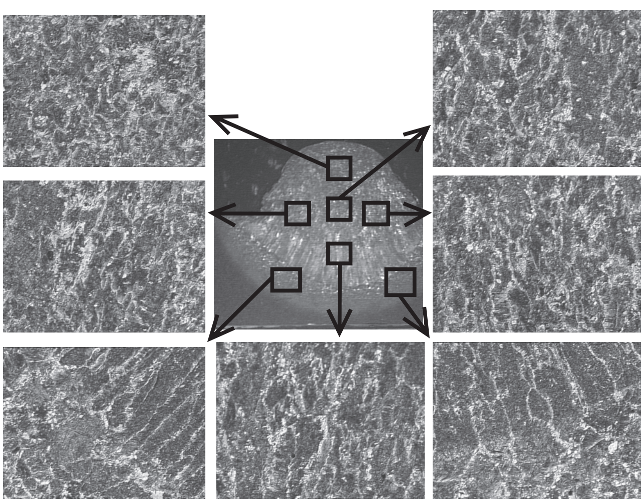

Fig. 1 Mosaic of underwater wet weld produced with an experimental E6013 electrode using polymer as binder. Depth: 0.5 mm, polarity: DCEN; Electrode welding angle: 70°; welding current: 150 A; Chemical attach: Nital 2%; 100X[3].

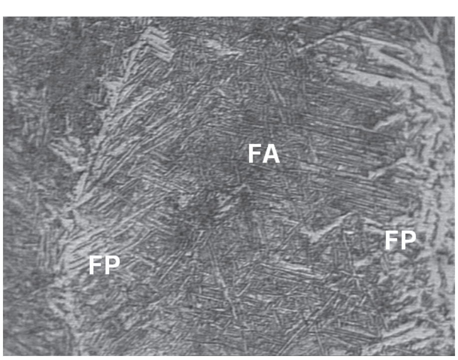

Fig. 2 Detail of the diagonal pattern region on Fig. 1. Despite the Primary Ferrite (PF), common in this type of weld metal, it is possible to observe the presence of a large amount of Acicular Ferrite[3].

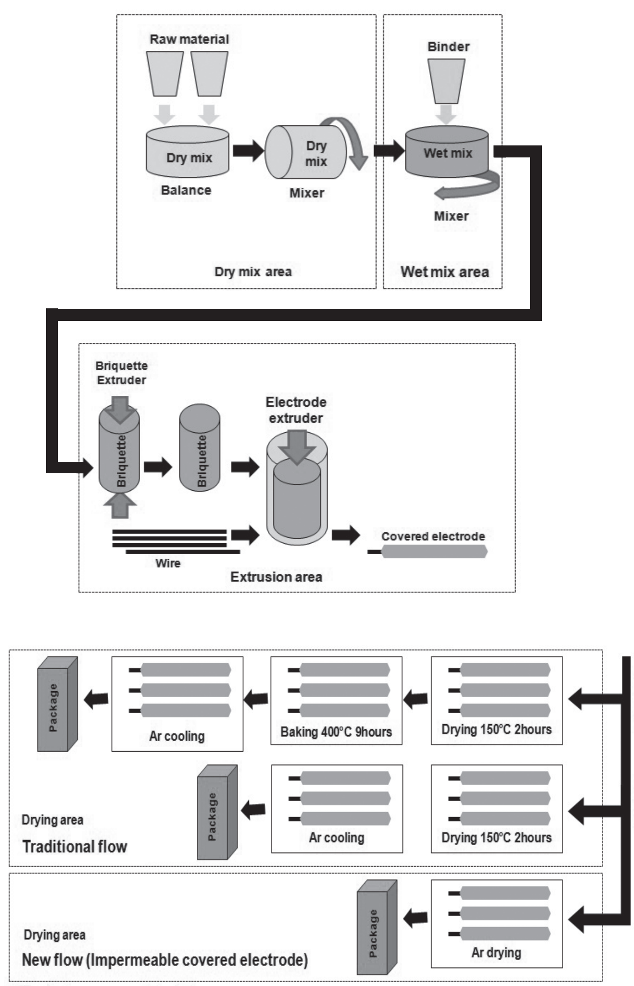

Fig. 3 Production flow chart of traditional and impermeable covered electrodes.

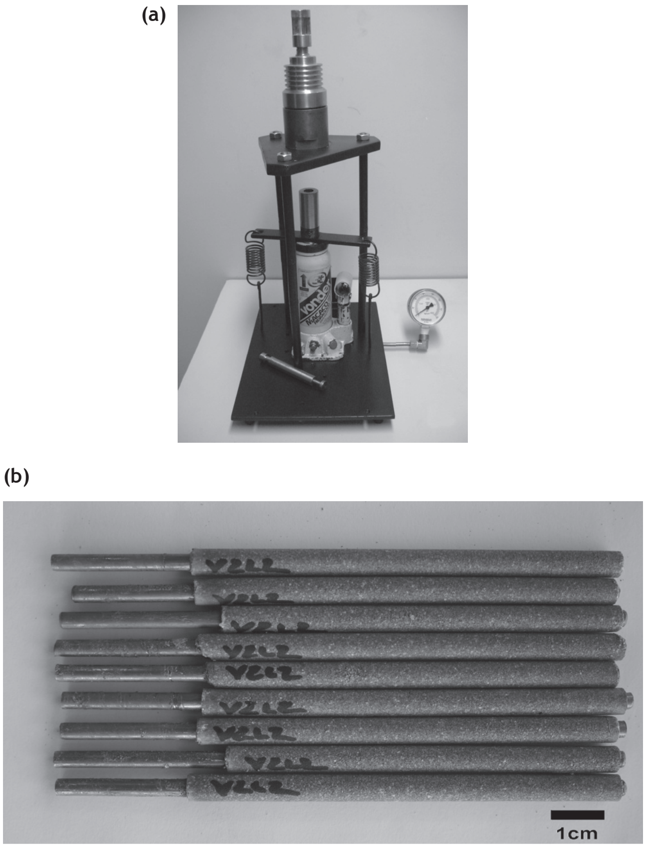

Fig. 4 (a) Laboratory device to produce very small amount of experimental electrode; and (b) experimental electrodes produced in laboratory.

2. Methods

To reach the proposed objectives the weld metal produced was subjected to chemical and metallographic analysis, diffusible hydrogen test, tensile test (to determine yield strength, strength, and elongation), and impact toughness (Charpy V-notch test). In addition, fumes produced during welding were analyzed using ion chromatography and slag produced was analyzed by X-ray diffraction.

To evaluate the structure and properties of the weld metal, 3.25 x 350 mm impermeable coated electrodes using the formulation of better performance in the study of Vaz *et al*.[5] were produced on an industrial scale. The welding was carried out using string bead technique. The current and heat input were 110 A (DCEP) and 1.2 kJ/mm, respectively.

The weld metal chemical composition was determined by optical emission spectrometry and all procedures were performed as proposed by the AWS A5.1 specification[2].

Bead-on-plate welds were produced for metallographic analysis. Transverse sections, at the center of these weld beads, were performed and samples were taken. These were sanded, polished, etched with Nital 2%, and observed in an optical microscope and photographed with magnification up to 1,000 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[6]. The hardness of the weld metal was done using the Vickers method with a load of 100 g.

Tensile and Charpy V-notch impact specimens were obtained from an A-36 steel V-groove joint prepared and welded in accordance with AWS A5.1 specification[2].

The weld metal diffusible hydrogen content 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 30-days period. Since the relative humidity was not monitored during the exposure period, the electrodes tested were kept under the same conditions.

The slag obtained in the welding with the impermeable and conventional electrodes were collected, milled, and subsequently analyzed by X-ray diffraction. Semi quantitative analysis of the slag by EDS was performed to enable identification of likely compounds and further the X-ray patterns evaluation.

The ion chromatograph technique was used to evaluate the welding fume generated by the impermeable and conventional electrodes.

3. Results

Table 1 shows the weld metal chemical analysis obtained by the impermeable electrode. Also are presented the values specified for E7018 class electrodes, established by AWS specification.

Fig. 5 shows the visual appearance of the weld bead deposited by the impermeable and the E7018 electrodes.

Table 1 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.

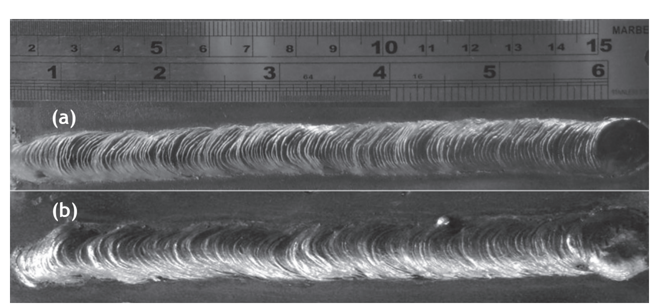

Fig. 5 (a) Visual appearance of the bead on plate weld deposited with impermeable electrode; and (b) conventional E7018 electrode.

Fig. 6 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. Fig. 7 presents, with magnification of 100 times, 200 times, 500 times, and 1,000 times, the corresponding microstructures.

The volume fraction of acicular ferrite in different regions of weld metal is shown in Fig. 8 and Table 2 presents the measurements of Vickers hardness (HV 100 g) of that constituent.

Table 3 presents the results of mechanical properties of weld metal deposited with the impermeable electrode and typical values for conventional E7018 electrode (yield strength, tensile strength, elongation, area reduction, and impact toughness).

Fig. 9 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.

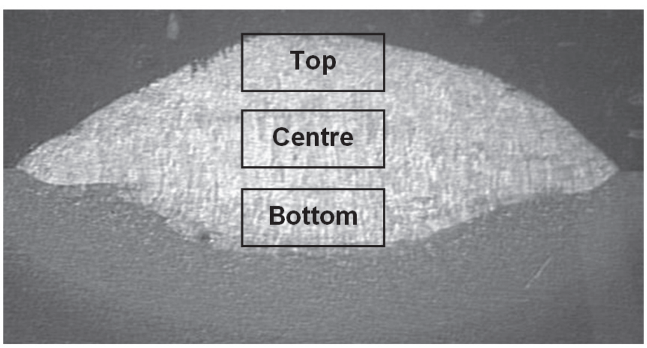

Fig. 6 Macrography of the weld metal.

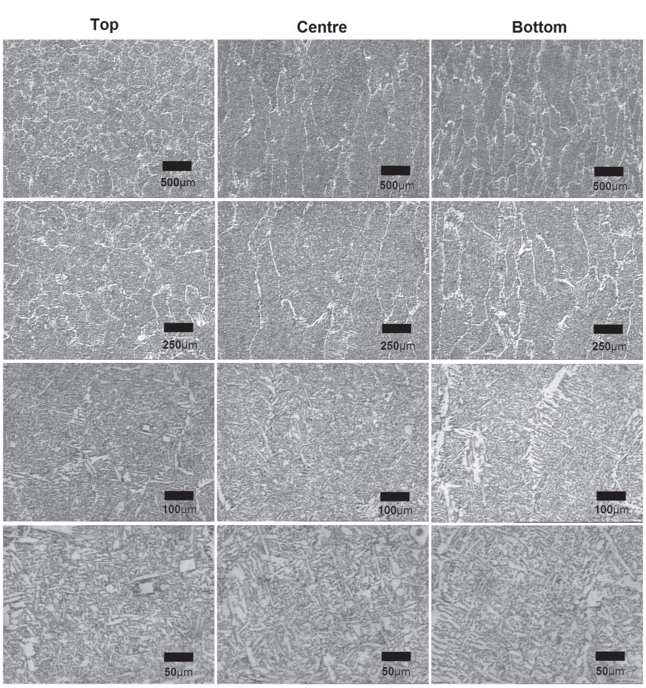

Fig. 7 Microstructure of the weld metal deposited with the impermeable electrode. Magnifications: 100 x, 200 x, 500 x, and 1,000 x.

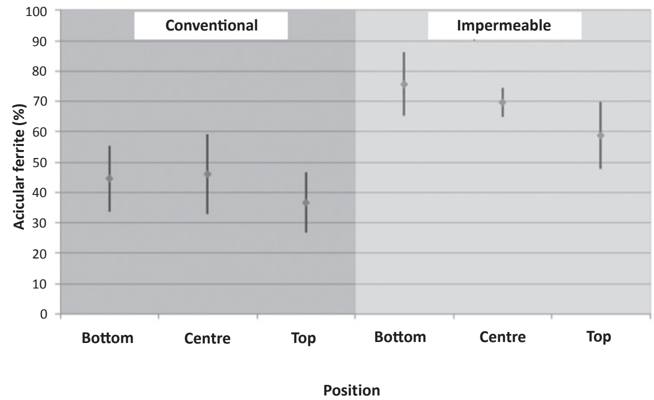

Fig. 8 Acicular ferrite content (impermeable and conventional covered electrodes).

Fig. 10 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.

Fig. 11 shows the ion chromatography patterns of welding fumes generated by the impermeable and conventional electrodes.

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.

The analysis of Fig. 5 shows 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 to the plastic characteristic of the coating at the tip that allows the tip of the wire to 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 Fig. 7 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

Table 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	279	252	286	277	270

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

	Tension test				
	Impermeable				E7018
Tensile strength	678 MPa				550 MPa
Yield strength	554 MPa				400 MPa
Elongation	29%				22%
Area reduction	67%				
	Impact toughness (Charpy V-notch)				
	Impermeable				E7018
(-30°C)	56J	62J	74J	64J*	90J*
(-45°C)	30J	48J	52J	43J*	

(*) Average

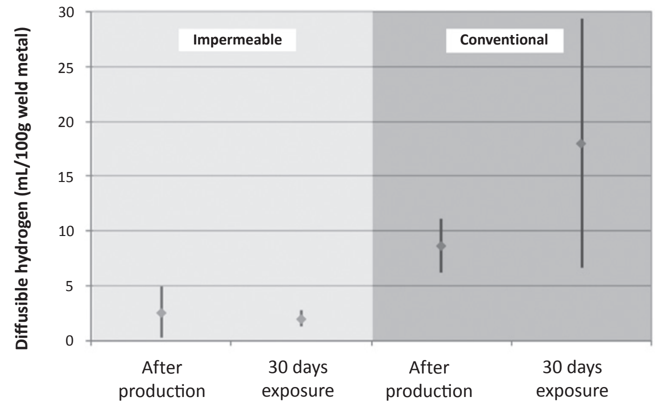

Fig. 9 Weld metal diffusible hydrogen (impermeable and conventional covered electrodes).

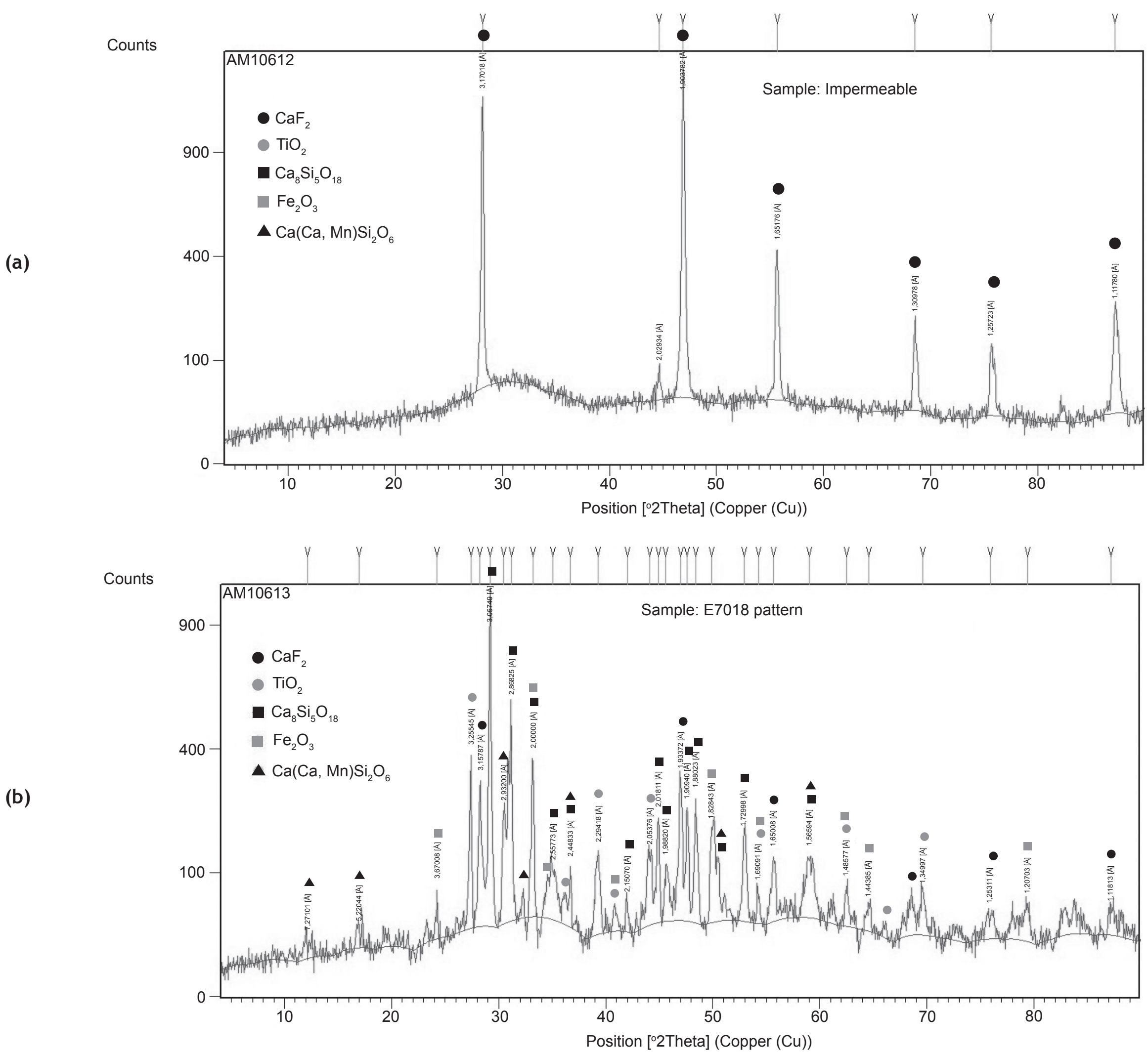

Fig. 10 (a) X-ray diffraction patterns of the slag obtained in the welding with impermeable; and (b) conventional class E7018 electrodes.

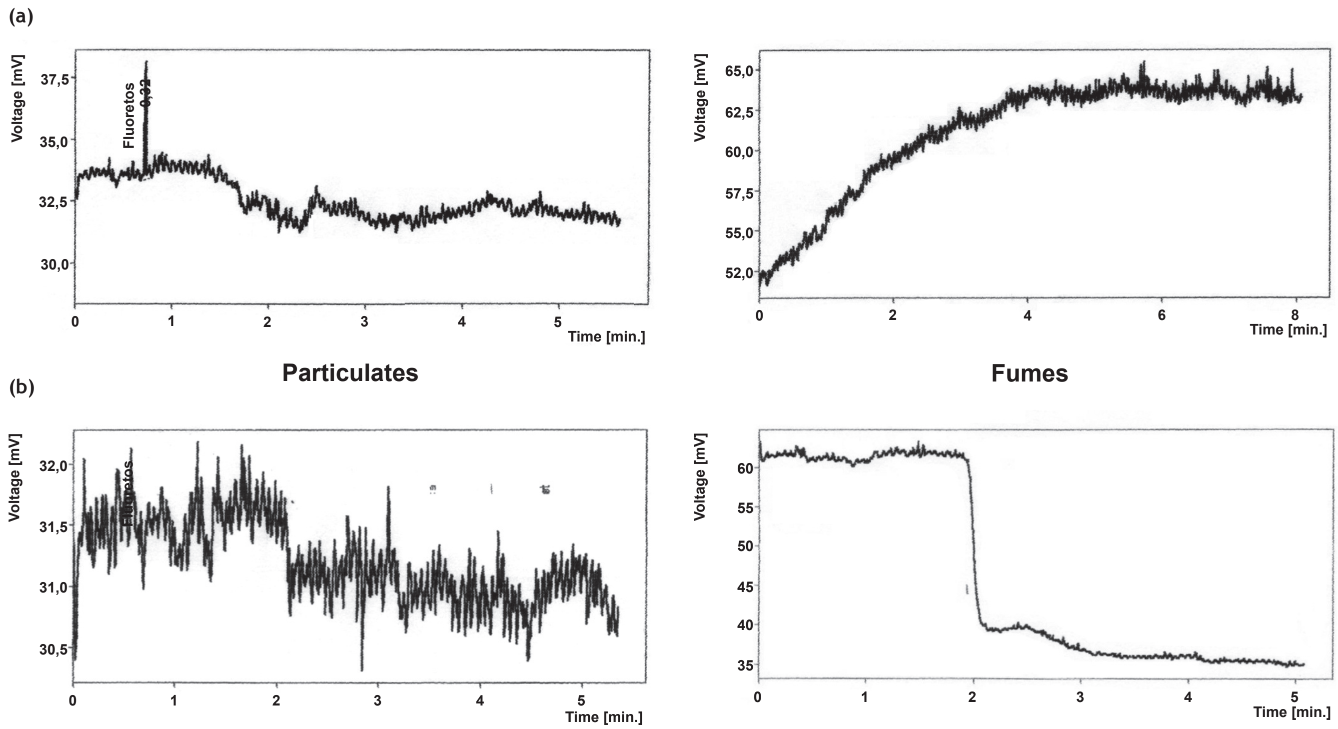

Fig. 11 (a) Ion chromatography patterns of fumes and particulates from conventional electrodes; and (b) from impermeable electrodes.

out in weld metal regions where was observed the occurrence of acicular ferrite indicated consistent with those obtained by Babu[7] for the same constituent.

The yield strength, resistance and elongation of the weld metal deposited with the impermeable electrode are well above the needed to meet class E7018 electrodes. Evaluating the weld metal chemical composition the results could be associated with silicon content. The average energy absorbed in impact tests at −30°C was 64 J and 43 J at −45°C. These results are 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 4 mL/100 g weld metal) are considered exceptionally low compared to the classic basic electrodes (generally below 8 mL/100 g weld metal). It must be also emphasized that these low results of diffusible hydrogen were obtained with impermeable electrodes that do not require drying ovens and maintenance in those greenhouses before its application.

The analysis of the diffraction patterns in Fig. 10, 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, i.e., 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 unusual 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 the coating ingredients used are acting in a different way expected for electrodes. This can be related to the low hydrogen content obtained in the weld metal and, as commented, needs further evaluation.

The ion chromatography patterns showed a difference between the fumes generated by the impermeable and conventional electrodes. A peak, probable related to traces of fluoride, was identified on the conventional electrodes analysis. On the other hand, the impermeable electrode fumes analysis did not presented traces of dangerous compounds.

5. Conclusions

- The impermeable electrode microstructure presented higher acicular ferrite volume fraction (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 relatively long periods (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 and chemical composition 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 have a strong influence on the composition of the slag.

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