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Investigation of mechanical and microstructural properties of S 235 JR (ST 37-2) steels welded joints with FCAW

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Abstract

Ship building industry has been growing and the industry struggling to meet the building and repairing needs. Ship building sector has started using flux cored arc welding technique that removes the negative effects of coated electrode and submerged arc welding techniques and has the superior properties of the gas metal arc welding technique regularly. In this study, S 235 JR (St 37-2) steel plates with 10 mm thickness have been welded 60° and butt welded on PA, PF and PE welding positions, in a CO_2 protective environment, with E71 T-1 rutile based wire electrode, and heat between increments kept stable. Hardness, tensile test, Charpy V-notch impact test, radiographic investigations, and lastly microscopic investigations were conducted in order to define the strength and microscopic properties of the weldments. As a result of these investigations, tensile strength and impact test results have been obtained for different welding positions. Hardness values were between limits set by IIW. According to the radiographic tests, for specimens welded on PE welding positions, the porosity is observed. Weld metal has been seen to have Widmannstaetten interior structure as a result of the fast cooling down on PF and PE positioned weldments, as seen on micrographs. Regions made of this interior structure were seen to be hard and brittle.

Key words: Flux Cored Arc Welding, microstructure, toughness

1. Introduction

Flux-cored wire electrode welding method is a MIG/MAG welding method in principle. This welding method is classified as a method of arc welding. In 1950s, the developments and studies on the MIG/MAG welding method led to the formation of FCAW. It has been used widely in the steel welding since 1957.

Usage of bare and flux cored electrode is increasing day by day especially in terms of high efficiency and ease of application as shown in Fig. 1. Flux cored arc welding method has the highest application rate particularly in the ships and marine craft [1].

The actual work area in carbon steel welding with flux cored welding electrodes focused on the issues of obtaining greater efficiency and speed. For this reason, higher fill rates and welding rates and compliance to robotic welding applications were obtained. Figure 2 shows the need of the industry for flux cored electrode

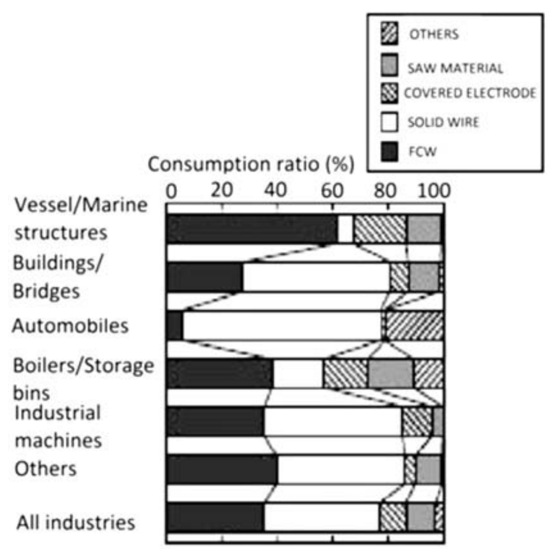

Fig. 1. Investigation results on application ratio of welding materials in various fields [1].

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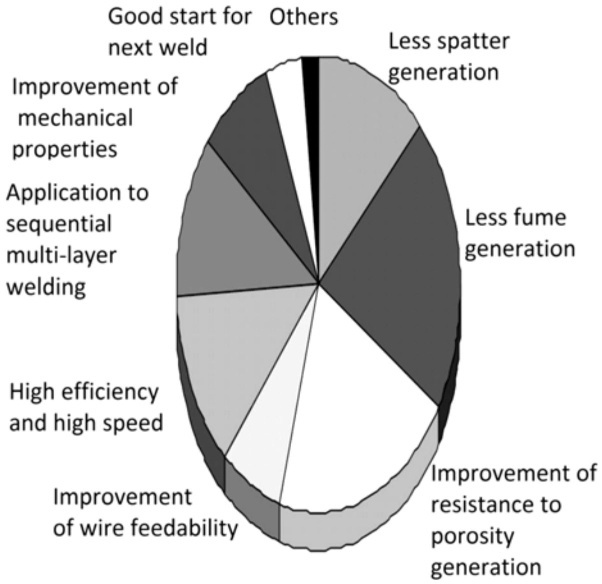

Fig. 2. Market needs for welding materials [1].

in the arc welding applications. It is obvious from the figure that requirements other than less smoke formation is for ensuring the needs of high efficiency and speed [1].

A significant increase of power is obtained in the welding methods in which infinite wires are used. In the welding made with coated electrodes, the degree of mechanization and the power increase are limited due to the external coating and the electrode length. Welding made with coated electrodes is not economical due to the relatively low melting power of the electrodes, loss of time occuring due to frequent change of electrodes and the loss of material arising from electrode residues not having any usage feature. Flux-cored wire electrodes which are also called reverse electrodes and formed by the coated components in the coated electrode being moved inside, have created new horizons for the welding technique. Welding made with flux-cored electrodes is more economical compared to the welding made with coated electrodes due to the elimination of the electrode change procedure, the absence of electrode residues, high melting power and due to its suitability of mechanization for a continous welding procedure. In the near future these are expected to take the place of coated electrodes [2].

In the flux-cored wire electrode, shielding gas mixtures have a great effect on the characteristics of the weld metal and the cost of welding. Ref. [3] examined the effect of the shielding gas mixtures in the non-alloy steel E70 T-5 (basic) and E71 T-1 (rutile) on the electrode welding seam penetration and their mechanical properties. The effect of Ar-CO_2 shield gas mixtures was found to have a seam penetration effect at most on the CO_2 gas (both for the basic and rutile flux-cored electrodes) [3].

Fig. 3. Flux cored arc welding of the stiffener corner weldings [7].

Ref. [4] examined the static and dynamic strength of the rutile, basic flux-cored and solid wire welding and the effect of the welding parameters on the welding seam. It was seen that the mechanical properties of the flux cored wire welding were better than the others and due to the high current density used in the cored welding, it was found that a smoother surface was obtained with the cored wire electrode [4].

Ref. [5] examined the effect of the electrode type in the MAG welding on the properties of the welding seam. In the experiments, S 235 (St 37) low carbon structural steel was used as the base metal, and 76 % Ar + 20 % CO_2 + 4 % O_2 gas mixture was used as the protective gas, and also solid wire electrode and flux-cored electrode with rutile character were used [5].

FCAW is a gas welding method with the usage of tubular electrode which is filled with minerals and serves as the cover of cored electrodes instead of the solid wire in the MIG/MAG welding method.

It is protected by a protective gas cover applied externally or by molten metal in the welding area or by a protective gas atmosphere obtained as a result of the composition of the core. Here, the core acts as the cover on the flux-cored electrode. Molten electrode metal is moved to the weld pool by the arc and a layer of slag, which is easily cleanable, occurs over the solidified bath [6].

Among its usage areas in the shipyards, there are several areas such as: the outer lining of ships, block joints (e.g., double bottom, deck, shell, internal wall), ship's bottom requiring full penetration, stiffener corner weldings as in Fig. 3, and difficult welding positions occuring in the head-bottom pitch blocks [7].

Also, fully automatic flux-cored wire welding

Table 1. Chemical composition and mechanical properties of the base metal

Chemical composition (wt.%)					
C	Si	Mn	P	S	N
0.17	0.30	1.4	0.045	0.045	0.009
Mechanical properties					
$R_p0.2$ (MPa)	R_m (MPa)	Elongation (%)			
min. 235	360–510	15–26			

Table 2. Chemical composition of filler wire (wt.%)

C	Si	Mn
0.05	0.55	1.2

method is used in the corner welding of profile-mails and the ceramic substrate-cored welding procedures (CB-FCAW) [8].

These electrodes are called as seam type and pipe type. Strip and pipe to be used can be selected from the desired alloy. There are dust flux and ferroalloy dusts. In the inside part of the ones with pipe shape and also among the folds of others, dezoxidation and alloy obtainment of the welding seam are performed by this core [6]. The advantage of such clamped-type electrodes is the lack of self-spills and the disadvantage are their high production costs due to their complex forms.

The classification of the cored wire electrodes is generally made according to the AWS standards as AWS A5.20, AWS A5.22, AWS A5.29.

2. Material and experimental procedures

In this study, S 235 JR steel sheet samples are welded in the horizontal, vertical and overhead positions with the usage of flux cored electrode welding method in the CO_2 protective gas atmosphere. In order to determine the strength and the microscopic properties of the weldments, radiographic examination (RT), tensile, hardness, impact test, and finally microscopic examination were made.

The size of the base material chosen for this investigation was 150 × 100 × 10 mm^3 sheets corresponding to S 235 JR steel, with chemical composition and mechanical properties as given in Table 1. Rutile flux cored wire with a diameter of 1.2 mm was used in this study; its chemical composition is demonstrated in Table 2.

Table 3. Welding parameters

Welding position	Pass	Voltage (V)	Current (A)	Stickout (mm)
PA	Root	26	190	15
	Cap	32	140	15
PF	Root	26	190	15
	Cap	26	190	15
PE	Root	26	190	15
	Cap	26	190	15

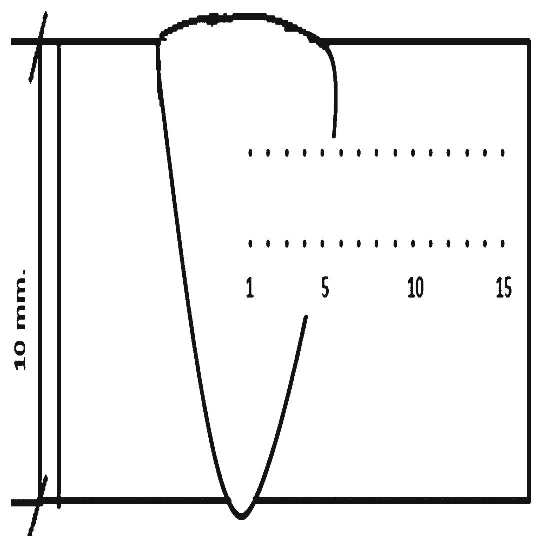

Fig. 4. Hardness measured areas.

Welding was performed with pure carbondioxide shielding gas with a flow rate of 15 ℓ min^{-1} and welding speed of 12.5 cm min^{-1}. According to the welding designation, two passes were required to fill the gap. The interpass temperature was measured to be less than 150 ℃ using a contact thermocouple. The heat input was adjusted to 18.9 kJ cm^{-1} for the root pass, 17.2 kJ cm^{-1} for the cap pass for the PA weldment and 18.9 kJ cm^{-1} for both root and cap passes in PE, PF weldments. The details of the welding parameters are demonstrated in Table 3.

The microhardness values of weldments were measured from the weld zone (WZ), across to the heat-affected zone (HAZ) to the BM, in direction using a Krautkramer Branson (Microdur) micro Vickers hardness machine in accordance with the EN 1043-1 standard.

In this study, 5 N load was applied to samples for 10 s in the WM, HAZ, BM and a set of fifteen microhardness readings was taken in each as shown in Fig. 4, and so microhardness patterns were tried to be determined for the WM, HAZ and BM.

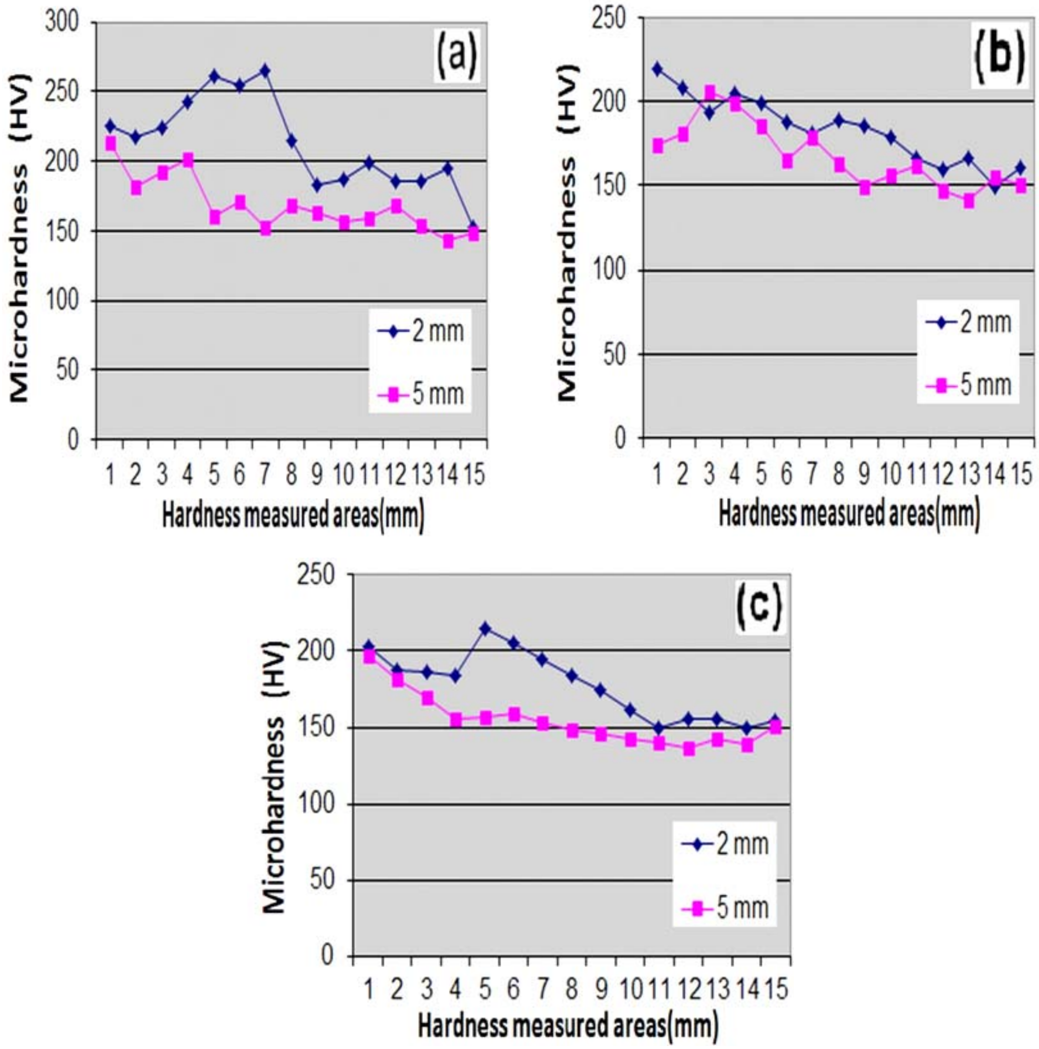

Fig. 5. Hardness patterns of each sample: (a) PA, (b) PF, (c) PE positions.

Tensile test of the weldments has been made with the WOLPERT brand universal tensile machine in accordance with the EN 10024:2004 3.1 standard.

Three tensile test samples for each welding position, and three test samples were prepared from weld and base metal.

Three impact test samples for each welding position were prepared. Impact toughness values of samples, which were prepared for each position, were determined and average values were used. Test samples were cooled off in the CO_2 environment at –20 ℃.

Radiographic films of the samples welded in PA, PF and PE positions were taken. RT was made by using AGFA D5 film (10*16 cm size) including the HAZ and WM in accordance with the EN 1435-B/TS EN 12517 standard. A single film was taken for each sample in 700 mm FFD distance. 10 FE EN penetrameter was used for the determination of the image quality which had a density of 2.2 for PA and 2.3 for PF and PE.

For the microstructural studies of weldments, samples were prepared with the semi-automatic saw and cooling liquid for each welding position. Each of the prepared samples was grinded with a 600, 800 and 1000 mesh grinder by changing the grinding direction each time and they were polished in the polishing disk with an alumina with a size of 1 µm. Samples were brought to the same brightness, were etched with the Nital 2 (2 % nitric acid + 98 % ethyl alcohol) solution, and microstructures were examined. Micrographs were taken from the BM, HAZ and WM for each sample, respectively.

3. Results and discussion

3.1. Hardness testing

Hardness values are presented in Fig. 5. Microhardness values were measured for the 2 mm and 5 mm depth close to the surface and microhardness patterns

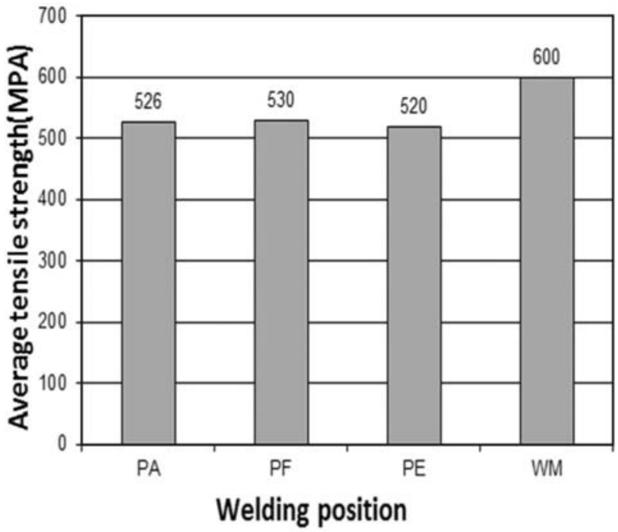

Fig. 6. Average tensile strength values of the weldments and WM.

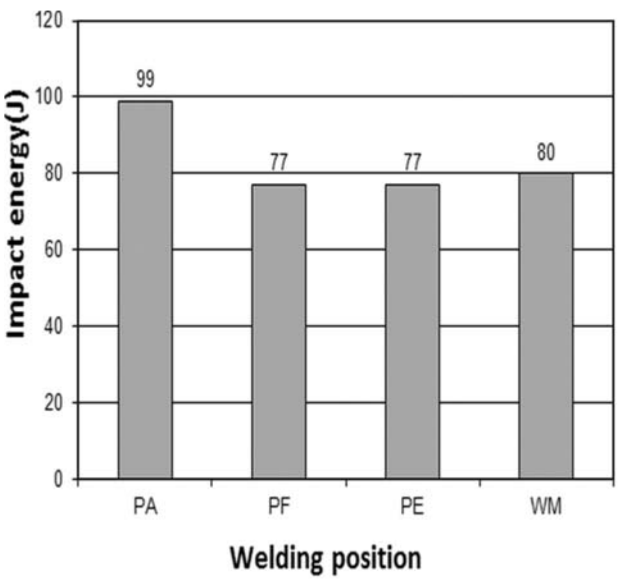

Fig. 7. Impact energy values of weldments and WM.

were obtained for the weldments. Microhardness values measured for the 2 mm and 5 mm depth close to the surface were determined to be quite close. This result shows that the interpass temperature and welding parameters are under control. There is no need of any heat treatment after welding.

Fig. 8. Radiographic films of the specimens: (a) PA, (b) PF, (c) PE positions.

3.2. Tensile test

Tensile values are presented in Fig. 6. When the tensile test results were examined, it was understood that the rupture took place from the base metal in all of the samples. Nevertheless, the tensile strength values obtained from all of the weldments seem to be quite close. Tensile strength values obtained for the weldments were also lower than for weld metal. It was determined that weldments were made in accordance with the conditions required by the standards, and they were found to be safe.

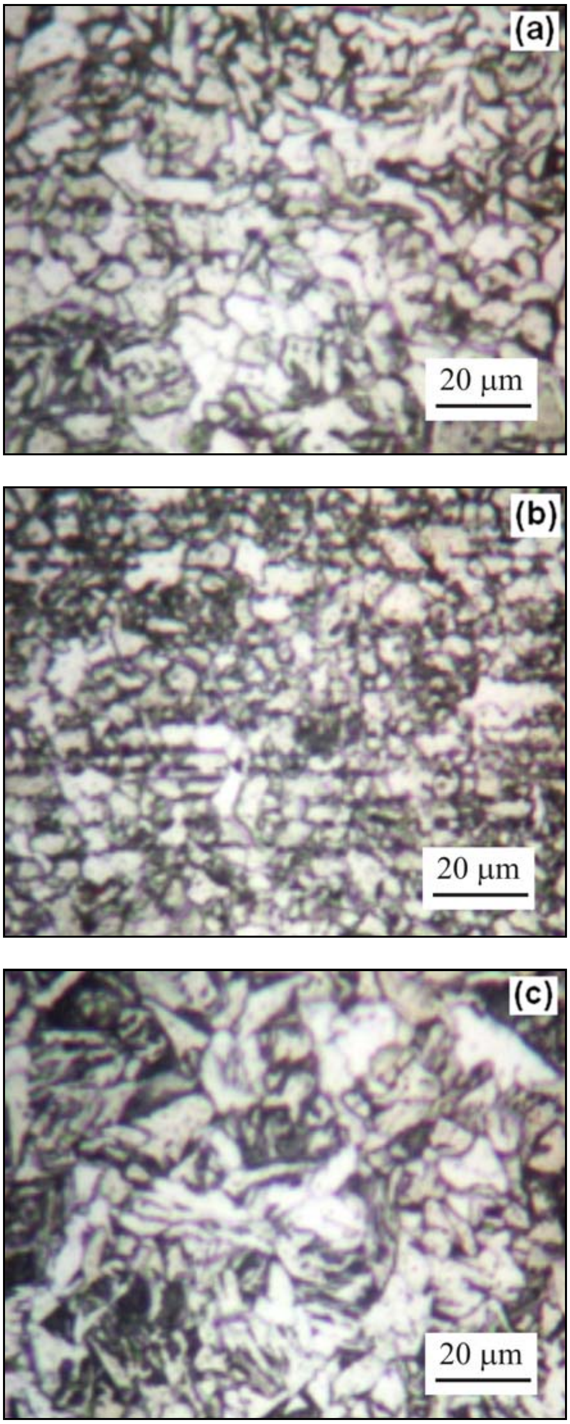

Fig. 9. Optical micrographs of PA specimen: (a) base metal, (b) HAZ, (c) weld metal etched with Nital 2, 400×.

3.3. Charpy V-notch impact test

Impact energy values of the weldments are presented in Fig. 7. It was determined that the impact values were higher than the 27 J (at –20 ℃) value required by the standard for weldments and the weld metal, and the weldments were determined to be safe against dynamic stresses.

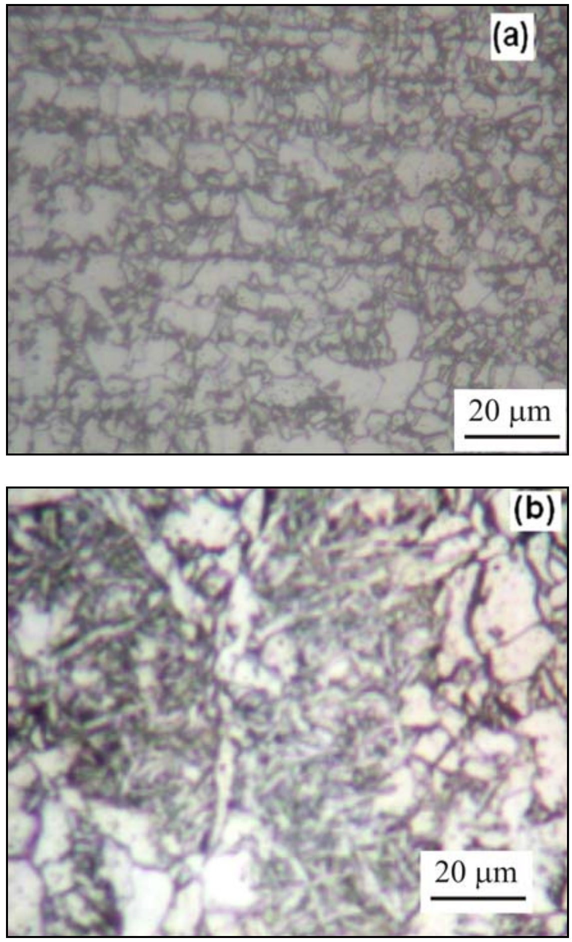

Fig. 10. Optical micrographs of PF specimen: (a) HAZ, (b) weld metal etched with Nital 2, 400×.

3.4. Radiographic examination

Radiographic films of the specimens are presented in Fig. 8. It is seen that 1-PA and 2-PF samples were in the scope of the standards and there was no weld defect. 3-PE samples, on the other hand, were determined to have porosity within the acceptable limits. It is thought that the porosities occurred due to a welder's error.

3.5. Microstructural studies

Micrographs of the samples are illustrated in Figs. 9, 10, 11, respectively.

HAZ in the 1-PA sample seems to have a thinner grain structure and the weld metal seems to have more coarse-grained structure. In the 2-PF and 3-PE samples, although HAZ has a thinner grain structure compared to the base metal, it is seen that there is a Widmannstaetten internal structure in the weld metal. In this internal structure formation, soft ferrite plates and hard pearlite colonies go into each

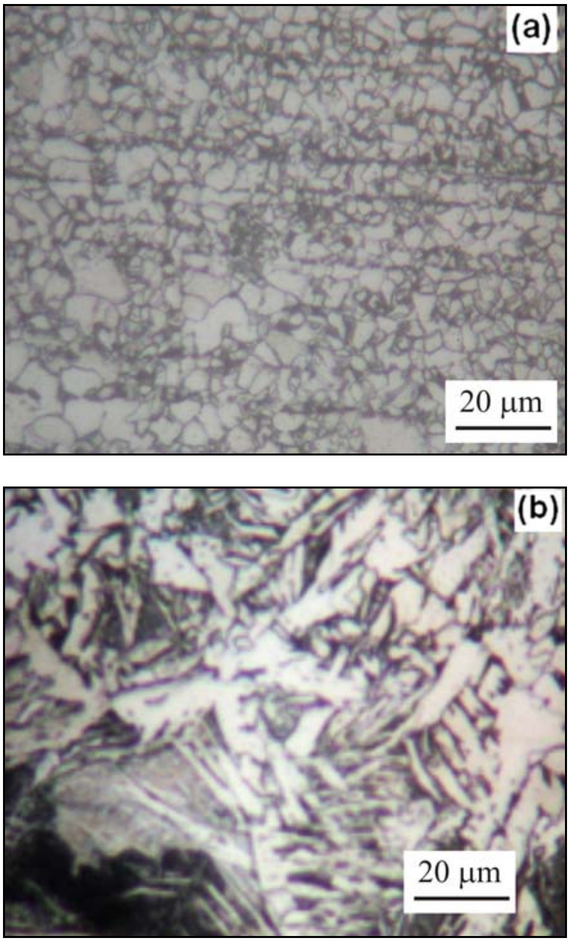

Fig. 11. Optical micrographs of PE specimen: (a) HAZ, (b) weld metal etched with Nital 2, 400×.

other, for this reason, this area is more hard and brittle compared to the base metal. The formation reason of this structure is the high cooling speed. The formation of this internal structure can be avoided with the implementation of interpass temperatures and the examination of its results.

4. Conclusions

1. Notch impact values measured from both the weldments and weld metal are high.

2. The measured hardness values are below the limits recommended by the IIW.

3. Tensile strength values measured from the weldments and weld metal are high for different welding positions.

4. There was no weld defect on PA and PF samples. It was seen PE sample had porosity within the acceptable limits.

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