DISCONTINUITIES EVALUATION ON SUBMERGED WET WELDS

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Abstract. *Higher porosity is characteristic of underwater wet welds due to surrounding water involving the electric arc and welding pool. For measure and count these discontinuity type the AWS D3.6 M standard recommends radiographic analyses. This work express the results obtained with X-ray analyses of underwater wet welds made at four depth levels, 0, 20, 40 and 60 meters, in fresh water. A gravity feed welding system was used in a hyperbaric chamber of 200m pressure capability to made V-groove wet welds using E6013 electrodes on ASTM A-36 steel plates. Three different directions of X-ray exposition was used to evaluate the porosity levels. The analyses conclude that the radiographic analysis is not adequate to evaluate porosity and another wet welds discontinuities. Additionally, it was observed that porosity increases with depth increase.*

Keywords*: submerged wet welding, porosity, radiographic testing, weld discontinuities.*

1. Introduction

Weld metal porosity is a common discontinuity that occurs on surface welding and is one of the biggest problems found in the underwater wet welding.

Porosity is a result of entrapment, supersaturation of dissolved gases, or gas producing chemical reactions. The nature and amount of pores in the weld metal depend on four competing time dependent processes: nucleation, growth, transport and coalescence of pores, Trevisan at all (1990).

The necessary physical condition for the pores formation is that the sum of the partial pressure P_g of the soluble gases must exceed the sum of the following pressures:

$P_g>P_a+P_h+P_b$, where P_a is the atmospheric pressure, P_h is the hydrostatic pressure and P_b is the pressure increasing due to the porous curvature.

In the case of underwater welding, P_h is the controlling factor because it is directly related to depth, Welding Handbook (1996), explaining why porosity increases with depth, Suga and Hasui (1986).

According to Ibarra et al (1994) the $D_{t8/5}$ (cooling time from 800°C to 500°C) is between 1 and 6 seconds for a heat input changing from 20 to 90 kJ/in. This high cooling rate hinders the gases to leave the weld pool, forming internal pores Bracarense et all (2003).

Suga and Hasuí (1986), affirmed that the principal gas in pores found in weld metal deposited by rutile and oxidizers electrodes is H_2 (97%). Other found gases are CO, CO_2 and CH_4.

Porosity is responsible for mechanical properties reduction. Liu et al (1994), affirm that the influence of porosity in the weld metal is similar to that in sintered steels, where porosity produces reduction of toughness, ductility, yield and ultimate strength limits. The same authors affirm that the main factors that affect weld metal porosity are depth (pressure), electrode coating and arc stability.

The AWS D3.6 M standard (1999) specifies the porosity evaluation procedure by X-ray analyses and classifies underwater wet welds in four classes, according to many aspects, including porosity level.

The objective of this work is to evaluate the weld metal porosity level of wet welds using radiography testing.

2. Materials and Methods

Plates, 16 and 25mm thick of ASTM A-36 steel with 220-250MPa yield strength (YS) and 400-550MPa Ultimate strength (US) were used in the experiments and equivalent carbon up to 0,4%, as recommended for AWS D3.6 M (1999).

E6013 commercial covered electrodes with 6.0mm wire diameter and 350.0mm length were prepared to be used in the experiments. All electrodes were coated with a thin layer of water proof varnish.

The welds were made at depths of 0, 20, 40 and 60m using a gravity feeding system inside of a pressurized chamber filled with fresh water.

V-grooves with 45° were prepared in 150 x 300mm plates. The coupons were mounted with 6.0mm root opening with backing bar. Travel speed changed from 4.0 to 5.0 mm/s. 300 amperes DCEP (cc^+) current polarity was used, implying in 15 A/mm^2 current density and 29 KJ/cm of heat input.

To fill the groove, about of twenty five passes were made.

All X-ray tests were carried out following ASME code - Sec V - Article 2 and all radiographic were made with Image Quality Indicators ASTM – IQI B 1-11. The top of welds and the backing bar were removed by machine operations before the X-ray examination.

The X-Ray was made in two different directions, perpendicular to the top of weld, normal to surface B shown in Fig. (1) and perpendicular to the cross-section samples removed from the welds, normal to surface A shown in Fig. (1).

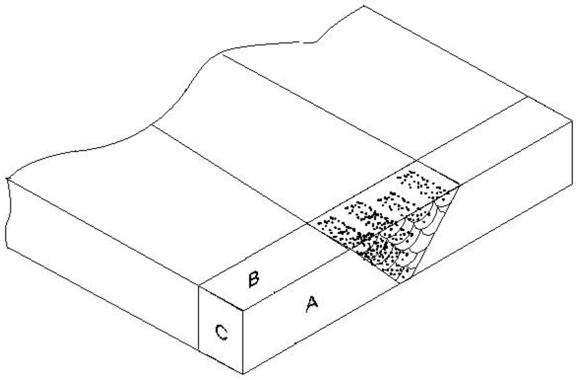

Figure 1 – Schematic drawing showing the two surfaces irradiated in radiographic tests, where A is cross-sectioning weld surface, B is the top weld surface and C is the longitudinal weld surface.

A schematic drawing of a conventional radiography made normal to surface B is shown in Fig. (2), it exemplifies the expected appearance, where is possible to observe many weld beads and its pores dispersed. This radiographic type is applied in non-destructive X-ray inspections as recommended by AWS D3.6 M Standard (1999)

Figure 2 – Schematic drawing of a conventional radiography made normal to surface B

The same porosities are expected, when irradiates the weld in normal to surface A direction in a sample with 20 mm thick, are schematic shown in Fig. (3).

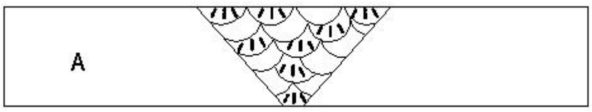

Figure 3 – Schematic drawing of a non-conventional radiography made normal to surface A

The same porosities what would be expected, when irradiates the weld is in normal to surface C direction are schematic shown in Fig. (4). (This was verified by metalography, only).

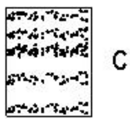

Figure 4 – Schematic drawing of a non-conventional radiography if would being done normal to surface C

The schematic drawings presented in Figures (1) to (4) were produced using AUTOCAD® software and rotated in orthogonal planes.

These radiographic schemes are expected when the weld passes were made alternately.

As showed, through the non conventional radiographs, could know better the porosity distribution and others wet welds characteristic discontinuities as cracks, lack of fusion and slag inclusion.

Charpy V-notch samples 10x10mm were extracted along the V-groove welds in direction normal to welding direction.

3. Results and dicution

All weld samples evaluated achieve the radiographic test acceptance criteria of AWS D3.6 M class B standard in the porosity aspect, for class B welds.

Due to high pores quantity observed in wet welds made at various depths, a quantitative evaluation of these discontinuities by the radiographic analyses becomes difficult.

Figures (5 to 8) shows radiographs of welds made at four depths, radiographs of welds made at 20, 40 and 60 meters depth clearly shows high distributed porosity.

Figure (5) shows the radiograph of weld made at 0m depth in 17mm thickness plates. Neither cracks nor porosity was observed. In this radiograph, four traces IQI can observed, indicating the excellent quality of this x-ray, above of that demanded for AWS D3.6M (1999) standard. Due to great arc instability, the plate edges of all wet welds have inferior qualities and were discarded. With the IQI 1 ASTM B 11, the bigger width wire has 0,8mmof diameter, below of the acceptable dimension of discontinuity for norm AWS D 3.6M(1999) class B, in which pores with width lesser 1,5mm are acceptable.

Figure 5 – Weld bead radiograph made at zero meter depth

Figure (6) shows the x-ray of wet weld made at 20 meters depth in 17mm thickness plate. Distributed pores with diameter lesser than 1,0mm can be observed. Cracks or other discontinuities were not observed.

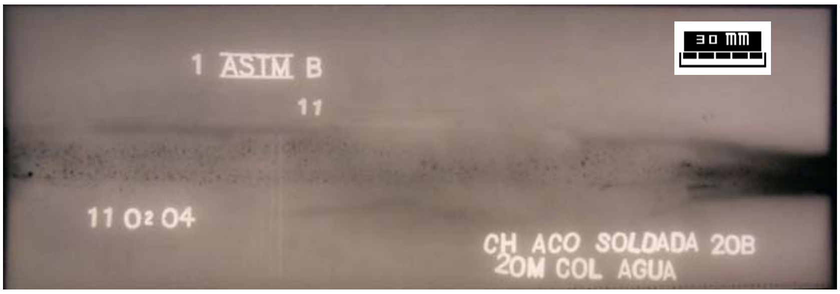

Figure 6 – Weld bead radiograph made at 20 meters depth

Figure (7) shows the x-ray of wet weld made at 40 meters depth in 17mm thickness plate. As observed in weld made at 20m depth, distributed pores with diameter lesser than 1,0mm can be observed. Cracks, slag inclusions or other discontinuities were not observed. In the region of plate beginning and end, bigger electric arc instabilities were observed, consequently, greater porosity densities occurred.

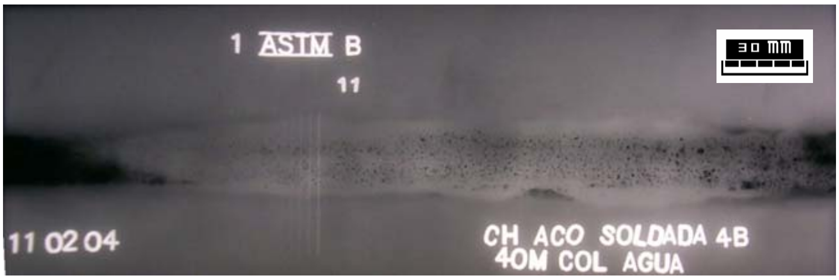

Figure 7 – Weld bead radiograph made at 40 meters depth

Figure (8) shows the x-ray of wet weld made at 60 meters depth in 17mm thickness plate. As observed in welds made at 20 and 40m depth, distributed pores with diameter lesser than 1,0mm can be observed. Cracks, slag inclusions or other discontinuities were not observed. An increase in size and amount of pores with depth increases was visually detected.

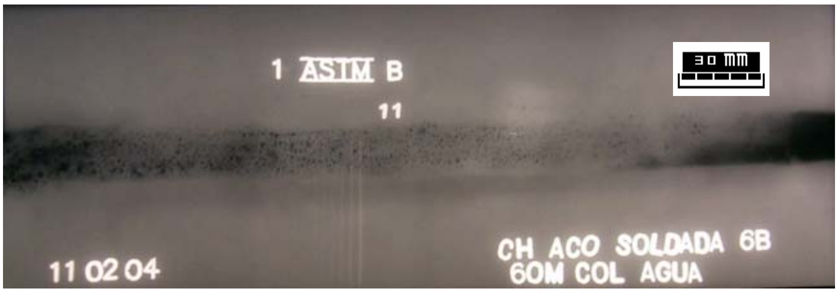

Figure 8 – Weld bead radiograph made at 60 meters depth

The pores density in wet welds made above of 20meters depth are qualitatively raised, as verified in the x-rays. However, a quantitative evaluation of these porosities for x-rays was not possible.

X-rays of cross-section samples sliced of welded joint in its transversal direction were made as schematized in Fig. (3) and shown in Figures (9 to 12). With cross-sections radiography, the discontinuities distributions in the volumes can be evaluated. Weld beads equivalent width around 20mm thickness in its longitudinal direction.

Transversal section x-rays got interesting results in relation to pores distribution concerning to depths. The porosities are sporadically distributed in each weld bead. In these ones was observed that exists preferential directions for discontinuities positioning in relation to weld bead, same of solidification direction, as reported by Suga and Hasui (1986). The structure of discontinuities in each welded joint is similar to a coarse fusing structure as fast cooling dendritic type.

Figure (9) shows the cross-section radiograph of weld made at 0m depth in 25mm thickness plates. Neither cracks nor porosity was observed.

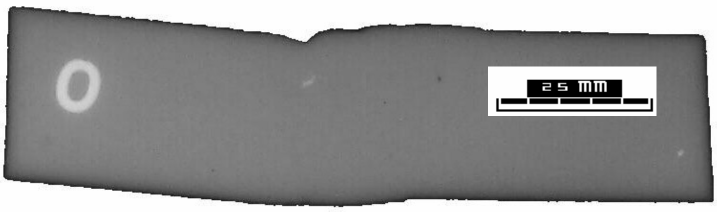

Figure 9 –Radiograph of cross-section sample removed from welded joint made at 0 meters depth

In Figures (10 to 12) transversal section x-rays of welds joints made at 20, 40 and 60 m depths respectively are shown. Dark regions, characteristic of porosity in solidification directions, in each welded joint can be observed. These pores are not in one transversal section plan only, but in diverse layers in relation to the cross-section face, normal to the surface, as shown in Fig. (3). Macro and micrography examination confirm the affirmation of that these porosities are not in an only face or layer. The pores observed in macrographs have diameters normally lesser that 1,0mm. However, all the porosities in diverse plans seem to be guided in the solidification direction of each weld bead.

Figure 10 –Radiograph of cross-section sample removed from welded joint made at 20 meters depth

Cross-section samples radiographs, Fig. (10 to 12), visually presented higher porosity than top or conventional radiographs, shown in Fig. (6 to 8), this occurs probably due to discontinuities overlapping in different plans, as considered in Fig. (1) These porosities did not appear in conventional X-rays. Large pores, bigger than 1,6mm, occurred sporadically.

The same results could be observed in FIG. 11 e 12, in submerged wet welding for 40 and 60 meters of depth.

Figure 11 –Radiograph of cross-section sample removed from welded joint made at 40 meters depth

Figure 12 –Radiograph of cross-section sample removed from welded joint made at 60 meters depth

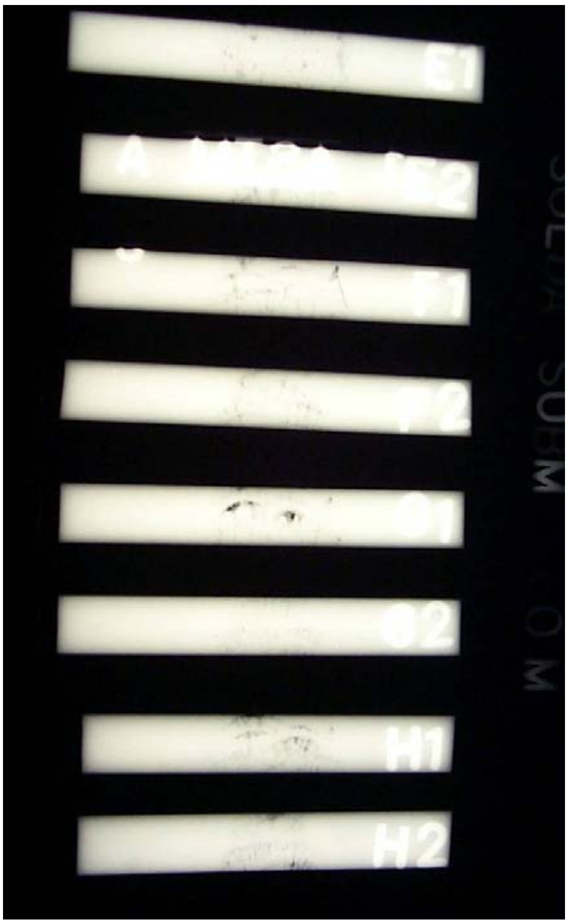

Figure 13 – Radiographs taken of 0° of Charpy pre-machined samples removed from welded joint made at 60 meters depth

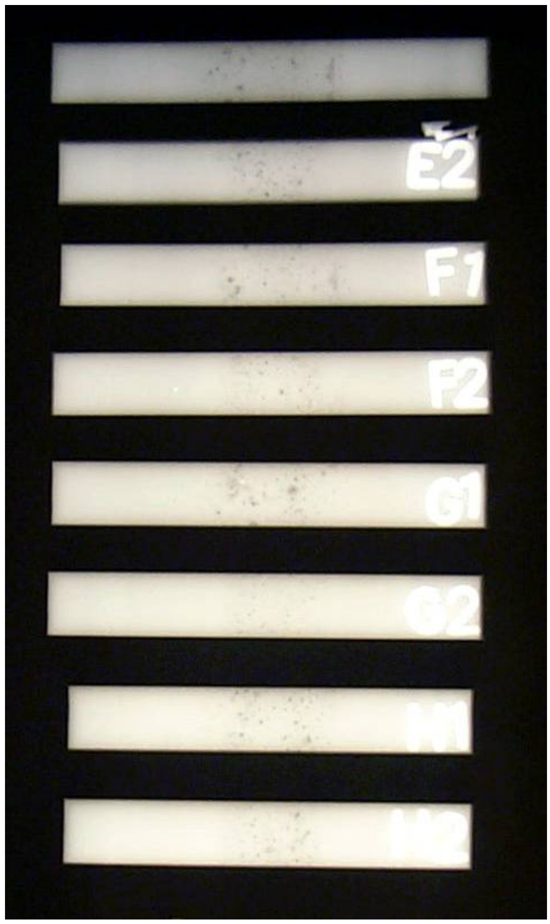

Figure 14 – Radiographs taken of 90° of Charpy pre-machined samples removed from welded joint made at 60 meters depth

As observed in conventional radiographs analyses, an increase in size and amount of pores with depth increases was visually detected in cross-sectional radiographs, mainly in the welded joint made at 60 meters depth, as related by Watson et all (1994) and Ibarra et all (1992).

Also did not observe some porosity in x-ray of welded joint made at 0 meter, agreeing to the work of Suga and Hasui (1986), indicate that porosities are initiated only above 5,0 meters depth (0,5 atm). Spherical or tubular pores were not distinguished by x-ray analyses, as considered by Suga and Hasui (1986), only pores formations in solidification lines directions was observed as cited for the same authors. Cracks or other discontinuities were not observed.

Figure (13 and 14) shows radiographs of Charpy test samples removed from weld made at 60m depth, irradiated in welding direction (0º) and normal to weld top section (90°), respectively. Similar results were observed for welds made at 20 and 40 meters depth. Only the sample identified as G1 presented large pores, not observed on others welds. In all others samples the porosity behavior is symmetrical and characterized for spread porosity with dimensions lesser than 1,6mm, acceptable ones for AWS D3.6M standard (1999).

The sample identified as G1 would be acceptable if it had only a great pore, since this is lower than 1,5mm.

5. Conclusion

The inspection by conventional, x-ray normal to top surface of submerged wet weld bead, does not give a good indication of the weld quality, since the porosity is spread in longitudinal direction of the weld. There are porosities that locate in solidification directions of weld bead, and cannot be detected by conventional x-rays, but for macrography examination, ultrasound or transversal section x-ray.

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