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MECHANICAL PROPERTIES OF WELDING JOINTS OF AH 36 STEEL PROCESSED UNDER DIFFERENT WIND ACTIONS

R. M. Lessa de Azevedo, ricarlessa@uol.com.br
Y. P. Yadava, yadava@ufpe.br
R. A. Sanguinetti Ferreira, ras@ufpe.br
Universidade Federal de Pernambuco, Departamento de Engenharia Mecânica, Avenida Professor Hélio Ramos s/n Cidade Universitária, CEP:50.740-530, Recife-PE
J. L. Lauriano Gama, jorgelauriano@gmail.com
IFAL, Rua Mizael Domingues, 75, Centro, , CEP:57.020-600, Maceió-AL

Abstract. *The influence of the action of the winds over the mechanical properties of the welding joint of AH36 steel welded by FCAW (flux-cored arc welding) processes with externally supplied shielding gas (FCAW-G) and FCAW with self-shielded wires (FCAW-S) had been studied in this work. Although decades of use of process FCAW, it has little available literature on the action of the winds in this process of welding. For the accomplishment of this study, the wires commercially found Supercored71(E71T1-C) and Fabshield XLR-8 (E71T-8J H8) had been used. The shielding gas used for the first case was a commercial mixture (75% Air / 25% CO_2). The welding for the two cases had been carried through in four situations: absence of winds and under action of wind speed of 2.3 m/s, 3.3 m/s and 4.4 m/s, which are within the average range of wind speed in Pernambuco State coast, generated by controlled ventilation. The liquid penetrant inspection (LPI) demonstrated clearly that the process with externally supplied shielding gas is extremely sensitive the action of the wind, resulting in extreme porosity, the same limitation not occurring for the process with self-shielded wire. The microstructural analysis with the optical microscope and the guided bending test ratified this conclusion. The microhardness profiles obtained showed that the effects of wind influence the heat convection on the weld fillet, influencing the final properties. The tensile strength test showed that the FCAW-S process can produce welded joints with the same qualities both in absence and presence of wind, since that care is taken in the slag clearance. If the slag is not correctly removed, fragile points can damage the welding joint.*

Keywords: *Wind Effects, Mechanical Properties, FCAW process.*

1. INTRODUCTION

The welding process more widely used in ship production is Shielded Metal Arc Welding (SMAW). Alternative/complementary possible process is the Flux-Cored Arc Welding (FCAW) which produces the coalescence of metals, by metal melting with later solidification, using heat produced by an electric arc established between continuously-fed consumable tubular electrode and the workpiece. Protection of the arc and weld fillet is made by a welding flux contained within the electrode, which can be supplemented by an externally supplied shielding gas. (Vilani, 2007) In addition to protection, the welding flux can have other functions, similar to those of electrodes coating in SMAW. There are two basic types of FCAW:

- FCAW-G: This process uses externally supplied shielding gas for the protection of metal deposited. The equipment used is the same equipment of the GMAW (Gas Metal Arc Welding).
- FCAW-S: This process uses no externally supplied shielding gas, all the shielding gas is supplied by the welding flux contained within the electrode.

A basic difference between FCAW-G and FCAW -S is the external wind effect on the quality of welding. According to “FEMA-355B , State of the Art Report on Welding and Inspection (2000) ", the FCAW–S is a better solutions in field situations. As no external gas supply is necessary, the process can be used on wind presence without considerable losses in quality of the weld joint. With any other process with external gaseous protection, protections against the wind should be erected to prevent the influence of the winds in welding. Many studies have shown that the use of FCAW-G is sensitive to disturbances produced by winds (Boniszewski, 1992) (Yeo, 1986, 1988, 1989), (Prior, et al., 1986, (Henrie and Long, 1982), (Schinkler, 1992) and (Autio, et al., 1981). Other studies (Boniszewski, 1992) and (Shlepakov, et al., 1989), determined that the increased speed of the winds has little influence on the integrity of FCAW-S welding. Due the necessity to find alternatives to the laborious erection of protection against wind, that is required in field welding operations with gas-shielded processes, this article studies the effect of wind disturbances in FCAW-G and FCAW-S welding processes. The chosen wind speeds are within the average range of wind speed observed in coastal region of the State of Pernambuco, where a shipbuilding industry is being installed. It is expected that FCAW-S process will reduce the necessity of protection erection in wind presence.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

The welding was carried out in plates with dimensions 300 x 100 x 12.7 mm of AH 36 steel. Consumables used were the flux cored E71T-1C 71 (1.2 mm diameter), with shielding gas Argon (Ar) + 25% CO_2 and E71T-8J H8 (1.6 mm diameter), self protected. The welding in the two cases was done in four situations: absence of wind and under action of winds with speeds of 2.3 m/s, 3.3 m/s and 4.4 m/s, which are within the average range of wind speed in Pernambuco State coast, generated by controlled artificial ventilation.

The typical chemical composition of weld metal for the two flux cored wires is provided in Tab. 1.

Table 1 Typical Chemical Composition of Weld Metal

	C	Si	Mn	P	S	Al
E71T-1C 71	0.03	0.51	1.26	0.010	0.011	-
E71T-8J H8	0.19	0.17	0.51	0.009	0.006	0.51

2.2 Welding Procedures

It has been used a single V-groove (50º) weld, butt joint and flat position, with dimensions shown in Fig. 1. The sequence of welding passes used is shown in Fig. 2

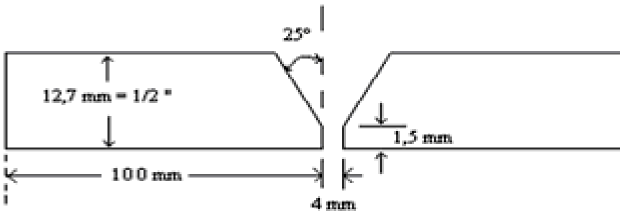

Figure 1. Dimensions of Welding Sample.

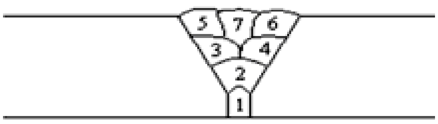

Figure 2. Sequence of Welding Passes

The steel welding was made with welding parameters control as shown in Tab. 2 (FCAW-G) and Tab. 3 (FCAW-S).

Table 2 Welding Data - FCAW-G

Wind Conditions	Passes	Voltage (V)	Current (A)	Interpass Temperature (K)	Wire-Feed Speed (m/min)	Period (s)
No Wind						
Gas Flow – 14L/min	1- Root	24	160	-	6,7	70
	2- 7	24	162-169	418 - 428	6,7	75
Wind - 2,3 m/s						
Gas Flow – 14L/min	1- Root	24	160	-	6,7	90
	2- 7	24	160-172	418 - 428	6,7	90
Wind - 3,3 m/s						
Gas Flow – 14L/min	1- Root	24	155	-	6,7	150
	2- 7	24	159-170	418 - 428	6,7	90
Wind - 4,4 m/s						
Gas Flow – 14L/min	1- Root	24	155	-	6,7	100
	2- 7	24	158-170	418 - 428	6,7	95

Table 3. Welding Data - FCAW-S

Wind Conditions	Passes	Voltage (V)	Current (A)	Interpass Temperature (K)	Wire-Feed Speed (m/min)	Period (s)
No Wind						
	1- Root	19	160	-	3,2	200
	2- 7	19	158-165	418 - 428	3,2	115
Wind - 2,3 m/s						
	1- Root	19	160	-	3,2	155
	2- 7	19	156	418 - 428	3,2	155
Wind - 3,3 m/s						
	1- Root	19	150	-	3,2	180
	2- -7	19	158-164	418 - 428	3,2	135
Wind - 4,4 m/s						
	1- Root	19	148	-	3,2	160
	2- 7	19	157-162	418 - 428	3,2	120

2.3 Liquid Penetrant Inspection

To detect surface-breaking flaws during welding, welded joints were tested with liquid penetrant inspection.

2.4 Microstructural Analysis

For the_microstructural analysis, samples were polished with sandpaper according to the sequence: 200, 400, 600 and 1000 mesh and then polished on a cloth disc with diamond polishing paste with grits of 1 µm. After polished, the samples were attacked by Nital 5% (Shanmugam, et al 2007) for 15 seconds. The microstructural characterization of all different welded joints was made by optical microscopy. The influences of welding processes used in microstructures of molten zone and heat-affected zone were analysed.

2.5 Microhardness Profiles

Microhardness profiles were raised to assess the effects of convection during welding, considering the effects of winds on the side of the weld fillet (90º). The microhardness testing used a diamond Vickers indenter and loads of 500 g by 15 seconds.

Microhardness tests were conducted in cross sections welded joints and regions examined were the base metal, heat-affected zone (HZA) and weld metal according to the schema shown in Fig. 3.

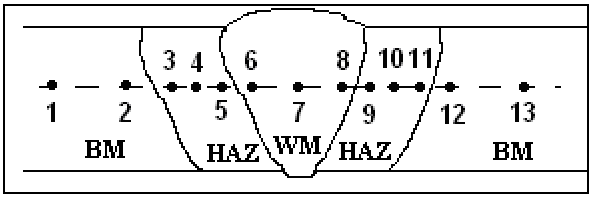

Figure 3. Layout of measurement points of microhardness. Legend:

1 = Base material (BM) far from HAZ
2 = Base material (BM) 0,5 mm from HAZ
3 = HAZ - 0,5 mm from BM
4 = HAZ Center
5 = HAZ - 0,5 mm from Weld Metal
6 = Weld Metal (WM) 0,5 mm from HAZ
7 = Weld Metal (WM) Center
8 = Weld Metal (WM) 0,5 mm from HAZ
9 = HAZ - 0,5 mm from Weld Metal
10 = HAZ Center
11 = HAZ - 0,5 mm from BM
12 = Base material (BM) 0,5 mm from HAZ
13 = Base material (BM) far from HAZ

NOTE: Measures 8 to 13 were only required in situations under action of winds

2.6 Bend Test

It has been performed Guided Bend Test, with a final angle of 120º.

Three bend tests were conducted for each situation of welding, first a root bend, after a face bend and finally a side bend. All tests were made according to ASME – IX (2001). This standard requires that the bended sample should not have opened discontinuities exceeding 3.2 mm on the weld metal or HAZ.

2.7 Tensile Strength Test

Tensile strength test were conducted with 100 kN load, with jaw separation speed equal 5.0 mm/min (0.083 mm/s)

The test samples were cylindrical, Fig. 4, and the longitudinal axis of the test samples was perpendicular to the longitudinal axis of the weld fillet, according to ASTM A370 (2003).

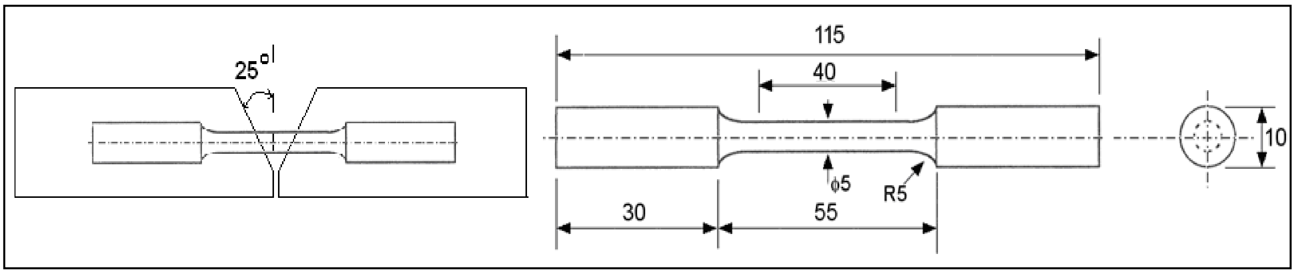

Figure 4. Weld Position and Dimensions of Test Tamples.

24 test samples were made, being 03 for each of the 08 possibilities: welding processes FCAW-G and FCAW-S, each one in 4 situations: no wind and with winds of 2.3; 3.3 and 4.4 m/s.

3. RESULTS AND DISCUSSION

3.1 Macrographic analysis

A macrographic analysis of welded joints under action of the winds is already sufficient to show the poor quality of welding with FCAW-G process. For whatever the wind speed between 2.3 and 4.4 m/s, the weld presents an excessive splashing and porosity, even for wind speed of 2.3 m/s, as can be seen in the figure below (Fig. 5). On the other hand, macrographic analysis did not find any loss of quality of welding with FCAW-G process to none of speeds of wind generated (Fig. 6).

Figure 5. FCAW-G; wind speed of 2.3 m/s

Figure 6. FCAW-G; wind speed of 4.4 m/s

3.2 Liquid Penetrant Inspection

The Liquid Penetrant Inspection (LPI) showed a good quality of welding with the FCAW-G process only in the absence of winds, Fig. 7. In the absence of winds were not observed relevant indications and the welding bead was in accordance with the AWS code 1.1. In the presence of winds, to whatever the speed, the reagent showed significant presence of linear and rounded indications, along the entire bead weld, as illustrated in Fig. 8. With the process FCAW-S, the results were surprising: both in the absence and presence of winds at all speeds, the reagent has not revealed signs of discontinuities along the bead weld (Fig. 9 and 10).

Figure 7. LPI, FCAW-G, absence of winds

Figure 8. LPI, FCAW-G, presence of winds

Figure 9. LPI, FCAW-S, absence of winds

Figure 10. LPI, FCAW-s, winds of 3.3 m/s

3.3 Bend Test

Bend Test have ratified the evidences of LPI. Bend test, for the condition without wind, did not provide discontinuities in convex region that are visible to the naked eye for both processes FCAW-G and FCAW-S. Under the influence of winds, to whatever speed wind, bended joints welded by process FCAW-G presented discontinuities (Fig. 11) that exceed the acceptable values for standard (cracks exceeding 3.2 mm). Partial fractures were observed for the bend of the face and bend of root and craters were opened with transverse side bend (Fig. 11).

On the other hand, bend tests held in samples from plates welded by FCAW-S process did not show discontinuities noticeable to the naked eye (Fig. 12), regardless of the speed of the winds and the bend test position.

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Figure 11. Bend Test, FCAW-G, wind speed of 2.3 m/s

Figure 12. Bend Test, FCAW-S, wind speed of 4.4 m/s

3.3 Microstructural Analysis

Microstructural analysis of FCAW-G process in the absence of winds are shown below. In the fusion line (Fig. 13) can be observed the effects of dilution, featuring the good penetration and a low pore density. The molten zone also shows absence of cracks, pores or important defects of macrosegregation (Fig. 14). Heat-affected zone, particularly the coarse grained area (Fig. 15), also introduces a morphology without anomalies, where no cracking was observed.

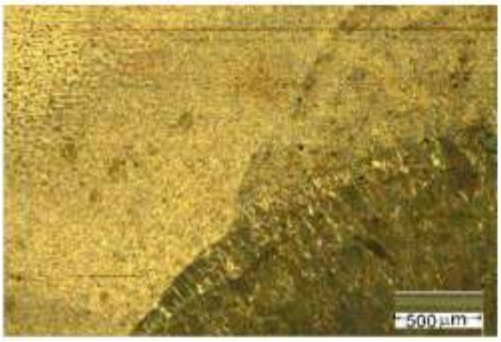

Figure 13. Fusion Line, FCAW-G absence of winds (Magnification 50x)

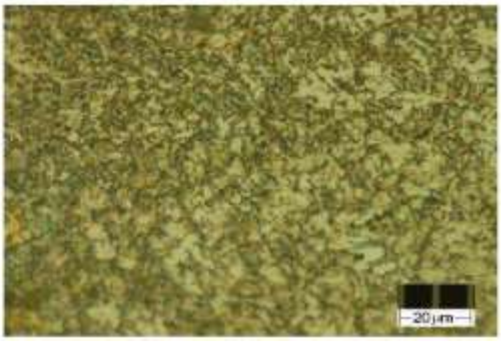

Figure 14. Weld Metal, FCAW-G absence of winds (Magnification 1000x)

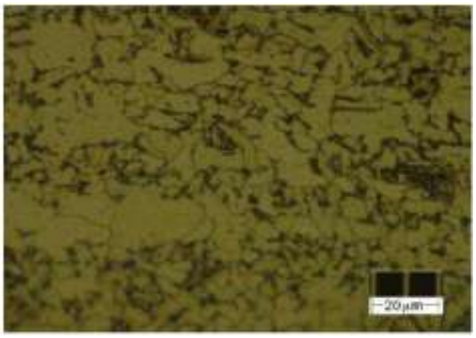

Figure 15. HAZ, FCAW-G absence of winds (Magnification 1000x).

Microstructural analysis of FCAW-G process in the presence of winds are shown below. The results showed (Fig. 16 and 17) that, to whatever the speed used, the weld joint presents significant discontinuities, like large pores (more than 1.0 mm) and inclusions. This harmful effect of wind on the weld fillet of FCAW-G process has also been observed by Boniszewski (1992); Yeo (1989) and Prio et al., (1986).

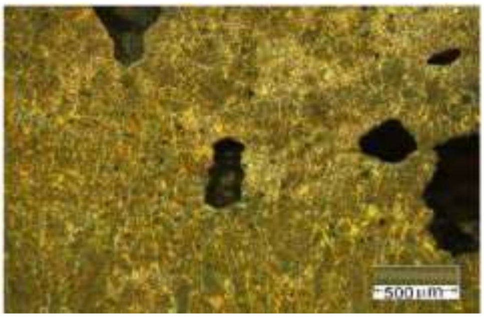

Figure 16. Weld Metal, FCAW-G, 2.3 m/s (Magnification 50x)

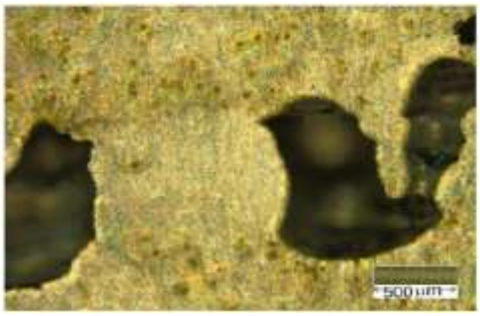

Figure 17. Weld Metal, FCAW-G, winds 4.4m/s (Magnification 50x)

Microstructural analysis of FCAW-S process showed that, with or without the effect of the wind, welding can be performed without presenting discontinuities. Fig. 18 and 19 show the weld fillet and HAZ, respectively, of a weld under the influence of winds at a speed of 2.3 m/s.

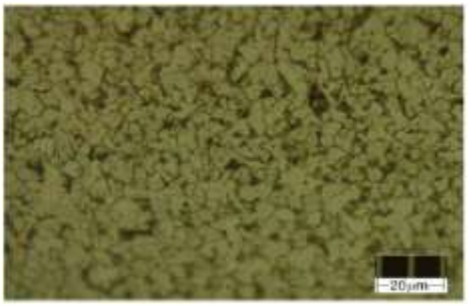

Figure 18. Weld Metal, FCAW-S, winds 2.3 m/s (Magnification 1000x)

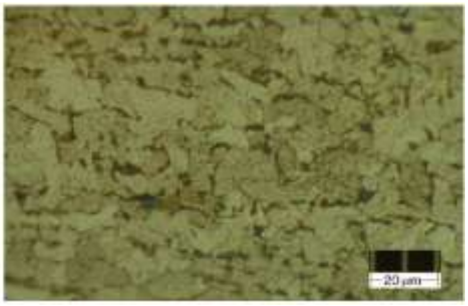

Figure 19. HAZ, FCAW-S, winds 2.3 m/s (Magnification 1000x)

Similar result was obtained for other speeds, as shown in Fig. 20 and 21. Generally, these results are consistent with what was envisaged by the "Guide of Welded Steel" and with the results of Shlepakov (1989). However, comparing the microstructures obtained with speeds of 2.3 m/s and 4.4 m/s, the results showed that for greater speed, the structure was more refined, indicating that the increment of convection can avoid grain growth both in molten zone (Fig. 18 and 20) as in heat-affected area (Fig. 19 and 21)

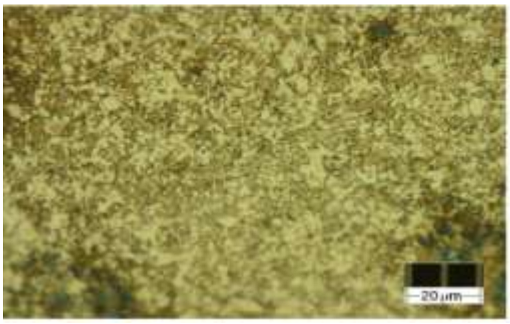

Figure 20. Weld Metal, FCAW-S, winds 4.4 m/s (Magnification 1000x)

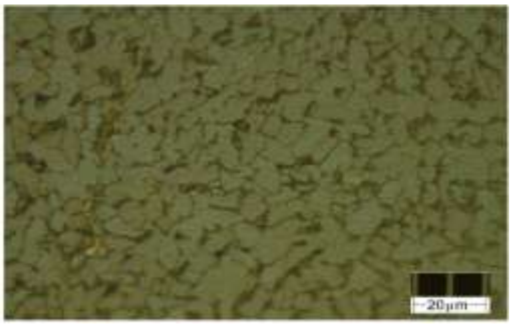

Figure 21. HAZ, FCAW-S, winds 4.4 m/s (Magnification 1000x)

3.4 Microhardness Profiles

The following diagrams (microhardness profiles), Fig. 22 to 25, compare the values of microhardness found in joints produced by different conditions, revealing some peculiarities due to the influence of the winds.

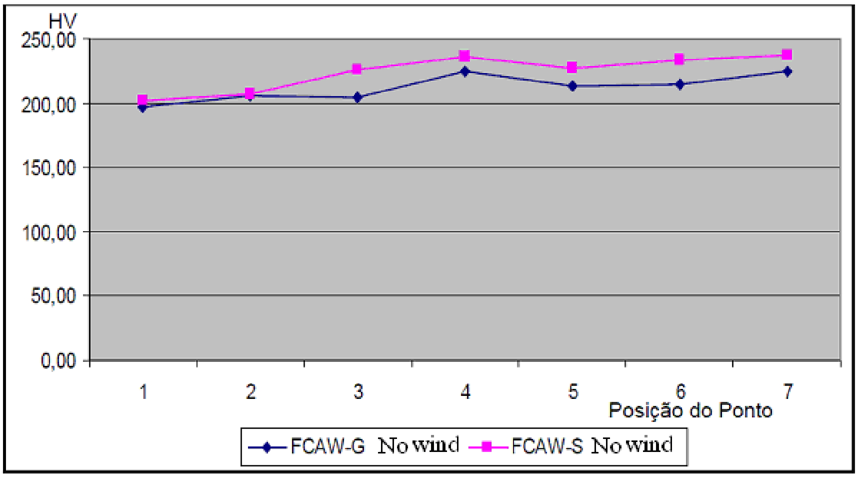

Figure 22. Vickers Microhardness Profiles, FCAW-G and FCAW-S, absence of winds.

The results shown in Fig. 22 show that, in the absence of the winds, the hardness produced by FCAW-S process is slightly above the hardness produced by FCAW-G process. This result is only justified in two ways: either the flux of FCAW-S contributed with alloy elements to this increase (based on the values of the tab. 1, the carbon equivalent is slightly higher for the weld metal in the FCAW-S process), or the auto generated shielding gas becomes more effective in protecting the joint than mixture Ar-25 % CO_2 .

The observation of the hardness comparative diagrams produced by FCAW-S process without wind and under action of winds with increasing speed (Fig. 23, 24 and 25) shows that the chaotic formed wind flows can lead to different results.

In the first case, winds 2.3 m/s has an asymmetry in the profile of hardness. Already for winds of 3.3 m/s, the profile of hardness is more symmetrical. To winds of 4.4 m/s, hardness bead weld grows in relation to hardness bead weld produced when there is no wind. This result is justified by the fact of forced convection be more active in this case and modify the cooling rate of the joint, influencing also the symmetry of hardness profile. In Fig. 25, we can see that the hardness drops faster on right side, that is the side correspondent to the output of the winds (OW), where convection is less effective.

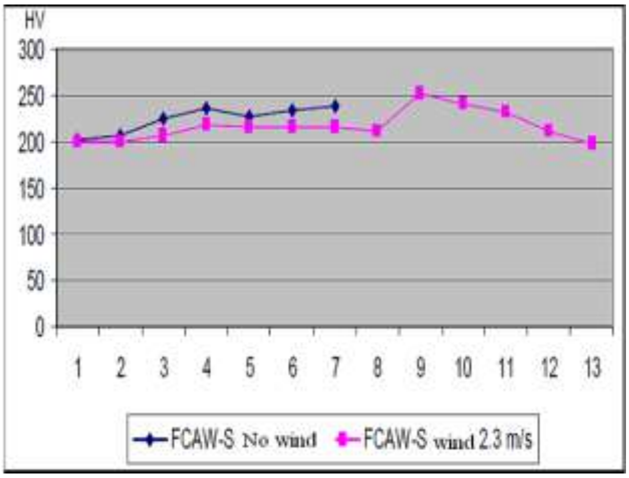

Figure 23. Vickers Microhardness Profiles - FCAW-S without winds and with winds of 2.3 m/s.

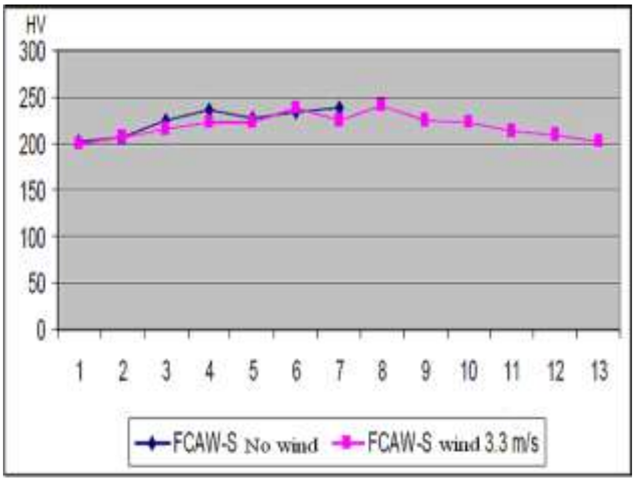

Figure 24. Vickers Microhardness Profiles - FCAW-S without winds and with winds of 3.3 m/s..

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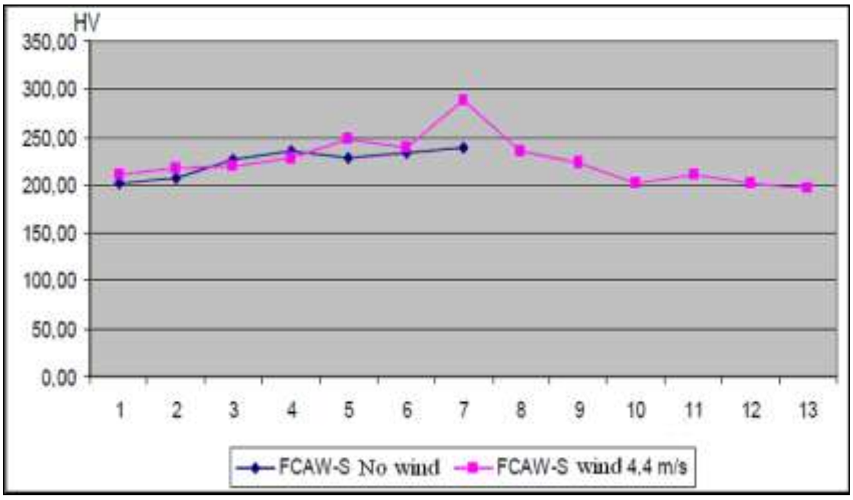

Figure 25. Vickers Microhardness Profiles - FCAW-S without winds and with winds of 4.4 m/s.

3.5 Tensile Strength Test

The curves obtained were True Stress (MPa) X True Strain (%) for each sample.

Tensile strength test for FCAW-G process showed expected results, i.e. a good weld in the absence of winds and the opposite in the presence of winds, as shown in Tab. 4 below.

Table 4. Ultimate Tensile Strength and Ultimate Strain - FCAW-G.

	No Wind	Wind 2.3 m/s	Wind 3.3 m/s	Wind 4.4 m/s
Ultimate Tensile Strength (MPa)	523,0	390,0	420,0	397,4
Ultimate Tensile Strength (ksi)	75,8	56,5	60,9	57,6
Ultimate Strain (%)	12,9	8,2	6,9	4,3

Tensile strength test for FCAW-S process (Tab. 5) in the absence of winds do not showed any problem, with the value of ultimate tensile strength higher than expected for the welding (70 ksi) and perfectly compatible with the FCAW-G process in the absence of winds.

Table 5. Ultimate Tensile Strength and Ultimate Strain - FCAW-S.

	No Wind	Wind 2.3 m/s	Wind 3.3 m/s	Wind 4.4 m/s (1)	Wind 4.4 m/s (2)
Ultimate Tensile Strength (MPa)	515,0	403,0	522,0	547,0	365,0
Ultimate Tensile Strength (ksi)	74,6	58,4	75,7	79,3	52,9
Ultimate Strain (%)	13,3	5,0	13,3	14,5	4,0

NOTE: tests for winds of 4.4 m/s have been split into two cases: (1) there was the presence of slag inclusion in one sample and (2) there was the presence of slag inclusion in two samples.

However, the tensile strength test for FCAW-S process in the presence of wind drew attention to a problem that hadn't been discovered yet.

Some samples welded in the presence of wind showed the existence of brittle slag inclusion, Fig. 26, with deleterious effects on the welding joint. This occurred in all samples for winds of 2.3 m/s, no sample for winds of 3.3 m/s and two samples for winds of 4.4 m/s.

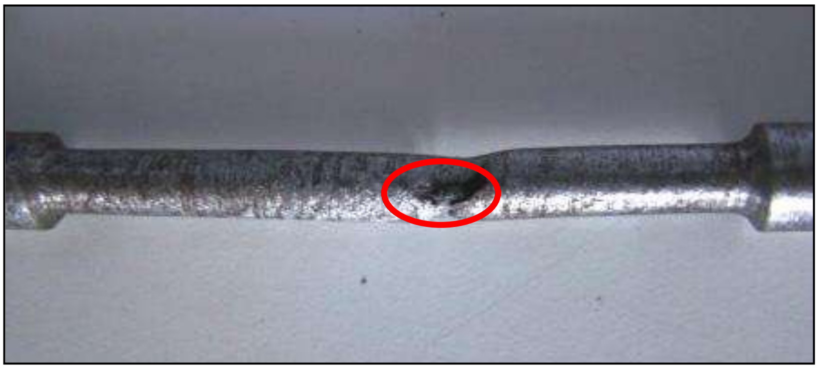

Figure 26. Brittle Slag Inclusion FCAW-S - Winds of 2.3 m/s.

It has been evaluated that it happened not by limitations of the process, but because of the inexperience of the welder with this kind of wire and he was acquiring experience along the welding process. This explains why situations with worse conditions of wind (3.3 m/s 4.4 and m/s) had better results than 2.3 m/s.

In Tab. 4, it can be observed that the values obtained for winds of 3.3 m/s and for the case with winds of 4.4 m/s without slag are compatible or better values than those obtained in the absence of winds.

4. CONCLUSIONS

This study compared two welding process, FCAW-G and FCAW-S, in the absence and presence of winds. It has been used three wind speeds: 2.3 m/s, 3.3 m/s and 4.4 m/s.

The results agree with the literature on the topic that points to the total loss of quality of welding by FCAW-G process in the presence of winds, even if moderated. Therefore, protections against the wind should be erected for welding by this process in open places. The results also agree with the literature regarding the usability of FCAW-S in case of presence of winds without needing to use protection for them. The quality of welding obtained in this situation was compatible with the obtained in the absence of wind. Such conclusion can be of great importance in mounting projects of large structures that require intensive soldering as is the case of shipyards. Other very important conclusion is that the welding with FCAW-S process requires a specific training, due to the large production of slag and smoke, as well as to the fact this process usually demand direct polarity when the more common in arc welding processes is the use of reverse polarity. If cautions are not taken, there will be retention of slag weld fillet, forming fragile inclusions that compromise the quality of welding.

5. ACKNOWLEDGEMENTS

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