COMPARATIVE STUDY OF MECHANICAL PROPERTIES AND THE MICROSTRUCTURE OF MAG WELDING AND DOUBLE WIRE MAG WELDING WITH COLD WIRE ADDITION

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Abstract. *The proposal of the MAG welding process with addition of not energized wire (cold) is established as a technical and economical alternative to the MAG welding. This new welding version requires only traditional equipment (a constant voltage welding power source) with an extra welding head to the cold wire feeding connected to a welding torch and to a device docking until the end of the torch in order to lead the cold wire until the liquid metal pool. The cold wire has reduced dimensions and it allows the semiautomatic welding. The main features of the double wire MAG process are high productivity, high deposition rate, conditions which decrease the defects in welding, among others. This study presents the experimental research of filling MAG welding and MAG welding with cold wire in V-groove. During the development it was utilized AWS ER 70S-6 wire, with 1,2 mm diameter, and AWS E 71T-1 wire, with 1,2 mm diameter. In MAG welding with cold wire, it was used AWS ER 70S-6 (electrode) and AWS E 71T-1 (cold) wires. The welding was performed in ABNT 1020 steel with 16,4 mm thickness, 60 degrees chamfer, without a backing, using a semiautomatic process with four passes to the filling of the joint in flat position, positive direct current with a constant voltage power source. The shielding gas used was the* CO_2 *in 15 l/min. The effect of microstructural variation of the weld metal of the welded joints on the test results was studied and impact, micro hardness and tensile tests were carried out at room temperature. The results reveal that the viability of MAG welding with addition of cold wire process due to the good operational performance. These results showed changes in the microstructure of the weld metal with addition of cold wire, compared to MAG welding, because of the elements of alloy, in particular manganese, has changed the metallurgical properties of the welding joint. Mechanical strength tests showed that MAG welding with cold wire addition overcomes the conventional MAG welding process by the appearance of Martensite and Tempered Martensite in its microstructure.*

Keywords*: MAG with cold wire, microstructure and mechanical properties.*

1. INTRODUCTION

The use of MIG/MAG welding processes are getting more frequent and it is currently the most used welding method in Western Europe, in The United States and in Japan. It happens due to its high productivity and its automation facility. We can say that versatility is the main feature in MIG/MAG welding process, because the experiments can happen in many kinds of metals, low steel alloys, stainless steel and aluminum, with thickness from 0.5 mm, in all welding positions. This new labor market is getting more and more demanding, and that is the reason why new processes are being developed. These new processes allow an increase in production and in quality of new products, but with low costs.

Under the conditions given, the GMAW (Gas Metal Arc Welding) with double wire process was developed. This process is based in the constitution of two electric arcs between the specimen and the two consumables which are fed continuously. Externally supplied gas or gas mixtures provide shielding for GMAW with double wire, as well as it happens in the GMAW conventional process, recent work (Motta, 2002). However, the GMAW with double wire increase the costs because of the equipment and power resources involved in the process, which restrict its use in industrial scale. We wanted to decrease the costs of the GMAW with double wire process, but without losing its advantages. Then a new proposal appeared, the GMAW with a cold wire addition (GMAW-CW) process, as an alternative proposal on GMAW with cold wire (both energized wires), recent work (Barrozo, 2006).

This new welding version requires only traditional equipment with an extra welding head to the cold wire feeding connected to a welding torch. The GMAW-CW process uses only one power source and one shielding gas system, while the power provided to the extra welding head to the cold wire feeding comes from the same power source, recent work Bacelar *et al.* (2005).

The advantages of this new process, when compared to the conventional process, are associated to the control of economical and geometric features, to the wire feeding in two different speeds, to the use of electrode wire and cold wire with different diameters, to a small heat affected zone (HAZ), to a decrease in emission of radiation and smoke, to a decrease in costs with equipments and power, it reduces the torch weight because of the new device used in the cold wire feeding and it avoids magnetic deflection. Speaking about the conventional MAG (Metal Active Gas) process, specifically about MAG-CW (Metal Active Gas – Cold Wire), this last one has some main advantages like shielding gas economy and high productivity, high deposition rate, conditions which decrease the defects in welding, among others, recent work (Sábio, 2007).

2. MATERIALS AND METHODS

During the development it was utilized AWS ER 70S-6 wire, with 1,2 mm diameter, and AWS E 71T-1 wire, with 1,2 mm diameter. In MAG welding with cold wire, it was used AWS ER 70S-6 (electrode) and AWS E 71T-1 (cold) wires. The welding was performed in ABNT 1020 steel with 16,4 mm thickness, 60 degrees chamfer, without a backing, using a semiautomatic process with four passes to the filling of the joint in flat position, positive direct current with a constant voltage power source. The shielding gas used was the CO_2 in 15 l/min.

After the machining process, the grooved specimens were dotted, as it is shown in Fig. 1, by MAG Process. Figure 2 shows the welding bench, and figure 3 shows the cold wire feeding device.

It's reliable to say that MAG-CW welding begins with the opening of the voltage arc by the ignition of the electrode AWS ER 70S-6 and, after 1 second, the feeding of the cold wire E71T-1 begins. The conclusion of the welding in the specimens must happen in two moments: the interruption of the cold wire feeding and the extinction of the arc. In double wire welding was used the parallel position.

In this paper, current and voltage parameters of welding were controlled through oscillograms and they were kept constant in the filling passes of joints to make possible comparisons between both welding processes.

In MAG-CW welding process, it was used a feeding speed of approximately 40% corresponding at the feeding of electrode wire. Table 1 and Table 2 show the parameters used in for deposition of root pass and filling passes to the processes.

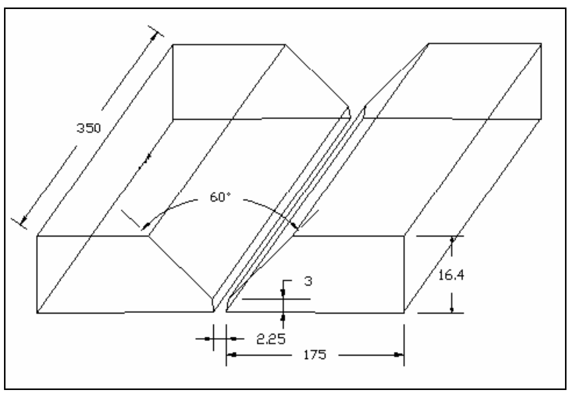

Figure 1. Specimen used in the experiment. Dimensions in mm.

Figure 2. Welding bench used in the welding deposition. (1) Welding power source; (2) Auxiliary power source; (3) Auxiliary wire feeding welding head; (4) Auxiliary cold wire welding head; (5) Torch; (6) Notebook used for data purchase.

Figure 3. Wire feeding device connected to the welding torch.

Table 1. MAG conventional welding parameters.

MAG	Voltage(V)	Current(A)	Speed of Electrode Wire (m/min)
Root passes	26,5	112	3,5
Filling Passes	27,5	200	6

Table 2. MAG-CW Welding parameters.

MAG-CW	Voltage (V)	Current (A)	Speed of Electrode Wire (m/min)
Root passes (MAG)	26	93	3
Filling passes (MAG-CW)	27	185	6

(1) : Speed of Cold Wire = 2.5 m/min.

2. METODOLOGY

2.1. Micrography

The micrography was used in this experiment to evaluate qualitatively the microstructure of the welded joint in the last pass and in the region which was retransformed evaluating the whole microstructure and correlate to the mechanical properties in the welded joint. All the surfaces have been polished previously using sandpaper starting from sandpaper 100–1500, they were burnished in order to finish using diamond suspension with granulometry 0.1 µm. Later on, they are cleaned using acetone or alcohol in order to eliminate grease. Then after being rinsed the surface went through a chemical etching in 2% solution of nitric acid in alcohol (Nital), which was controlled by partial immersion in the reagent during 5 seconds.

2.2. Mechanical Strength Tests

The following conditions that will be described to the accomplishment of the tests: tensile strength test, impact strength test and micro hardness test. The metal test specimens came from the welded joint.

2.2.1. Tensile Strength Test

The tensile strength test's purpose is to evaluate the tensile strength (σ_r), the yield stress (σ_e), the strain (ε), and the offset yield point (proof stress) (φ) in the welded joint specimens. This test was performed in environmental temperature according to AWS Standard A5.18. The specimens were removed from the central axial area of the welded joint. The machining process followed what is established in NBR Standard 6152 of ABNT standards, the final dimensions, in mm, are shown in Fig. 4.

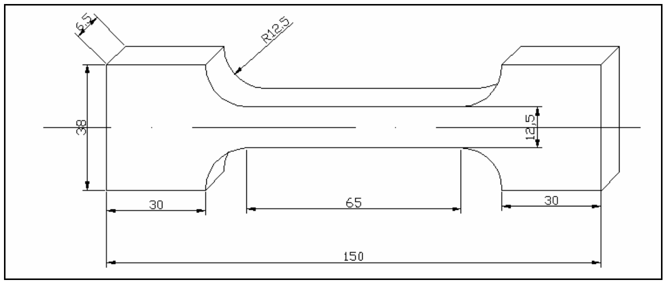

Figure 4. Sketch of the tensile strength test’s specimen, dimensions in mm.

2.2.2. Impact Strength Test

This notched-bar impact testing of metallic materials by the Charpy V-notch was performed to evaluate the toughness of the welded joint in room temperature. The test procedure followed the ASTM Standard E 23-01. The machining test followed the AWS Standard A5.18. The specimens came from the cross section of the welded joint, and they had been machined. Figure 5 shows its geometry, its dimensions, and where its notch can be found into the welded joint.

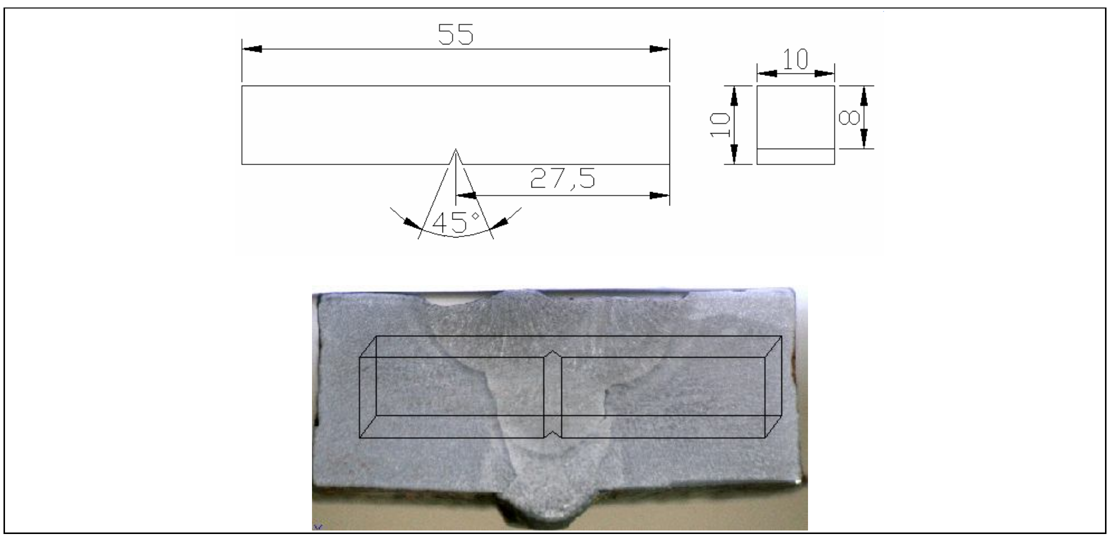

Figure 5. The specimen used in the impact test by the Charpy V-notch, dimensions in mm.

2.2.3. Micro Hardness Test

The purpose of this test is to evaluate the resistance to the permanent plastic deformation in the welded joint. The tests were performed with the Shimadzu HMV-2 microhardness tester in environmental temperature. The test procedure followed the ASTM Standard 384-99. The microhardness indentation has a space between another one, which is 0.5 mm. The microhardness indentations have been made in the flat cross section of the welded joint, after the surface has been burnished, and under its central line on the way top-root. For the Vickers hardness test, it was used a load 4.903 N or 0.5 HV, and 30 s was the time of load application. The first measurement, under the last welding pass, was performed around 1.0 mm down the face reinforcement. According to the ASTM Standard 384-99, the length between two microhardness indentations must be 2.5 times larger than the indentation size, which is shown in Fig. 6.

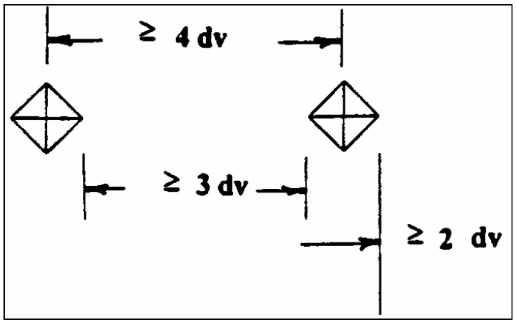

Figure 6. Distance between the microhardness indentations. (ASTM Standard 384-99).

2.3. RESULTS

2.3.1. Micrography and Mechanical Properties

One of the biggest goals in metallurgical development in welding processes is the welding productivity which combines high mechanical strength and good results of toughness at low temperatures in order to decrease costs in the whole process. It is known that mechanical properties, particularly impact strength, are quite sensitive to small variations in the welding operational parameters, the welding procedures, the chemical composition and the microstructure of the welded metal, recent work (Mota, 1998).

2.3.2. Micrography

The qualitative analysis of the micro constituents was performed in the columnar zone in the last pass and in the retransformed area, which coincides with the notch in the Charpy-V specimens. The analysis was possible because it was used an optical microscopy, MO (400X). The pictures of the microstructures were compared to the ones in Handbook, Vol. 9, to confirm that the micro constituents exist.

The analysis of the Fig. 7 shows long shafts of Primary Ferrite (PF), Secondary Ferrite (FS) and Polygonal Ferrite (FG). In MAG welding we could see the formation of Martensite (M), if we compare to the microstructure of MAG welding with cold wire, which we didn't found it. It was probably due to higher heat input used in MAG welding. It was observed the microstructure of the refined zone by the previous pass. The analysis of the Fig. 8 shows the microstructure of the refining zone by MAG welding process previous pass. This picture revealed the predominance of Primary Ferrite (PF), with a different microstructure observed in the previous pass.

The analysis of the Fig. 9 indicates the presence of Primary Ferrite (PF), Secondary Ferrite (FS) and lines of Martensite (M). Looking at the Fig. 10, we found the microstructure in the previous pass and in the retransformed area of MAG welding with cold wire. The analysis of this picture suggests the presence of tempered martensite, which characterizes as a different micro constituent if compared to the one observed in the previous pass (columnar zone). This is due to the manganese that exists in the flux inside the cold wire which contents was not enough to stabilize the stages of the columnar zone. The microscopy of the welded joint showed the presence of micropores.

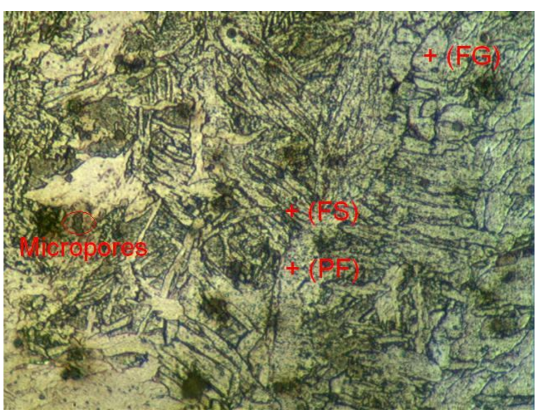

Figure 7. Last pass MAG Welding, 400X.

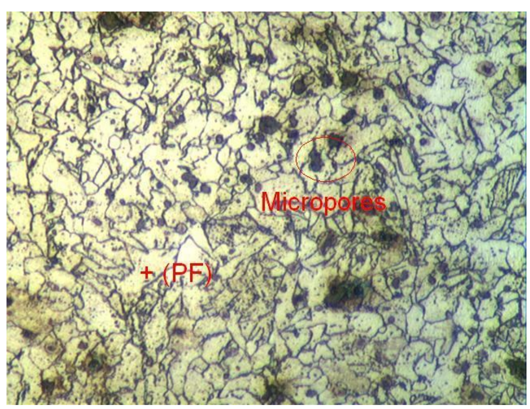

Figure 8. Refining Zone MAG Welding, 400X.

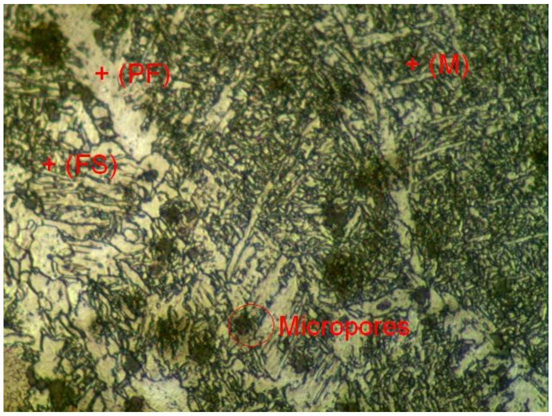

Figure 9. Last pass MAG welding with cold wire, 400X.

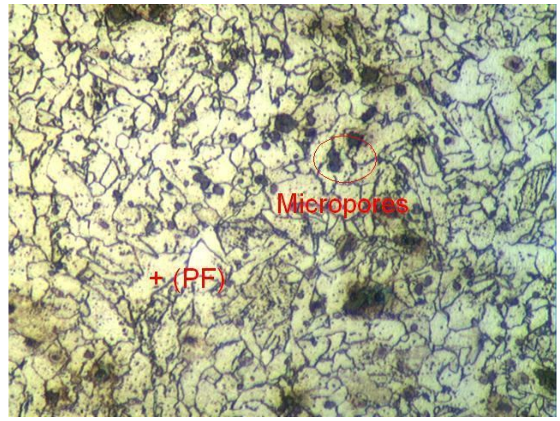

Figure 10. Refining Zone MAG-CW welding, 400X.

2.3.3. Microhardness Test

Table 3 shows information about the microhardness test in the cross section of the welded metal. In this table, the numbers mean the microhardness in the central line on the way top-root. Figure 11 shows the cross section of the welded joint before microhardness test.

Figure 12 shows the microhardness section of the specimens welded by MAG and MAG-CW processes. An increase in microhardness in the MAG-CW welded joint was noticed. There is no uniform decreasing in the microhardness on the way top-root, when it is compared to the microhardness section joint welded by MAG process. The increase in the microhardness on the root of the joint welded filled by MAG-CW process can be explained by the reheating effect in the later pass that refined the grains, once the welded joints were filled by MAG process.

The behavior presented by the MAG-CW welded joint has its ground on the changes in the metallurgical properties induced by the tubular wire AWS E 71T-1, due to the increase in the manganese content in the welded metal, which is going to influence in microhardness increasing.

Table 3. Microhardness Vickers in MAG and MAG – CW processes.

Connection Zone	**Measuring Points**	**Microhardness Vickers, HV 0,5**	
		MAG	**MAG - CW**
Top	1	208	194
	2	206	222
	3	194	233
	4	208	215
	5	193	201
	6	205	203
Notch	7	204	211
	8	212	214
	9	207	200
	10	209	212
	11	190	191
	12	185	200
	13	183	181
	14	190	198
	15	181	214
	16	179	209
	17	193	205
	18	207	200
	19	198	198
	20	187	198
	21	172	191

	22	185	198
	23	178	193
	24	184	184
	25	177	196
	26	187	208
Root	27	180	217
	28	175	212
	29	164	231
	30	165	217

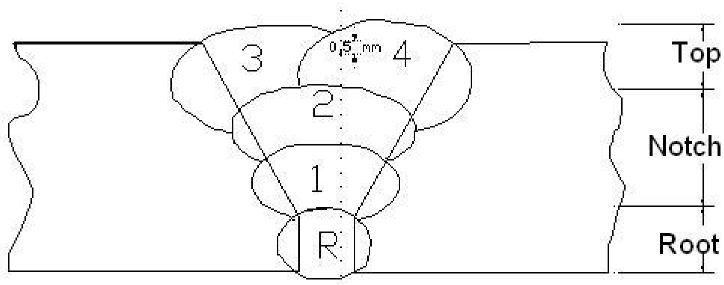

Figure 11. Cross Section of the welded joint.

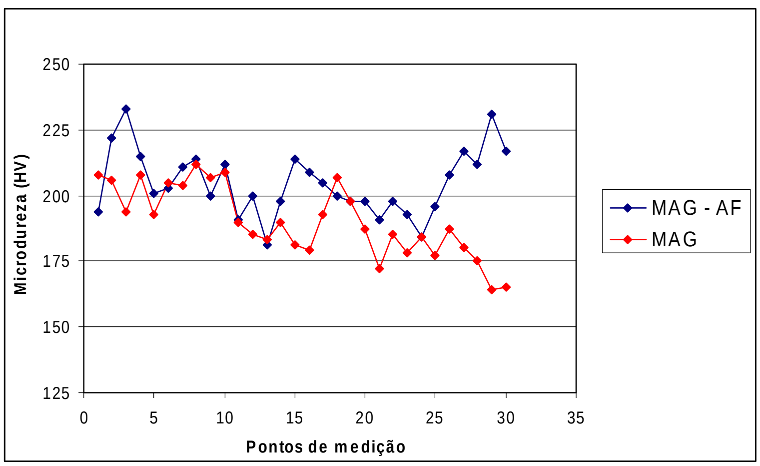

Figure 12. Microhardness contours of welded joints with and without cold wire addition.

2.3.4. Tensile Strength Test

The results of the Tensile Strength Test is shown in Tab. 4, where it is possible to compare the numbers of the tensile strength (σ_r), the yield stress (σ_e), the stretch perceptual (A) and the offset yield point (proof stress) (φ). In general, the numbers from σ_e and from σ_r obtained to the welding processes overcame the minimum value specified to the commercial wires that were used, besides that numbers used to the commercial steel of the base metal.

The test results also showed that the MAG - CW process obtained higher values of σ_e and σ_r, compared to conventional MAG process. Therefore, the incorporation of alloy elements such as manganese through the cold wire (AWS E 71T – 1) tended to modify the metallurgical properties of the welded metal by changing its microstructure, in this case it presented constituents as laminar constituent, martensite and tempered martensite, which advanced the increase of mechanical properties and influenced directly the tensile strength of the welded joint.

After the Tensile Strength Test, ruptures were found in the specimens, and they were analyzed to identify the behavior performance of the welded metal. The test can be considered reliable because there are not any defects in the rupture region of the specimens. In both cases the rupture was ductile. Figure 13 and Figure 14 showed graphics with behavior performance of specimens during the Tensile Strength Test.

Table 4. Numbers of Tensile Strength Test to the welding joints.

Specimens	σ_e (MPa)	σ_r (MPa)	A (%)	φ (%)
MAG (CP13)	450	545	20	60
MAG – CW (CP03)	480	571	21	60

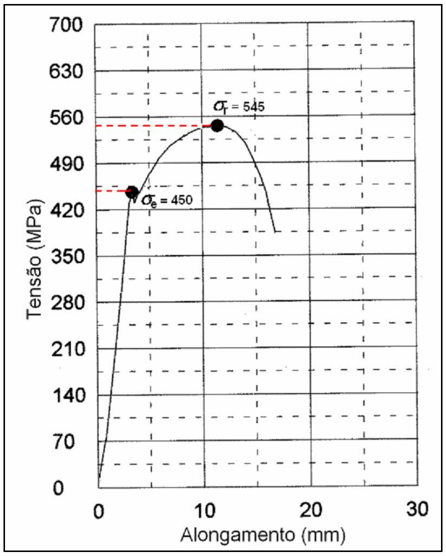

Figure 13. Graphic of MAG specimen after the Tensile Strength Test.

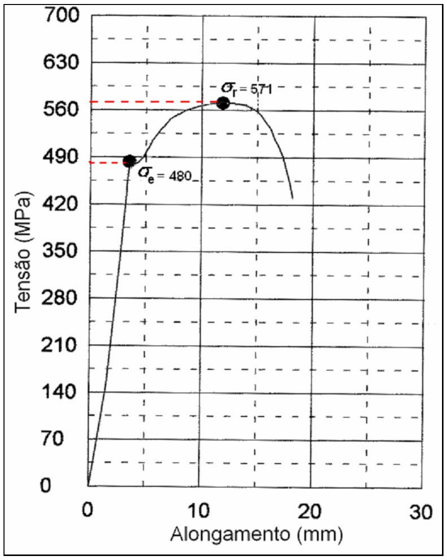

Figure 14. Graphic of MAG-CW specimen after Tensile Strength Test.

2.3.5. Impact Strength Test

Table 5 shows the results of Impact Strength Test by the Charpy V-notch, in room temperature (25ºC), to the welding processes with and without cold wire addition. There were five repetitions to each welding process, and extreme values were despised. In MAG-CW specimens, only one of them presented discontinuities and slag inclusions after the rupture, as it is shown in Fig. 15, but this one has not shown the lowest value. In the table of impact strength test, besides the intermediary values of strength impact and its medium values, it is shown the standard deviation.

Evaluating the Tab. 5, it is possible to see that the highest values for strength impact were assigned to MAG-CW welding process. This increase may be due to changes in metallurgical features of welded metal imposed through alloy elements addition in cold wire, particularly manganese, which influence directly the microstructure of welded metal (with presence of tempered martensite). Figure 16 helps in interpretation of the numbers, because it shows the variation of impact strength in welding processes.

After the impact strength test, surfaces of rupture in the specimens were evaluated, according to Fig. 16, to identify the kind of fracture in the welded joint. The ductile fracture predominated in both processes which were studied.

Table 5. Numbers of Impact Strength Test, (J).

Specimens	Impact Strength, (J).		
	25 °C	Average	Standard Deviation
MAG (1)	158	163	11,4
MAG (2)	158		
MAG (3)	172		
MAG - CW (1)	190	201	14,6
MAG - CW (2)	198		
MAG - CW (3)	215		

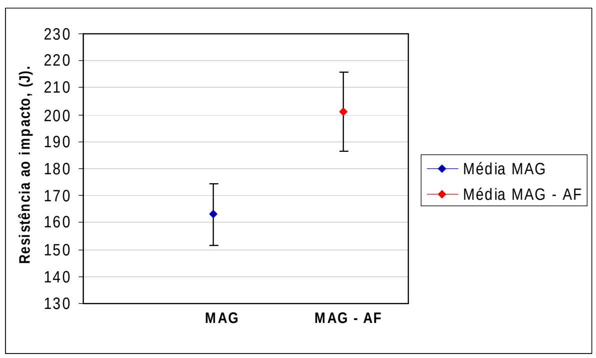

Figure 15. Average to the impact strength to welding processes with and without cold wire addition.

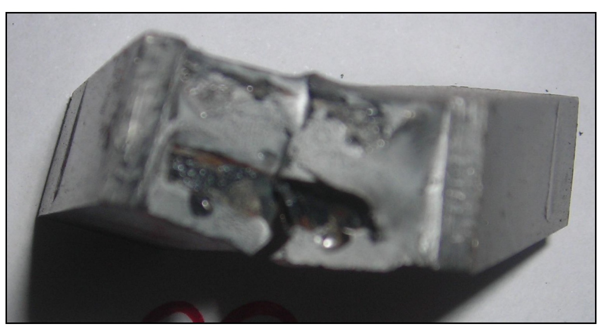

Figure 16. MAG-CW Charpy specimen after the Impact Strength Test.

3. CONCLUSIONS

The analysis of the results which were obtained during the experiments based on the references allowed the following conclusions. The welded joints of both processes presented a good superficial aspect, despite the entire undercutting weld in MAG process specimen and the presence of splashes in the welded joints. The torch's manipulation influenced the quality of these joints. The slag inclusions presented in MAG-CW specimens did not affect its mechanical strength. The changes in the metallurgical properties induced by the tubular wire AWS E 71T-1 influenced the welded metal's microstructure and its mechanical properties. The numbers of the microhardness increased in the process with cold wire addition, the microhardness did not increase on the way top-root, in a constant way, it decreases in the top area, it sways in the groove area and it increases in the root of the welded joint. MAG-CW specimen's tensile strength test obtained higher values than MAG specimen's test. Both results were higher than the base metal's test. Finally, it is possible to say that alterations in parameters, as welding energy or the shielding gas used during both welding processes may contribute in the decreasing of the discontinuities found and make both processes feasible in industry fields.

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