STUDY OF THE INFLUENCE OF WELDING PROCESSES MIG/MAG AND SHIELDED ELECTRODE ON THE MICROSTRUCTURAL BEHAVIOR AND HARDNESS IN WELDED JOINT OF THE API 5L X80 STEEL

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Abstract. *Welding is the principal means of joining pipes in industrial environment, and the shielded metal arc welding process is the most widely used, because of its operation and versatility ease. Aiming to reduce costs and increase productivity, particularly in long process, many companies use semi-automatic welding processes. In this work two processes were analyzed and compared, the MIG/MAG and the shielded metal arc welding. These processes are used in the welding of pipes in the area of ALUMAR, in São Luís doMaranhão, using argon as shielding gas. They are used in seamless tube API 5L welding, defining the best process for welding of that steel, in point of view of its weldability. They were realized microstructural and microhardness analysis at the following locations: Base Metal (MB), Heat Affected Zone (HAZ) and Weld Metal (MS). The employed test was the Vickers microhardness, which it was realized in three parallel lines drawn in the specimen, in a bottom line, a central line, and a superior line. When it was using the MIG/MAG process, practically no variation in microhardness was found, when it is comparing the three regions. Already with the shielded metal arc welding process, in the measurements taken on the bottom line and on the central line, it was finding a higher microhardness in the MS. This increase in microhardness may indicate a principle of embrittlement in this region. In the MS region using shielded metal arc welding process was found basically a microstructure of acicular ferrite, while in other regions, and in the three regions using MIG/MAG process, second phase ferrite with polygonal ferrite were predominant. Of the microhardness and microstructure analyze is concluded that the most recommended process for API 5L steel welding is the MIG/MAG. This process facilitates the mechanization of the system production.*

Keywords*: API 5L steel, shielded metal arc welding, MIG/MAG welding, microstructure, microhardness.*

1. INTRODUCTION

HSLA steels (High Strength Low Alloy) were initially designed in order to meet the needs of the oil industry. They are called so because its content exists in a presence of carbon ranging from 0.05 to 0.25%, and percentage of manganese up to 2.0% (Ordóñez, 2004).

Among the practices used in the fabrication of HSLA steels, the most widespread has been the controlled rolling, where various combinations of temperature and amount of hot deformation aim high values of strength and toughness from the effects of grain refinement and precipitation of carbides and nitrides of microalloying elements.

HSLA steels, due to its high toughness and his big yield strength, good weldability and formability, are used in the manufacture of pipelines.

Steels classified API are also HSLA steels called, they have with the characteristic, a high resistance, in line with good weldability and low level of inclusions and good surface quality. All these steels have its specification by the American Petroleum Institute (Ordóñez, 2004).

The basic chemical composition of the API 5L steel that was used in this work is shown in Table 1.

Table 1 - Composition of steel API 5L (Ballesteros et. Al., 2010)

Chemical element	C	Si	Mn	P	S	Cr	Mo	V	Nb
Percentage (%)	0.07	0.15	1.84	0.017	0.007	0.17	0.20	0.02	0.061

For low alloy steels must know the mechanical properties, besides having knowledge of its chemical compound (Modenesi, 2001).

Because of the wide variety of welding processes, there is a need to expand the studies in this area. Among them, checking the feasibility of the MIG/MAG process on steel API 5L, due to its high productivity and ease of mechanization.

The existence of various welding processes has raised the idea of comparing the quality of welding of seamless tube API 5L made with the SMAW process and the MIG/MAG process.

In Brazil the welding process with coated electrodes is still the most used by its ease of use, shift, which facilitates the field work, being employed in a wide range of field services.

The equipment used in this welding is one of the most simple compared to other welding processes.

However, this process, despite being widely used in the manufacture and maintenance of structures, and it is a process that has the facility to conduct their equipment; it needs skilled worker and frequent exchange of electrode. It must be done to remove the slag after each weld pass, so each weld passes, the slag must be removed.

The size of the weld pool and its shape are correlated with the current type and polarity.

Most of the weld quality is dependent on the field flawlessly, by the welder, the execution of movements. And depending on the type and thickness of the coating, the position of the electrode varies (Modenesi, 2001).

The angle of the electrode in relation to the workpiece is a very important variable in the SMAW process, because it is by adjusting the angle of the electrode in relation to that piece can get a good quality or not, and at the same welded joint time can have a poor quality weld because it has the appearance of defects in the weld bead, among many others.

The MIG/MAG process works with direct current (DC), normally with the wire on the positive, this is known as reverse polarity configuration.

The MIG/MAG process is used in most semi-automatic mode, although these days have grown to use this automated process.

Table 2 shows the chemical composition of weld metal using solid wire ER70S-6 for MIG/MAG process.

Table 2 – Chemical composition of weld metal using solid wire ER70S-6 (ESAB, 2008)

Chemical element	C	Si	Mn
Percentage (%)	0.08 – 0.10	0.90	1.50

The MIG/MAG process has relatively high advantage in semi-automatic and automatic welding of metals to the application of high and low production.

Its advantages compared with the coated electrode are:

- Welding can be executed in all positions;
- No need to slag removal;
- High deposition rate of weld metal;
- Total execution time of weld jointr about half the time for coated electrode;
- High travel speeds, less distortion of the pieces;
- Wide gaps filled easily, satisfied by making certain types of repair welding more efficient;
- No loss of points as the electrode coated.

Most alloys are weldable. Some are much more difficult to be welded by a given process than others.

At weldability of certain material is crucial to identify the process, welding procedure and its application.

To better determine the weldability must be verified if:

1 – The metal base is suitable for the desired application, i.e., if it possesses the properties necessary and appropriate to resist the application requirements;

2 - The design of welded structure and its welds is suitable for its intended use.

It is then necessary to evaluate the joint itself. Ideally the joint should present strength, ductility, toughness, fatigue resistance and uniform corrosion along the weld and the similar properties of the materials.

In most cases, the production of a weld involves using heat and/or plastic deformation, resulting in a different metallurgical structure of the base metal. Welds may also to show as voids, cracks, enclosed material, etc. (www.em.puc.br/feng).

This work was realized weld in seamless pipes of 6" Schedule 80 API 5L. The root pass made with the GTAW process, and filling with SMAW or MIG/MAG, and conducted study of microstructure and microhardness of the base metal, heat zone affected and weld metal. Thus we proceeded to a comparison between the two processes.

Both processes are used in the welding of pipes in the area of ALUMAR, in São Luís do Maranhão, and is used MIG/MAG welding with argon as a shielding gas.

2. MATERIALS AND METHODS

In this work, they were fabricated four samples, using the seamless tube API 5L as base metal.

In the manufacture of the specimens were utilized two welding processes: two specimens were manufactured using the SMAW process, and the other two specimens were using the MIG/MAG process.

In the welding of the specimens that used the SMAW process, the electrode E7018 was used, with 2.5 mm in diameter and DC, with 120 A. The electrode has a basic coating of the iron powder. Table 3 presents the manufacturer's recommendations. Despite the current used is relatively above the designated by the manufacturer, this was the current value provided the best condition of weld.

Os processos de soldagem, eletrodos e gás de proteção foram escolhidos de acordo com o que é utilizado para a soldagem de tubulação na área da Alumar.

Table 3 – Recommendations for welding parameter using coated electrode (Fortes, 2005).

AWS	Diameter (mm)	Current (A)	Best value (A)	Dep. Rate (kg/h)	Dep ef. (%)
E7018	2.5	65-105	90	0.8	66

In the welding of the specimen, which was used in the MIG/MAG process, was used copper-coated wire ER70S-6 with 1.2 mm in diameter, and the Ar (argon) as a shielding gas. The weld was made in the flat position and was used DC, 160 A, for filling.

The root pass of all specimens was realized using the GTAW process with rod diameter 3.25 mm and current of 145A.

2.1. Specimens

The specimens were prepared with pieces of steel pipe API 5L.

The tube was cut in half using a bend saw and made V-bevel, angle of 60 degrees, with root opening of 1 mm, to be made to the weld. After the welded had been cuts in the longitudinal welded pipe and then the strips were taken, which were cut with the following measures: length 65 mm, width 15 mm and 10 mm thick, which is the thickness tube. They were fabricated four samples with the same measurements, two specimens with the SMAW process, and two with the MIG/MAG process.

The specimens 1 and 2 were prepared using the MIG/MAG process, and 1R and 2R, using the SMAW process.

After removal of the strips of welded tube, it was made finishing in turning lathe and planer.

The welds were made by the same welder using the conditions and characteristics of the field.

2.2. Micrography

The specimens were prepared for the micrograph test by sanding and polishing. For sanding the specimens was used sandpaper in the following sequence: 80, 120, 220, 320, 400, 500, 600, 1200 and 2000.

The final polishing was performed on a polishing machine, single unit (a circular plate) with 2-micron alumina in suspension. Next, they were used 2% Nital solution to etching the region of the weld. The micrographs of the specimens were executed in an optical microscope model Olympus© BX51 coupled to a microcomputer. To capture the images was utilized the program Pro-Plus.

The micrographs were taken at the following locations: Base Metal (MB), HAZ Base Metal Interface (ZTAIMB), HAZ Central, HAZ Interface Metal Welding (ZTAIMS) and Metal Welding (MS), an increase of 500x for analysis and 200x for publication.

2.3. Microhardness test

Vickers microhardness test was performed in three parallel lines drawn on the specimen as shown in Figure 1. These lines are: lower, middle and top. It was used a microhardness HMV – Micro Hardness Tester – Shimadzu of the LCMM (Laboratory for Microstructural Characterization of Materials of the UFMA - Federal University of Maranhão). It was used a load of 0.2 kgf with a time of 10s for each indentation.

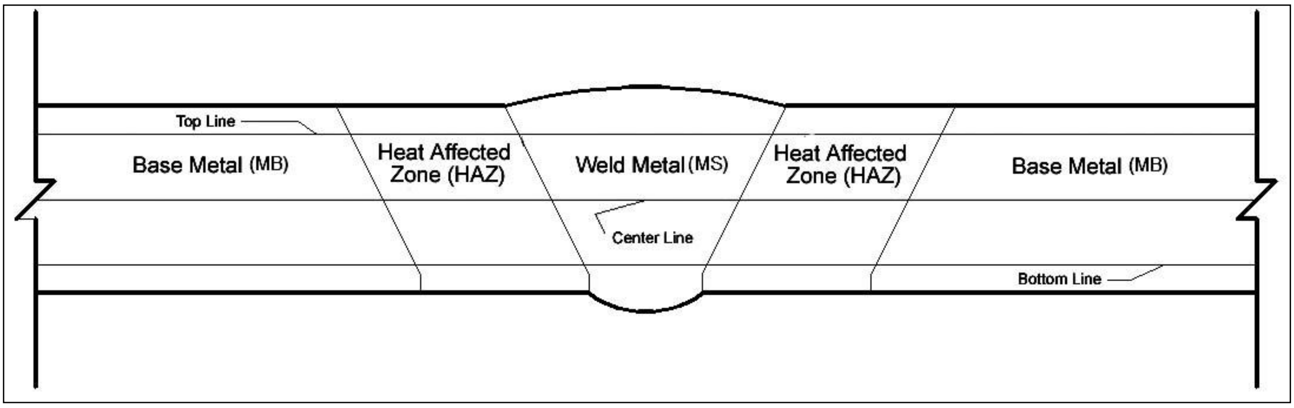

Figure 1 – Diagram of the lines of microhardness measuring.

All measurements were performed in order from left to right of the specimens.

3. RESULTS AND DISCUSSION

Table 4 shows the results of microhardness measured on the bottom line of the specimens, and Figure 2 shows the graph with the microhardness profile. The specimens 1 and 2 were welded by MIG/MAG process, and 1R and 2R, for the SMAW process.

Table 4 – Microhardness measurements on the bottom line of the specimens.

Bottom Line					
Specimen		1	2	1R	2R
Base Metal	1	186	146	162	172
	2	153	153	154	175
	3	160	151	167	184
	4	161	157	146	178
	5	187	170	162	185
Heat Affected Zone	6	180	184	208	255
	7	189	189	225	233
	8	214	181	189	220
	9	192	187	131	239
	10	199	208	228	229
Weld Metal	11	161	161	530	438
	12	194	152	447	490
	13	184	178	168	505
	14	185	165	178	495
	15	180	159	463	552

It is observed in Figure 2, that the bottom line of microhardness practically no varies in HAZ microhardness in relation to the base metal, even in the weld metal when the MIG/MAG process was using. When using coated electrode, there is a considerable increase in microhardness of the weld metal.

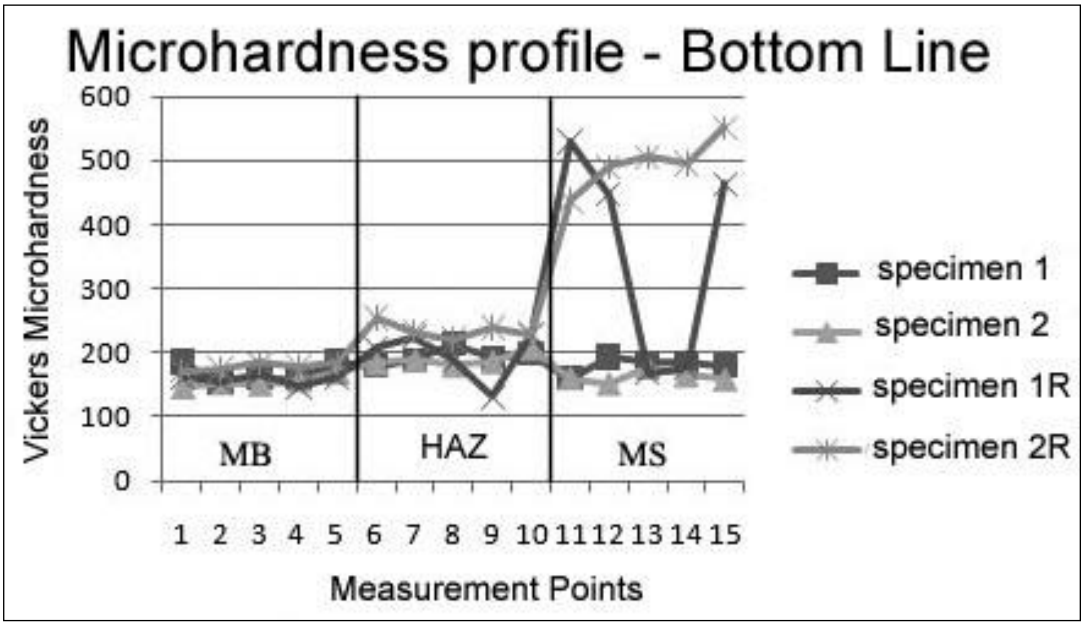

Figure 2 – Graph of microhardness profile of the bottom line of the specimens.

Table 5 shows the results of microhardness measured on the centerline of the specimens, and Figure 3 shows the graph with the hardness profile.

Table 5 – Microhardness measurements on the centerline of the specimens.

Centerline					
Specimen		1	2	1R	2R
Base Metal	1	172	197	201	210
	2	158	196	192	206
	3	155	173	174	203
	4	149	162	197	204
	5	149	170	184	202
Heat Affected Zone	6	180	182	211	254
	7	178	175	200	238
	8	165	152	199	233
	9	174	215	243	205
	10	208	230	201	219
Weld Metal	11	167	180	498	338
	12	188	211	604	377
	13	192	219	595	341
	14	180	198	623	320
	15	190	191	455	325

When analyzing the microhardness line in central region, it is noted that there were no significant changes in microhardness in relation to the bottom line.

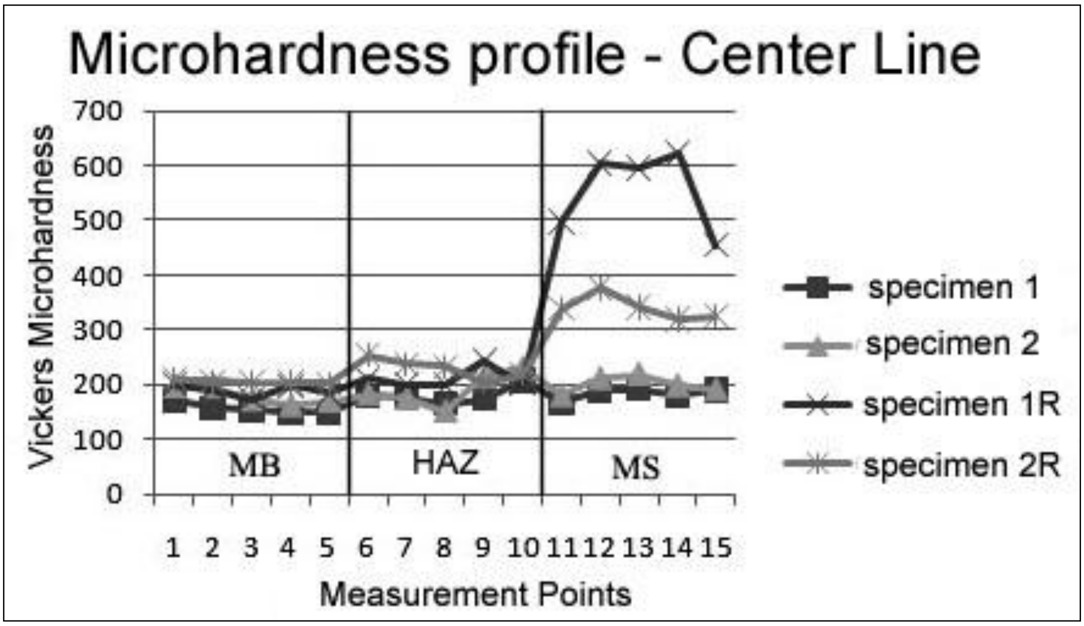

Figure 3 – Graph of microhardness profile of the centerline of the specimens.

Table 6 shows the results of microhardness measured on the top line of the specimens, and Figure 4 shows the graph with the hardness profile.

Table 6 – Microhardness measurements on the top line of the specimens.

Top Line					
Specimen		1	2	1R	2R
Base Metal	1	149	173	291	146
	2	153	152	217	192
	3	147	158	186	168
	4	154	155	176	197
	5	140	190	166	201
Heat Affected Zone	6	176	169	242	179
	7	225	157	244	186
	8	188	217	113	180
	9	226	217	181	180
	10	206	182	223	180
Weld Metal	11	198	287	355	220
	12	194	351	195	250
	13	195	238	233	243
	14	183	250	265	230
	15	184	256	221	234

This region is not influenced by the heat of subsequent weld passes, and no change in microhardness is observed, showing that they are in the same range both in the base metal, and in the HAZ and weld metal.

From the results, it can be assumed that the heat from subsequent passes influenced the microhardness of the weld metals, in the lower and central regions, when using the electrode coated.

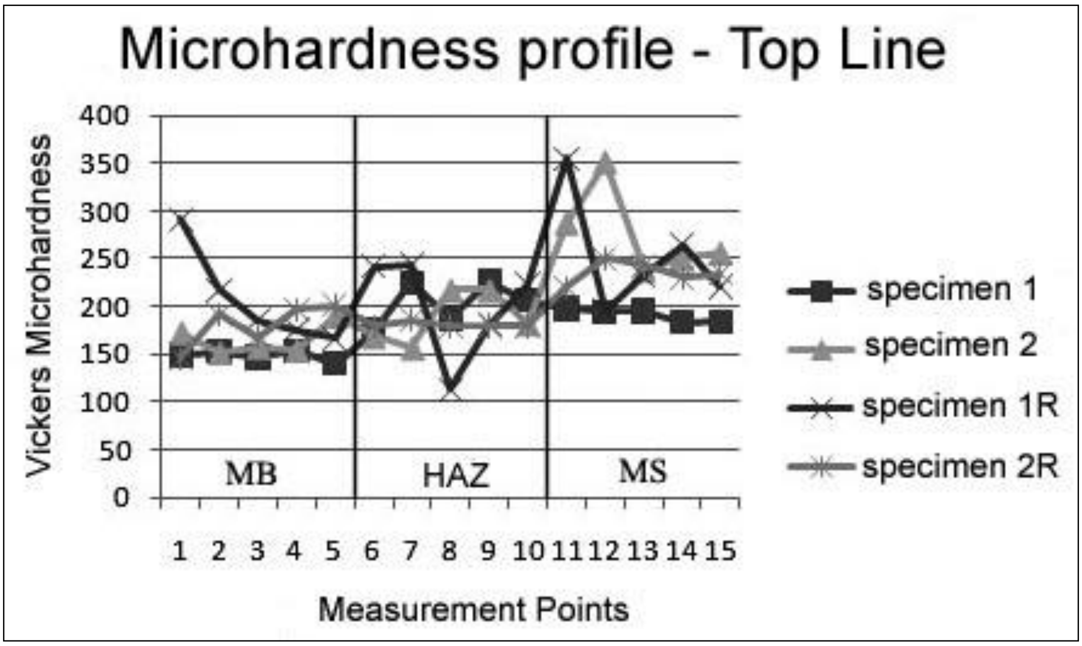

Figure 4 – Graph of microhardness profile of the top line of the specimens.

Figure 5 shows a micrograph of the heat affected zone of the specimen welded with SMAW process, showing a microstructure mainly composed of second phase ferrite and polygonal ferrite.

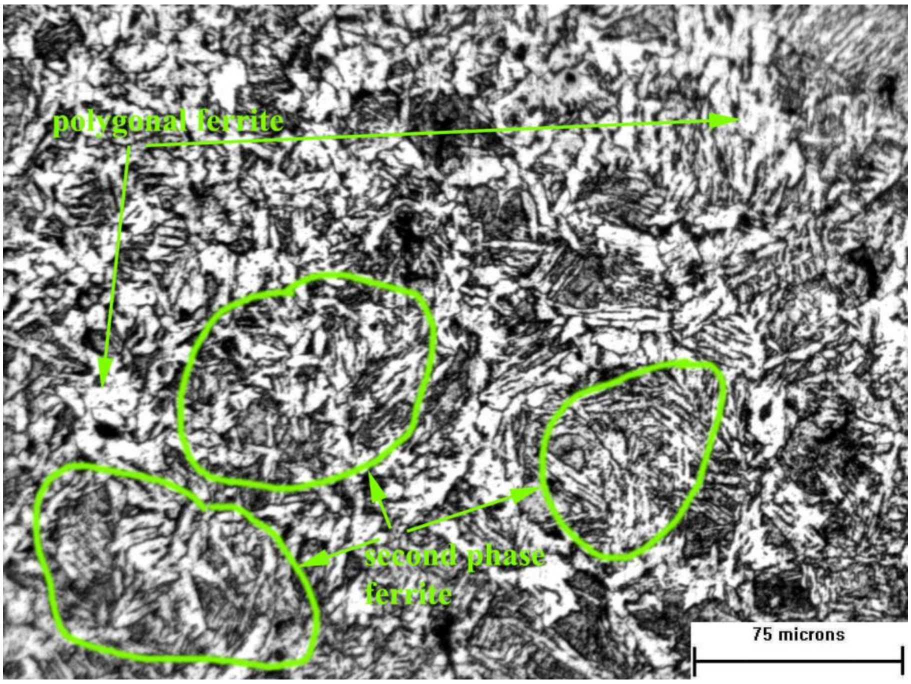

Figure 5 – Micrograph of the heat affected zone of the specimen welded with SMAW process. Etching – Nital 2%.

Figure 6 shows a micrograph of the weld metal of the specimen welded with SMAW process, showing a microstructure consisting of predominantly acicular ferrite.

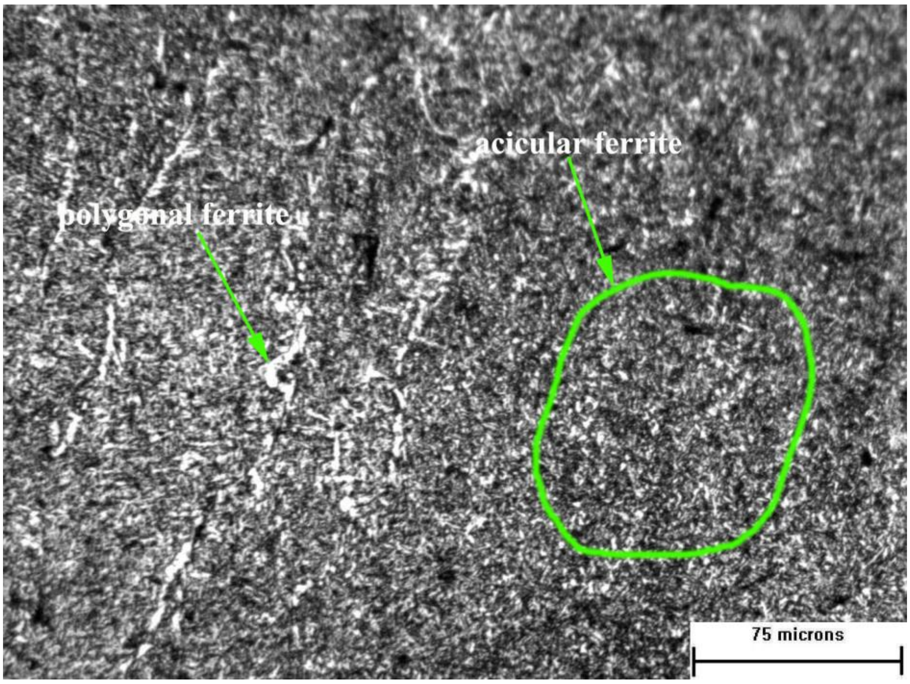

Figure 6 – Micrograph of the weld metal of the specimen welded with SMAW process. Etching – Nital 2%.

Figure 7 shows a micrograph of the heat affected zone of the specimen welded with MIG/MAG, showing a microstructure consisting of predominantly second phase ferrite.

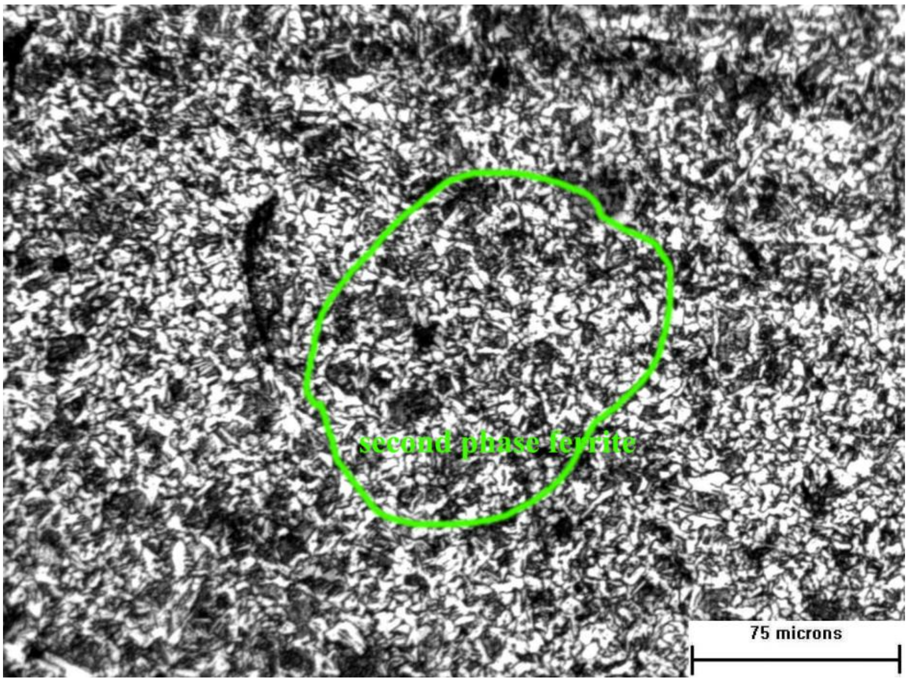

Figure 7 – Micrograph of the heat affected zone of the specimen welded with MIG/MAG process. Etching – Nital 2%.

Figure 8 shows a micrograph of the weld metal of the specimen welded with MIG/MAG process, showing a microstructure mainly composed of second phase ferrite and of polygonal ferrite.

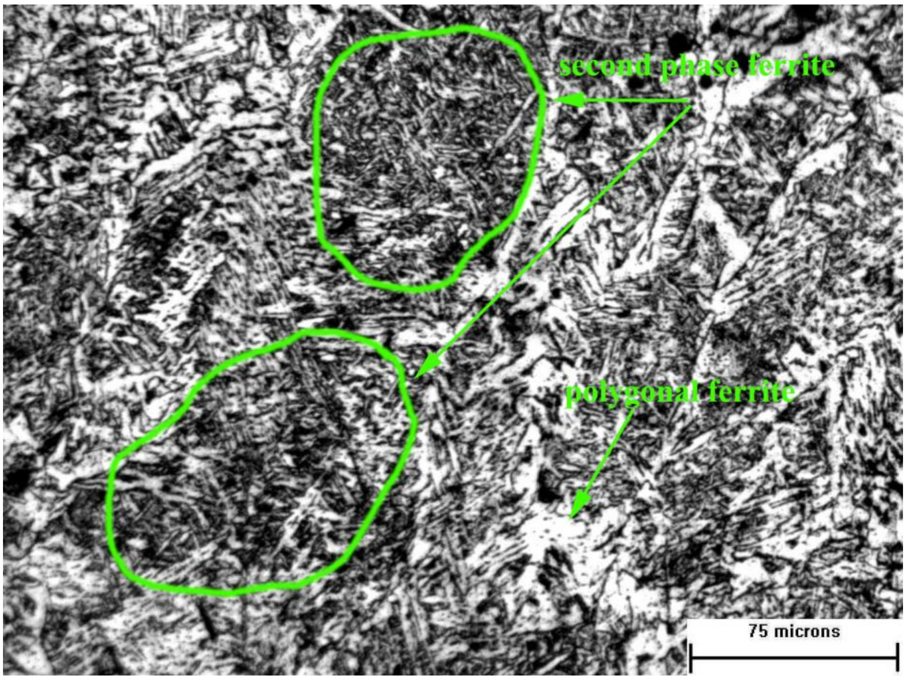

Figure 8 – Micrograph of the weld metal of the specimen welded with MIG/MAG process. Etching – Nital 2%.

By analyzing the microstructure of weld metals (Figures 6 and 8) and the results of microhardness of weld metals, it is observed that the weld metal using SMAW process showed a predominantly acicular ferrite microstructure and resulted, in general, a higher hardness than the weld metal using the MIG/MAG process, which showed a microstructure consisting of predominantly second phase ferrite, which coincides with Figueiredo (2004), who found higher hardness for the weld metal with the greatest percentage of acicular ferrite.

This indicates that the highest hardness weld metal using SMAW process can be more brittle than the one using the MIG/MAG process, according to Figueiredo (2004), who found a smaller absorbed energy and a brittle characteristic to higher rates of acicular ferrite.

The results indicate, in general, and to the conditions employed in this work, the best welding process for pipe API 5L is the MIG/MAG in view of the similarity in the microhardness of the weld metal, the HAZ and base metal and the microstructure of weld metal and HAZ, indicating a continuity in the mechanical properties of these three regions.

4. CONCLUSIONS

- There was no significant change in microhardness of the HAZ relative to the base metal, both using the SMAW process, as MIG/MAG.
- When using the SMAW process, the microstructure of weld metal was predominantly composed of acicular ferrite, whereas with the MIG/MAG process, was the second phase ferrite.
- In general, the welding metal that used SMAW process showed higher hardness than using the MIG/MAG process, it having regard with the microstructure type.
- When using MIG/MAG process, in general there was no significant change in microhardness of the weld metal relative to the base metal and HAZ.
- When using the SMAW process, in general it was observed a significant increase in microhardness of the weld metal relative to the base metal and HAZ.
- Under the point of view of microhardness, the welding process more suitable for welding pipe API 5L is the MIG/MAG process.

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