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EVALUATION OF MICROSTRUCTURE AND MICRO HARDNESS IN LASER WELDED JOINTS BETWEEN ADVANCED MULTIPHASE AND LOW CARBON STEELS FOR THE AUTO INDUSTRY

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This article presents the microstructural characterization of advanced low carbon steels used in laser welded joints of different thicknesses, and the influence of this process on the hardness of the materials used. The microscopic study of the welded materials in different thicknesses is of great importance because through it we can characterize the welded materials and analyze their behavior on a process that generates tensions and microstructural defects, which can be fatal when the material is requested. In this study were made qualitative and quantitative analyses in welded plates of TRIP, LC, BH and IF steels before and after the laser welding process. It was confirmed that the low-carbon steel, the predominant phase is ferrite, which when subjected to processes involving high temperatures, tends to increase, which increases the distance between the areas with the high energy in the grains, the boundaries, which works as crack "blockers". In the weld bead occurs athermic transformation of the ferrite into martensite, producing a zone of high hardness which if not controlled may weakened the already joint product. In this region micro hardness reaches values 5 times higher than the hardness of the material before the process, which can generate defects in the assembly after the process.

Keywords: *microstructural characterization, laser welded joints, advanced steels*

1. INTRODUCTION

The main objective of the automotive industry, in recent years, has been to reduce the weight of vehicles in order to reduce fuel consumption and emissions of gases that contributes to the greenhouse effect. The safety and impact resistance are also requirements that are part of the new concept vehicle to be developed in the coming years (Liu et al, 2009; Andrade et al, 2002; Wang; Chen; Lu, 2005).

According to the World Steel Association - Worldsteel (2009) and Zuidema et al (2001), these objectives are being achieved with a combination of innovative philosophy and processing of advanced materials, largely project outcomes Ultra Light Steel Auto Body (ULSAB), Ultra Light Steel Auto Closures (ULSAC), Ultra Light Steel Auto Suspension (ULSAS) and Ultralight Steel Auto Body - Advanced Vehicle Concepts (ULSAB-AVC).

The program ULSAB-AVC focused on conception of two light vehicles: A Class C European (called the Golf class), and another class PNGV (Partnership for a New Generation of Vehicles) North American. The vehicle chassis ULSAB- AVC uses 100% high strength steel, of which over 80% are Advanced High Strength Steels - AHSS (Worldsteel , 2009).

1.1 Tailored Welded Blank

Tailor welded blanks (TWB) is a method used in order to make full use of AHSS. The basic concept of the tailored blank is to join or sew one or more blanks with different thicknesses, where this union is made by laser brazing, see Figure 1. We can have different settings thicknesses, however the thickness ratio of 2:1 is rarely exceeded. The idea is to use smaller thicknesses which occurs less effort request, and thicknesses and / or higher strength steel in regions that suffer greater efforts and requests, see Figures 2 and 3 (Kavamura, 2007)

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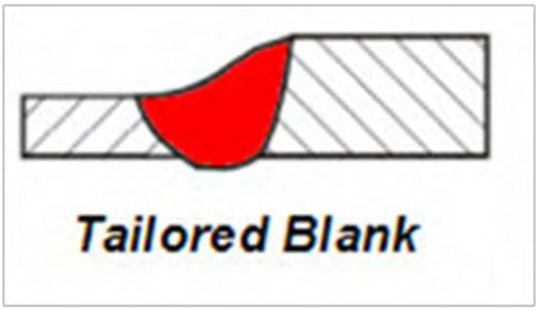
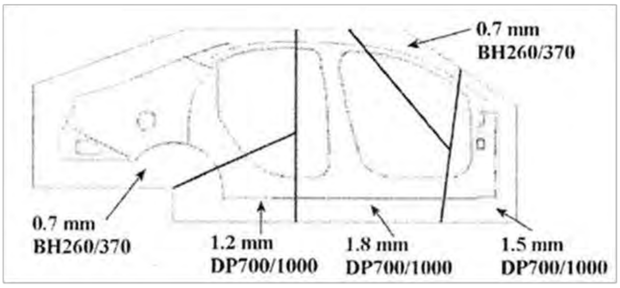


Figure 1- Junction of two blanks by laser weld.



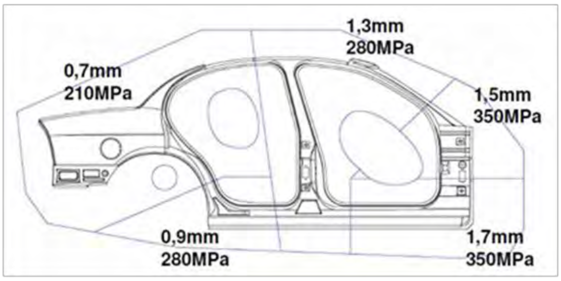


Figura 2 *– TWB side panel external (ULSAB-AVC Classe PNGV) (ULSAB).* ***Figura 3*** *- TWB Painel side panel external*

The laser welding is used as an alternative joining process in which one can achieve greater strength at the point of the weld. The heat affected zone is low, which implies less heat distortion; the fillet weld is narrower, which reduces the time for solder finishing work, the automation allows sequential welding work and can be used in places where one has access to only one side of the surfaces to be welded (Krumenauer, 2007).

The TWB method offers reduction in manufacturing costs, scrap, vehicle weight, as well as consolidation of parts and structural integrity improvements, optimization of assembly tolerances, improved structural behavior of the body, such as greater energy absorption in case of impact and weight reduction (Bayraktar; Isac Arnold, 2005)

1.2 Advanced High Strength Steels

According to Worldsteel (2009), steels used in the ULSAB - AVC Project are: low strength steels (IF - interstitial-free, C-Mn steels, bake hardening steels – BH), microalloyed steels of high-strength low alloy (HSLA), conventional high strength (HSS), and the advanced high strength steels – AHSS (which stand out: dual-phase - DP, TRIP steels, complex phases steels - CP) and martensitic steels - Mart.

Interstitial Free steels (IF) have been developed to allow the obtaining of textures appropriate to the conformation with the use of continuous annealing. The strategy adopted in the preparation of these steels is the reduction of the levels of interstitial to lower values technologically viable and the removal of these elements in solution through the formation of stable compounds as niobium or titanium.

Bake hardening steels (BH) are low carbon steels with high levels of controlled interstitials (carbon and nitrogen), with significant capacity of increase resistance through a combination of deformation and aging during the painting process.

The microstructure of TRIP steels is the retained austenite incorporated in a matrix of primary ferrite. In addition to a minimum of 5% by volume of retained austenite, hard phases such as martensite and bainite are present in varying amounts (Pereira, 2004).

The low carbon steels are steels with less than 0.005% of carbon, are more ductile (soft). Are capable of being rolled for use in automotive body applications. Carbon is removed from the steel bath by vacuum degassing.

2. METHODOLOGY

2.1 Materials

The materials used in this paper were: TRIP, LC, BH and IF. Its applications are intended for the automotive industry. The chemical compositions are represented by percentages of the alloying elements (%wt) in Table 1 and their mechanical properties are listed in Table 2.

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Table 1 - Chemical Compositions of Materials Used (Renault of Brazil, 2009)

	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Ti	V	Nb
BH	0	0,1	0,3	0	0	0	0	0	0	0	0	0	0
IF	0	0	0,2	0	0	0	0	0	0	0	0	0	0
Low Carbon	0	0	0,6	0	0	0	0	0	0	0	0	0	0
TRIP-800	0,2	0,9	0,3	0	0	0	<0,001	0	0	0	<0,001	<0,001	<0,001

Table 2 - Mechanical Properties of Materials Used (Renault of Brazil, 2009)

	Direction	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	R	n
Aço BH	T	316,4	195,6	32,33	1,99	0,19
	L	318,2	195,2	36,69	1,85	0,20
	45°	327,1	203,2	32,26	1,65	0,19
Aço IF	T	295,5	145,9	39,31	2,29	0,24
	L	297,1	144,7	40,97	2,38	0,24
	45°	299,1	152,1	41,66	2,33	0,23
Aço Low Carbon	T	354,2	239,7	32,89	2,34	0,20
	L	353,3	223,5	35,44	1,48	0,21
	45°	355,2	234,5	32,5	1,69	0,20
Aço TRIP 800	T	855,0	538,1	23,4	1,00	0,18
	L	854,2	548,2	23,1	1,09	0,19
	45°	849,4	539,0	19,1	1,01	0,19

2.2 Experimental procedure

The microstructures of the materials were analyzed before and after the laser welding process.

The techniques used for the metallographic preparation followed the standardized procedures of sectioning, mounting, griding and polishing.

The etchings were performed using reagents from 2% Nital and LePera (picral 4% and 1% sodium metabisulfite, at 1:1 proportion) with retention times between 10 and 15 seconds depending on the material being attacked.

The materials were submitted to laser welding process in the form of samples TRIP800 laser welded steel in different thicknesses with different materials. This combination is given in Table 3:

Table 3 - Relationship of welded joints analyzed

Sample	Material	Thickness (mm)
1	TRIP800 – TRIP800	1,4 – 1,4
2	TRIP800 - IF	1,4 – 0,75
3	TRIP800 - BH	1,4 – 0,75
4	TRIP800 – Low carbon	1,4 – 0,75

After the welding process, hardness tests were performed in order to analyze the effects of the procedure on the materials.

3. ACKNOWLEDGEMENTS

3.1 Microstructure: qualitative and quantitative analysis

The microstructural analysis of advanced steels has as purpose to present and discuss the different phases found in the materials through the application of chemical reagent Nital 2%. Figures 3 (a), (b), (c) and 4 illustrate photomicrographs of longitudinal advanced steels etched with reagent Nital 2%, using an increased 500x.

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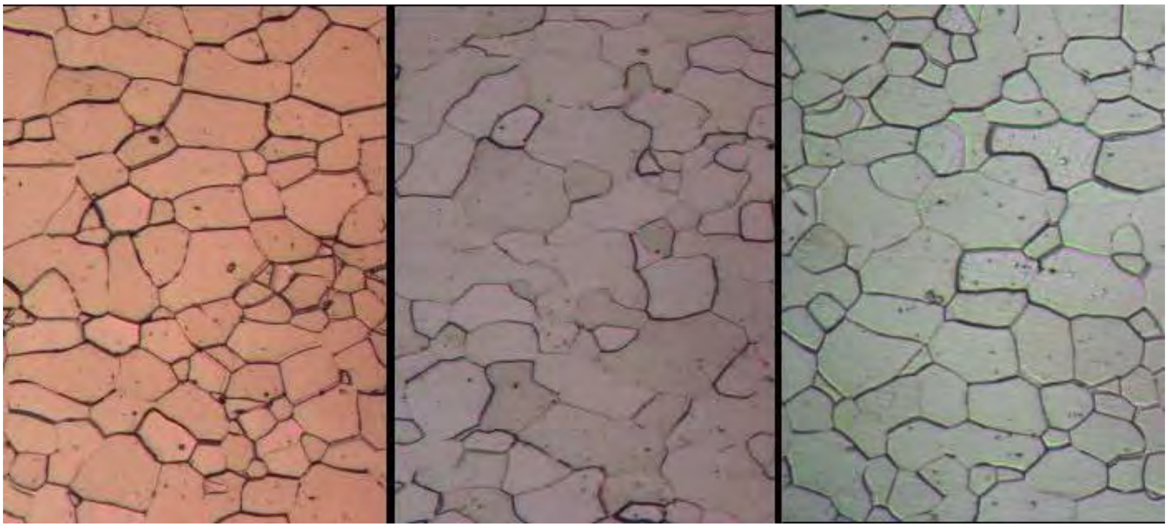

(a) **(b)** **(c)**

Figure 3: (a) Low-carbon longitudinal, magnification 500x. (b) Interstitial-free longitudinal, magnification 500x. (c) bake-hardening longitudinal, magnification 500x.

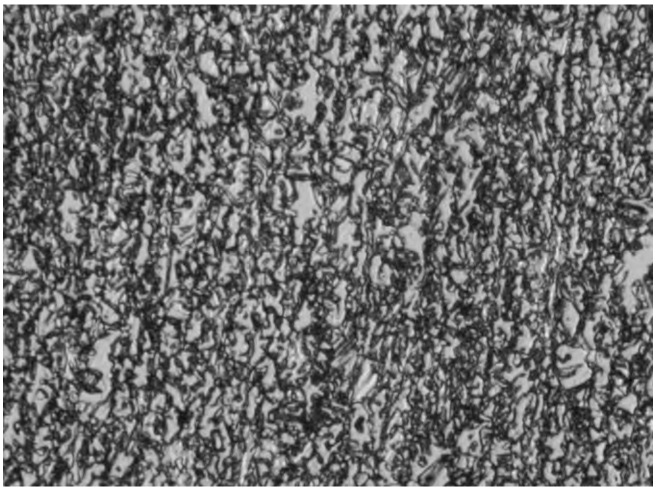

Figure 4: Microstructure - TRIP 800 steel. etching: Nital 2%. Magnification: 500x.

The etching with Nital 2% clearly revealed the grain boundaries of the phases present in steels. Only with this attack can be identify the ferritic phase in a lighter tone and the other phases that constitute the material in a dark tone. The chemical attacks were made with times between 10 and 15 seconds depending on the material being attacked.

In the table below has been posted ferrite percentage of each material obtained in attack with reagent Nital 2%.

Table 4: Volumetric fraction of the phases present in the microstructure of the analyzed material.

Material	% Ferrite	%Austenite/ Martensite/ Bainite
TRIP	62,06	37,94
IF	96,73	3,27
BH	98,86	1,14
LC	99	1

After characterizing the microstructure of advanced steels as they were supplied, the materials were submitted to laser welding process in the form of samples TRIP800 steel in different thicknesses with different materials.

The following images are the result of chemical attack made with 2% Nital in all the samples mentioned in Table 3.

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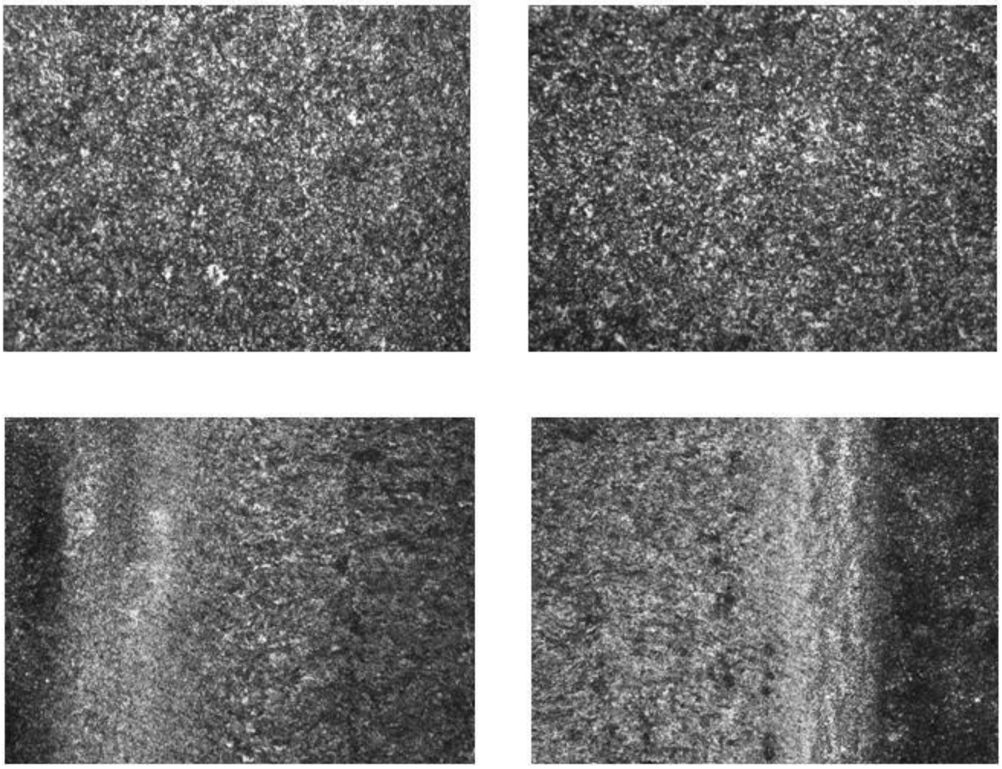

Figure 5: Different regions of the sample 1 (shallow section). Attack: 2% Nital. 50x magnification.

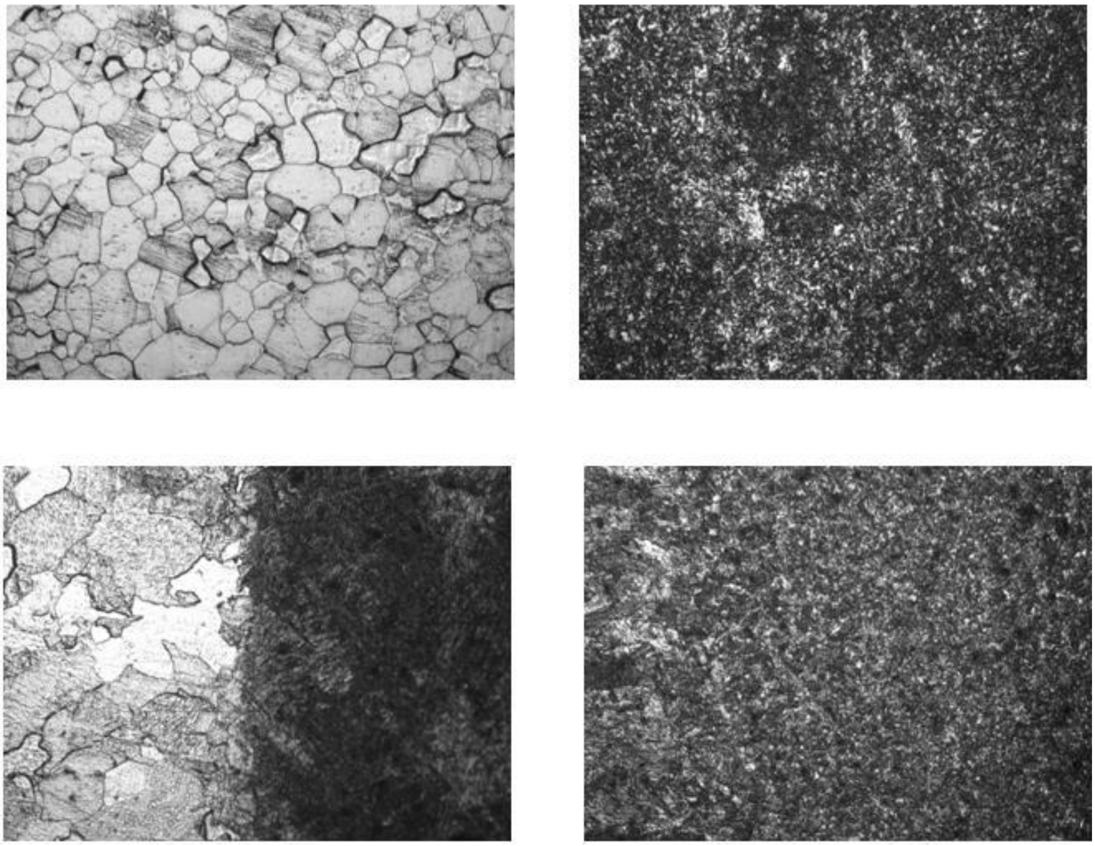

Figure 6: Different regions of the sample 2 (shallow section). Attack: 2% Nital. 200x magnification.

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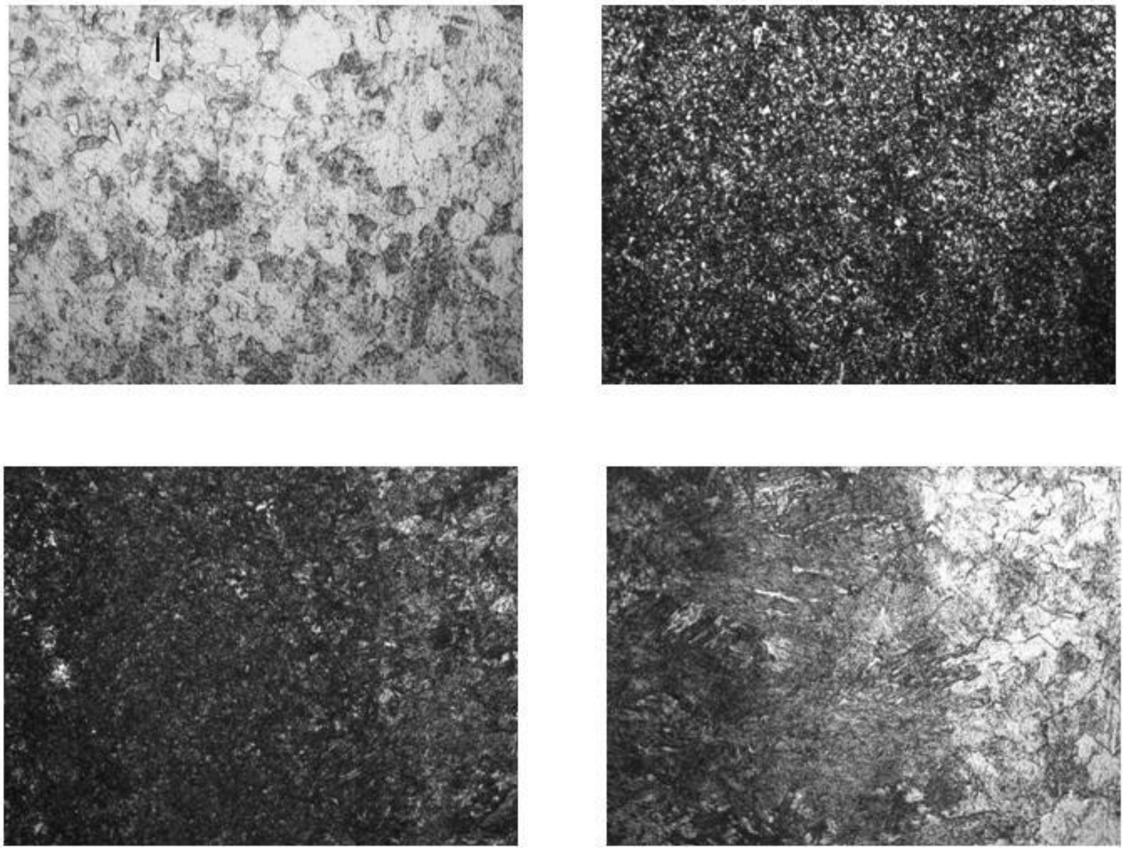

Figure 7: Different regions of the sample 3 (shallow section). Attack: 2% Nital. 50x magnification.

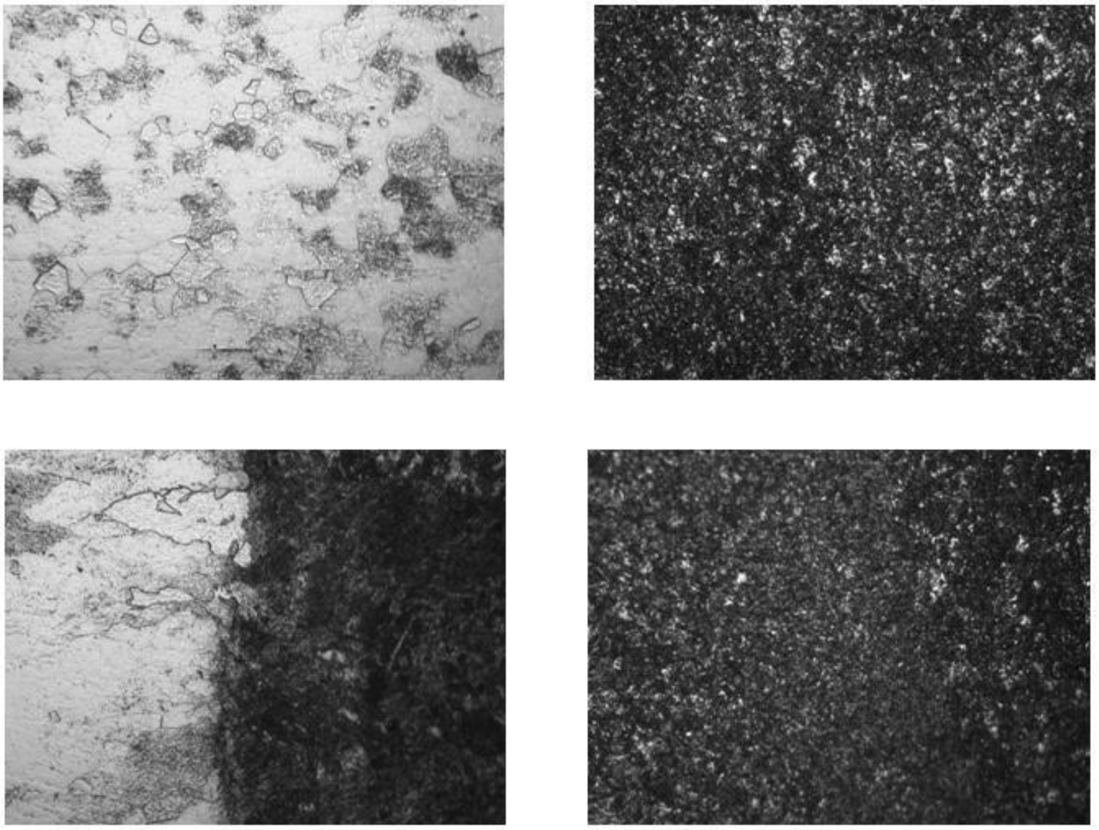

Figure 8: Different regions of the sample 4 (shallow section). Attack: 2% Nital. 200x magnification.

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We can see in the images above, it has three distinct regions. Shows a typical region of a steel TRIP800, a region we call Heat Affected Zone (HAZ) and a region clearly welded.

Figure 6: Different regions of sample 2 (shallow section). Attack: 2% Nital. Magnification 200x.

The image on the right (weld - TRIP800) continues in the same pattern of the other images of a TRIP800 steel, a region of the steel in its natural state, a HAZ and a welded region. Now the image of the IF steel - does not provide a HAZ similar to TRIP800 steel and DP steel, instead of this the ferritic grains of the steel increases due to the heat generated by welding, and this region is called coarse grain region.

Figure 7: Different regions of the sample 3 (shallow section). Etching: 2% Nital. 50x magnification.

Figure 8: Different regions of the sample 4 (section surface). Etching: 2% Nital. Magnification 200x.

In these images, the LC steel has a clear coarse grain region, not only the increase in size of the ferrite phase, but also in sharp phases and a difference tonality. However the TRIP steel behaved as in the other samples.

3.2 Microhardness test

The microhardness test was carried out in 6 distinct areas, as illustrated in Figure 9.

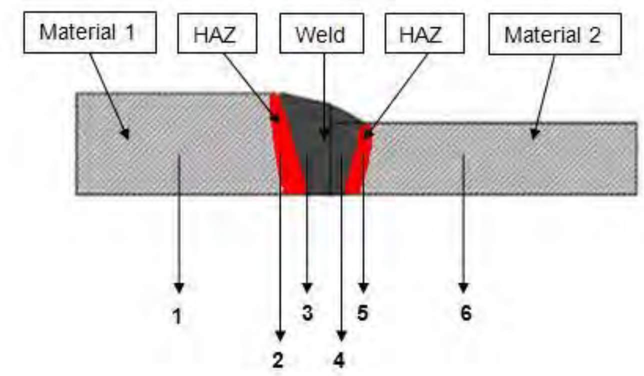

Figure 9: Areas of testing microhardness.

Table 5 and Figure 10 show the results of the tests.

Table 5: microhardness test results.

Região analisada	*Amostra 1* Hardness(HV)	*Amostra 2* Hardness(HV)	*Amostra 3* Hardness(HV)	*Amostra 4* Hardness(HV)
1	272,77	290,11	278,27	286,53
2	458,78	554,49	560,99	537,01
3	548,24	512,5	531,26	444,49
4	577,36	515,12	492,87	328,72
5	560,61	131,99	127,63	180,65
6	279,02	98,65	111,24	124,95

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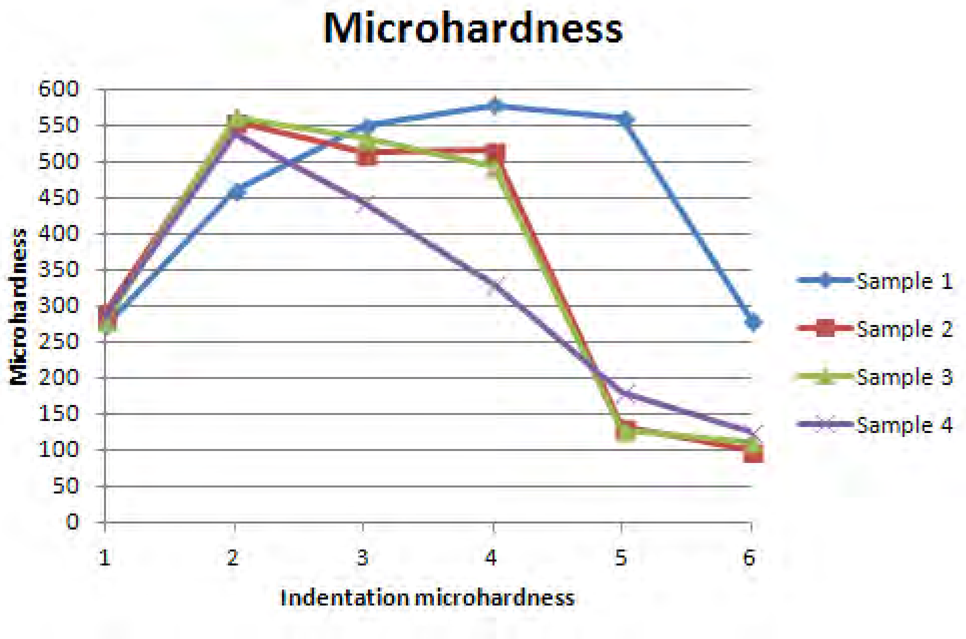

Figure 10: Microhardness tests results.

In Figure 10, the first point represents the microhardness of a TRIP 800 Steel without the effects of the welding process and therefore they are all coincident in microhardness of about 280 HV. Note also that a haz of a TRIP 800 steel (sample 1) has hardness higher than that of a welded region of a low carbon steel.

It is possible to identify that the curve of the first sample is ascending to a point of maximum (second solder point and the first of the ZTA), with maximum hardness of 560 HV. The two extreme points of the curve have 280 HV hardness.

IF and BH steels (samples 2 and 3, respectively) have a similar behavior when submitted to a welding process. The haz in low carbon steels have only a small gain of hardness.

The sample 4, LC steel, has an upward trend in the TRIP, and a descendant of almost constant starting from haz of the TRIP 800 steel.

4. CONCLUSION

Based on the microstructural characterization of welded high strength steels, submitted to attack with Nital 2% and microhardness tests was possible to observe the microstructure of the welded joint and study the behavior of each material analyzed.

According to the results obtained with low carbon advanced steels, such as BH, LC and IF, there is a notable growth of ferritic grains at the heat affected zone that because of this region is called coarse grains.

The TRIP steel has a typical heat affected zone of the welded region, whose mechanical properties and microstructure have been altered due to heat generation. As evidence of this we have increased the microhardness as the welded region approaches. In addition to a typical martensitic microstructure, which is characteristic of a welded region.

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