MECHANICAL AND MICROSTRUCTURAL BEHAVIOR OF DUAL PHASE DP STEEL WELDED JOINTS BY LASER AND GTAW PROCESSES

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Abstract. *Fuel economy, and hence the weight reduction, are extremely important factors for the automotive industry. The development of increasingly lighter vehicles has been achieved through the use of advanced high strength steels (AHSS), such as dual-phase steels, whose microstructure consists mainly of ferrite and martensite and represent an excellent choice for applications where high tensile strength and high ductility are needed. This study is an evaluation of mechanical properties (hardness, tensile strength and impact toughness) and microstructure of welded joints by the process of laser and GTAW welding, comparing them with the properties presented by the material as received. The results showed that the welded joints by laser process showed microhardness values higher than those of the joints welded by GTAW process. Tensile tests showed that there was an increase in the yield stress of welded joints when compared with the base metal. Values of Charpy experienced minor changes in the laser and GTAW welding metals compared with the base metal. The optical microscopy analysis of the base metal confirmed the ferritic microstructure with islands of martensite, as expected, while in laser and GTAW welding metals can be observed the predominance of the ferrite phase.*

Keywords*: Mechanical Properties, Dual Phase Steel, Laser Welding, GTAW.*

1. INTRODUCTION

Among the guidelines for car developments, passive safety (defined as the resistance of the vehicle in the case of collision) and fuel consumption, are of paramount importance. Therefore, the use of high strength steel is an effective solution for satisfying these needs. (Bayraktar *et al*., 2004) The unique combination of higher strength along with the larger elongation and higher work hardening rate of dual-phase (DP) steel, compared to the steel grades of similar yield strength, gave it better acquiescence to the automobile manufacturer. DP steels normally contain dispersed islands of martensite in the ferrite matrix. The ductility arises from ferrite while martensite accounts for the strength, and with increasing volume fraction of martensite, the strength of the DP steels increases and the ductility decreases. (Farabi *et al*., 2011)

A prevalent technology of production of the DP sheets is an intercritical annealing of a cold-rolled product combined with a quenching to the room temperature. (Adamczyk and Grajcar, 2005)

As the new alloys are available in the market it is necessary to develop a way to weld them, resulting in the most demanding specifications, increased productivity and quality, with improved quality control of welds and lower tolerances. (Rogana and Bracarense, 1999) Thus, the study of the processes and parameters used during welding is of fundamental importance to industries in order to ensure better mechanical properties of welded joints.

Among the welding process, the automotive industry began using the laser welding of the component parts of engine and transmission. One of the first chassis applications was in the welding of blanks (rough starting conformation). (Kavamura *et al*., 2007) Due to ease of automation and flexibility, laser welding has gained its popularity in metal joining industry and has been considered to replace potentially some other popular joining processes such as resistance spot welding and friction stir welding. The promising possibility of the laser welding has prompted the manufacturers to use it for both ferrous and nonferrous alloys. (Farabi *et al*., 2011)

The Gas Tungsten Arc Welding (GTAW) welding process, researched and developed over many years, has applications in several areas including the automobile industry. GTAW weld seams have a good finish and have good mechanical properties.

This paper presents a comparative study on the microstructure and mechanical properties of welded joints by laser and GTAW autogenous welding processes, both with argon (Ar) as a shielding gas, through mechanical tests and metallographic analysis.

2. MATERIALS AND METHODS

The material studied in this paper was the DP steel, with 4.15 mm thick, produced by USIMINAS. The chemical composition is shown in Tab. 1 and mechanical properties in Tab. 2.

Table 1. Chemical composition of DP steel (weight %).

C	Si	Mn	P	S	Al	Cu	Nb	V	Ti	Cr	Ni	N
0.0485	1.03	1.17	0.015	0.001	0.040	0.01	0.004	0.003	0.003	0.07	0.02	0.0028

Table 2. Mechanical properties of DP steel.

σ_Y (MPa)	σ_U (MPa)	Elongation (%)
340-440	> 600	21

The material was welded by automated laser and autogenous manual GTAW processes, both under the protection of Argon (Ar). Tables 3 and 4 show the used welding parameters.

Table 3. Laser welding parameters.

Power (W)	LASER Solid (Nd: YAG)		Velocity (mm/min)	Focus	Ar flux (ℓ/min)
3300	Conduction	Diameter (mm)	600	-0.5	16
	Optical Fiber	1.0			

Table 4. GTAW parameters.

Current CC (A)	Voltage (V)	Vel. (mm/min)	Ar flux (ℓ/min)
163	12	140	10

For each welding condition was produced a sample with approximate dimensions of 210 x 120mm. From each welded sample were cut 5 (five) test specimens for the tensile test and 3 (three) specimens for the testing of Charpy impact toughness, according to ASTM A-370 standard, and a test piece that was used for metallographic analysis and microhardness.

Tensile tests were performed under quasi-static loading in a servo-hydraulic machine, automated, with a load cell of 100 KN. Charpy toughness tests were performed at ambient temperature in a universal pendulum type machine with maximum capacity of 300J. The metallographic analysis was performed at the welded joints and base metal, through the usual procedure and etched with Nital 2%. For the testing method for microhardness Vickers indenter was used with electronic load of 0.5 kgf. The hardness was measured in the base metal (BM), heat affected zone (HAZ) and weld metal (WM).

3. RESULTS AND DISCUSSIONS

The tensile test was performed on material in the samples as received and welded by laser and GTAW processes. In all specimens the break occurred in the base metal, featuring a good resistance of the weld seams. The results are shown in Tab. 5.

The values of yield strength for the two welding conditions are higher than those found in the base metal, and the conditions for laser welding, the values are even higher. Microstructure changes due to welding process may have influenced the values of yield strength of the material, where high values of strain hardening coefficient are typical in this type of steels.

Table 5. Tensile tests results.

Specimens	Base metal			Laser welding			GTAW welding		
	σ_Y (MPa)	σ_U (MPa)	ε (%)	σ_Y (MPa)	σ_U (MPa)	ε (%)	σ_Y (MPa)	σ_U (MPa)	ε (%)
1	323	533	14.4	380	538	20.7	442	541	17.8
2	332	554	16.8	388	560	21.7	428	532	14.4
3	330	545	14.4	373	559	20.8	421	512	13.8
4	325	553	23	403	544	21.2	411	519	15.8
5	337	560	21.8	354	502	20.2	400	505	14.4
Average	**329**	**549**	**18.1**	**380**	**541**	**21**	**420**	**522**	**15**
Standard Deviation	5.6	10.4	4.1	18.1	23.6	0.6	16	14.7	1.4

The base metal presented elongation about 18%, which is slightly below the standard values, and it was observed a difference in stretching behavior by comparing the processes. From laser welded joints were obtained mean values of 20% elongation while the joints of GTAW values were around 15%.

The toughness Charpy was evaluated to the base metal and weld metal for both welding conditions. The results are shown in Tab. 6, where it is possible to notice a slight variation between the values. GTAW welded joints showed higher toughness (mean 35J), compared with the base metal (33J), and laser welding occurred in an opposite behavior, with a decrease in the toughness of the joint (31J).

Table 6. Charpy impact tests results.

Specimens	Charpy energy (J)		
	Base Metal	LASER	GTAW
1	32	32	36
2	33	32	34
3	34	29	35
Average	**33**	**31**	**35**
Standard Deviation	1.0	1.7	1.0

The Fig. 1 and Fig. 2 shows the microhardness profiles obtained along the joints, and the highest microhardness values were found in the weld joint, with the condition that presented the highest microhardness was laser welding. The condition of autogenous GTAW welding showed a wider weld joint compared to the other condition (laser), about 10mm wide, while the laser welding showed about 4mm.

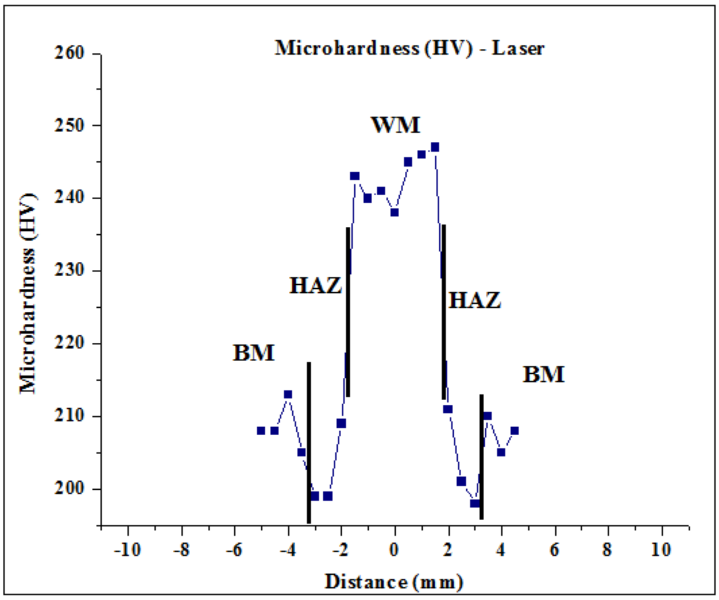

Figure 1. Microhardness (HV) *versus* weld Laser position.

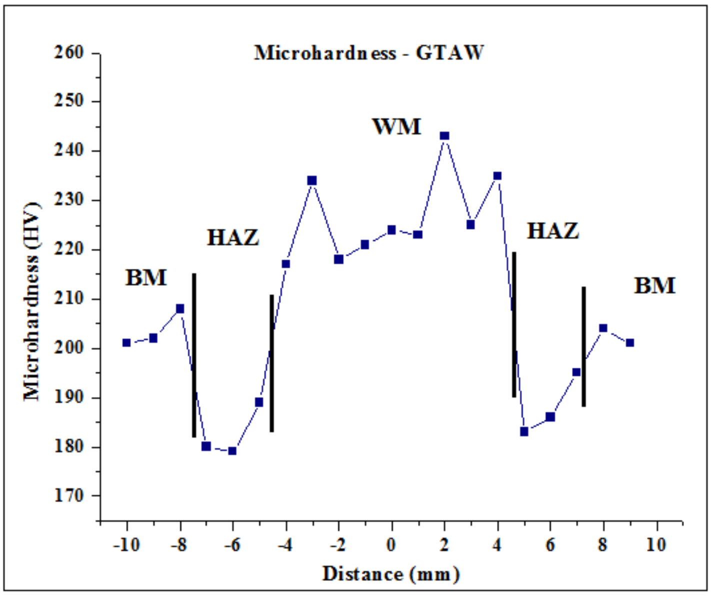

Figure 2. Microhardness (HV) *versus* weld GTAW position.

The microhardness results were obtained in the base metal, HAZ and weld metal at each joint. The data presented in Tab. 7 shows that microhardness values in the HAZ has values smaller than those obtained in the base metal, for both processes. The slight changes can be explained by the partial dissolution of martensite islands and/or by changes in the morphology as a consequence of the thermal cycle that have been submitted.

Table 7. Microhardness results.

Distance (mm)	Microhardness (HV)	
	LASER	GTAW
1	208	201
2	208	202
3	213	208
4	205	180
5	199	179
6	199	189
7	209	217
8	243	234
9	240	218
10	241	221
11	238	224
12	245	223
13	246	243
14	247	225
15	211	235
16	201	183
17	198	186
18	210	195
19	205	204
20	208	201

In optical microscopy analysis of the material in as-received condition (Fig. 3) was observed microstructure characteristic of ferrite matrix with islands of martensite.

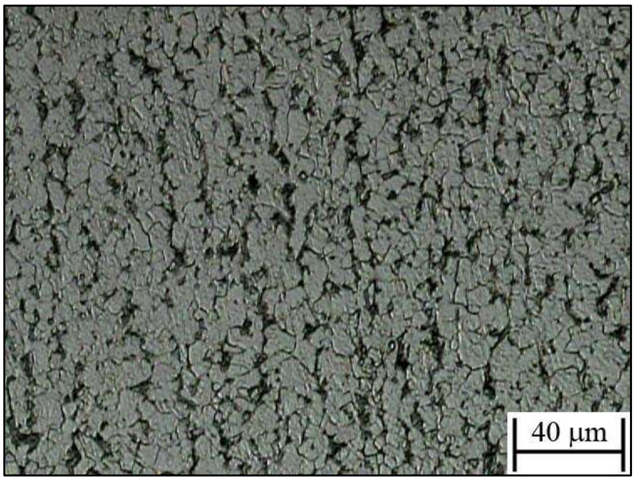

Figure 3. Metal base microstructure.

The figure 4 shows the microstructure of HAZ for laser welding process. This figure also shows the partial dissolution of martensite phase and a transition of phases presented in the base metal to the weld metal, where have predominance of the ferrite phase (polygonal, acicular, primary and second phase aligned), as shown in Fig. 5.

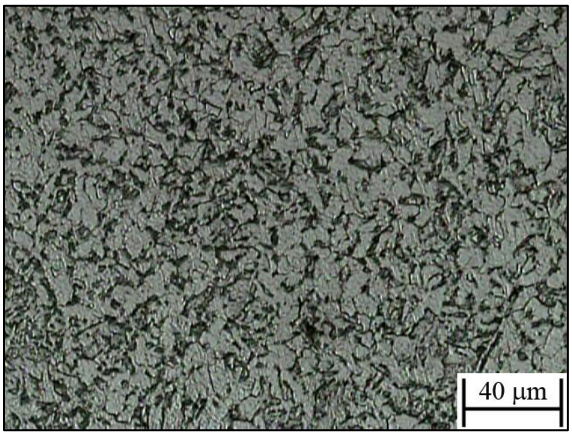

Figure 4. HAZ microstructure – laser welding.

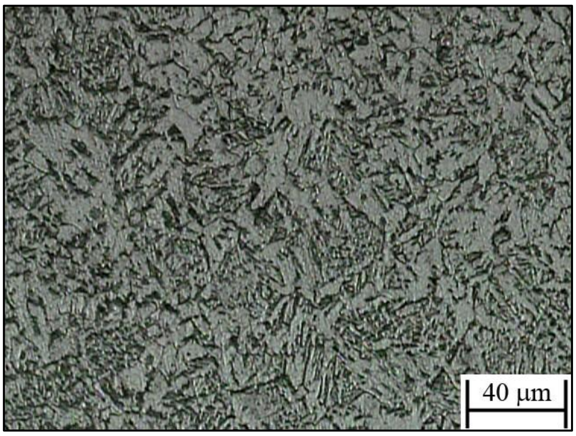

Figure 5. Weld Metal microstructure – laser welding.

In figures 6 and 7 are shown the microstructures of the welded joints obtained by the GTAW process, the HAZ and weld metal, respectively. Looking at the figures, can be observed a similarity in the characteristics of laser welded joint compared with the microstructures obtained by the GTAW process, with the transition from two phases (ferrite + martensite) to predominance of ferrite phase in the weld joint. But in HAZ there is a greater dissolution of martensite and predominance ferrite phase, unlike the HAZ in laser welding, where was observed very small amounts of martensitic phase.

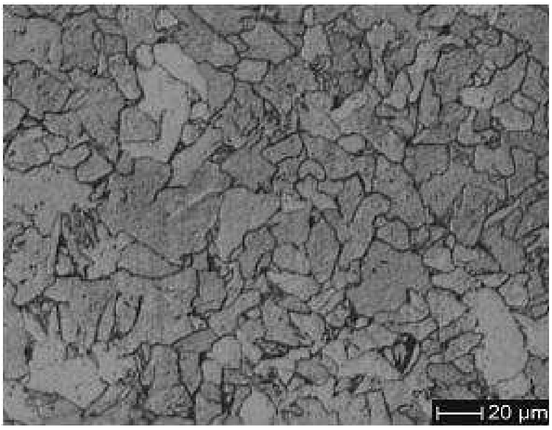

Figure 6 – HAZ microstructure – GTAW process.

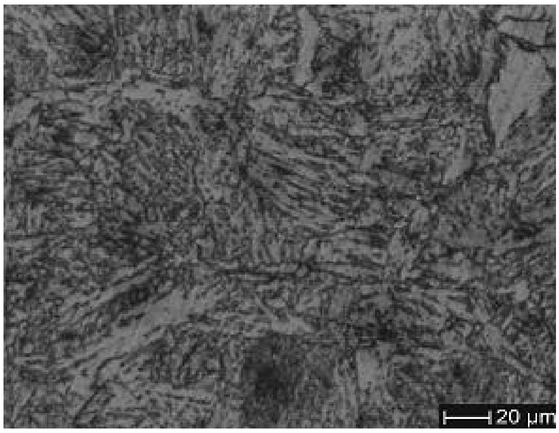

Figure 7 – Weld Metal microstructure – GTAW.

4. CONCLUSIONS

The results of this work have shown that:

1. In both conditions used for welding, GTAW and laser, there was degradation of biphasic microstructure produced in the controlled rolling of steel in HAZ and WM (welded metal), increasing values of hardness in weld joints.

2. The values of microhardness in HAZ was below compared with received material (at about 210HV). This fact can be explained because of the martensite phase in these regions. In GTAW process, the microstructural change was almost complete, which featured a greater decrease in microhardness values (HV 185 on average) compared to laser welding (about 200 HV).

3. The micrographs analyzed in both welding processes exhibit the same characteristics in the weld metal, but in the HAZ can be observed a significant difference in martensite phase dissolution, greater in GTAW process. In the micrographs for the weld metal, although there are coarse grains of polygonal ferrite, there is the formation of acicular ferrite, which justifies the high toughness values found in the weld metal.

5. ACKNOWLEDGEMENTS

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