MECHANICAL AND MICROSTRUCTURAL CHARACTERIZATION OF FLASH-WELDED JOINTS IN HSLA STEELS

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Abstract. *HSLA steels have been increasingly highlighted in the production of automotive parts. Their attractives are high yield and ultimate strengths, chemical resistance, weldability and formability. These features make the HSLA steels an important item in the development of new products, design for cost reduction and process improvement. In the present work, two HSLA steels, designated as S275JR and RD480, are evaluated as candidates to replace the current SAE 1010 steel in the manufacture of trucks and buses wheel rims. Since the welding process is a critical stage of the production of these parts, samples were taken from flash-welded blanks of the chosen steels in order to provide information on the microstructure and mechanical behavior of the weld and heat-affected zones and compare them to the conventional SAE1010 steel. The welded joints are characterized by means of notched and unotched tensile tests, impact tests and fracture toughness evaluation through CTOD measurements. The microalloyed steels presented more complex microstructures, and the presence of the elements Nb and Ti contribute to a microstructural refinement of RD480 steel. Both microalloyed steels showed higher hardness and tensile strength than the low carbon steel, and the three steels have similar hardness profiles with hard welded zone and softened HAZ. The CTOD and impact tests indicated that, although showing higher strength, the microalloyed steels toughness is comparable to that of the low carbon steel. RD480 steel, due to its microstructural and mechanical characteristics, should be preferred to replace the low carbon steel towards a weight reduction of the wheel rims.*

Keywords*: HSLA steels, resistance welding, fracture toughness, flash welding, microalloyed steels*

1. INTRODUCTION

The need for reduction of the vehicles' weight leads to the development of steels with improved chemical composition and microstructure. Thus, there is a strong drive in the steel industry to enhance the performance of the existing products, particularly, formability and toughness (Misra *et al*, 2003). These new materials, which include the high strength and low alloy (HSLA) steels and the microalloyed steels, have low or medium carbon content and small additions of alloy elements such as Mn, Nb, Mo, V and Ti. In general, the microalloying element additions don't overtake 0.1% wt. (Gladman, 1997). The HSLA steels have been increasingly distinguished in the production of automotive parts and their main attractive are the high yield and ultimate strengths, chemical resistance, weldability and formability.

Flash welding is largely employed in the production of automotive parts like wheel rims. In this welding process, the parts to be joined are pressed against each other by means of non-consumable electrodes, by which an electrical current is established. According to Joule's law, the thermal input is proportional to time, electrical resistance and current intensity, and must be enough to allow the contact region to achieve its melting point (Kang and Min, 2000). It can be stated that, in this process, the butt-welded joints are obtained by melting and forging the material (Bracarense, 2000). The impurities are ejected during the plastic deformation caused by the compressive force. A scratching device controls the exceeding material in the welded joint. During solidification, the melting zone of HSLA steels initially transforms into ferrite, and may suffer peritetic reaction with the formation of austenite. This phase, due to the high temperature, experiences a grain growth and tends to show a columnar grain structure. Upon cooling, austenite decomposition occurs at temperatures below 900°C, resulting in distinct phases or constituents (Modenesi, 2004). Thus, a variety of microstructures in microalloyed steels are obtained depending on the deformation temperature, cooling rate and the chemical composition (Naylor, 1998; Matlock *et al.*, 2001).

The welding process is a critical stage in the production of structural parts and the microstructure and mechanical properties of the welded joints must be appropriate in order to guarantee the reliability and durability of the components. The fracture toughness, which accounts for the residual strength of the component in the presence of flaws or cracks, is one of the most important properties to be evaluated (Anderson, 2005). The Crack Tip Opening Displacement (CTOD) test has been successfully employed for the fracture toughness evaluation of HSLA steels welded joints. It was observed that this property is strongly affected by the microstructure of the welded metal (Bose

Filho, 2007). However, this dependency seems to be observed only in the case of low-ductility joints. If the weld beads in HSLA steels are ductile, the CTOD values do not depend on local variations of the microstructure (Tuma, 2004). It was also observed that the CTOD measurements in HSLA steel joints may show huge differences for the same material and welding process, depending on the adopted measurement method (Rak, 1999). This means that the same measurement method should be adopted when comparing the fracture toughness of various materials.

In the present work, two HSLA steels were evaluated as candidates to replace the current SAE 1010 steel in the manufacture of trucks and buses wheel rims. Samples were taken from flash-welded blanks of the chosen steels in order to provide information on the microstructure and mechanical behavior of the weld and heat-affected zones and compare them to the conventional SAE1010 steel. Microstructural analysis was performed by optical microscopy. The mechanical characterization was performed by means of tensile and impact tests, as well as fracture toughness evaluation through CTOD measurements. The obtained results provide support for the understanding on how the welding process affects the materials' properties and give important information related to the conventional steel replacement towards a significant weight reduction of the component.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

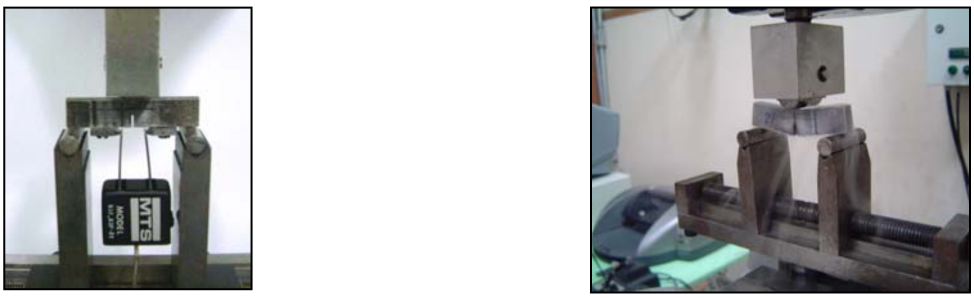
The microalloyed steels employed in the present work, designated as RD480 and S275RJ, were procured from local market in the form of plates with 6.0 and 5.0 mm in thickness, respectively. For comparison, samples were taken from from 6.05 mm thick SAE 1010 steel plates, currently employed in trucks and buses wheels. The chemical composition of these steels is given in Tab. 1. The welded blanks were produced by flash welding process in an automotive parts manufacturer, using a HESS WO 4158 machine. The programming parameters adopted for the welding machine were changed according to the individual characteristics of each of the chosen steels.

Table 1. Chemical Composition of the Steels (wt. pct.).

Steel	C	Mn	Si	P	S	Cr	Al	Nb	Ti
SAE 1010	0.1130	0.4810	0.0150	0.0090	0.0072	0.0160	0.0390	-	-
S275JR	0.1850	0.9060	0.0220	0.0105	0.0054	0.0180	0.0510	-	-
RD480	0.1000	1.2160	0.0670	0.0123	0.0041	0.0130	0.0260	0.0400	0.0200

Cross-section samples of the welded joints were polished, etched (3% nital) and observed under light microscope in order to reveal their microstructures. ASTM-E8M sub-size specimens were used for the tensile tests, with the weld positioned at the center of the gauge area and perpendicular to the loading direction. Sharp-notch tension testing was performed according to ASTM-E338 Standard. Two sets of specimens were machined, with distinct notch tip positions: in the weld metal and in the heat-affected zone (HAZ). The smooth and notched tensile specimens were tested in a MTS 810.23M servo-hydraulic system. Charpy-notched bar impact tests were performed in a HECKERT 23/121 machine, at two distinct temperatures: 23.5°C and -25.0°C.

Fracture toughness evaluation through CTOD measurements was performed according to BS 7448 (1997) standard test method. The specimens were cut in the SE(B) shape for three-point bend loading with a span of 48 mm. The fatigue pre-cracking of the specimens was performed under force control with load ratio (min / max) of 0.1, frequency of 10 Hz and sinusoidal waveform. The CTOD tests were conducted at room temperature in laboratory air. The specimens were then monotonically loaded with a displacement rate of 0.5 mm/min. A clip-on gage was attached to the specimens, as shown in Fig. 1, for the crack opening displacement determination. After slow stable crack extension occurred, the specimens were immersed in liquid nitrogen and broken in brittle manner in order to expose the crack surfaces. The crack length measurements were performed at nine equally spaced points across the specimen thickness with accuracy of 0.01 mm. For each of the chosen steels, three valid test results were obtained for each of the notch tip positions: in the weld metal and in the HAZ.



a ***b***

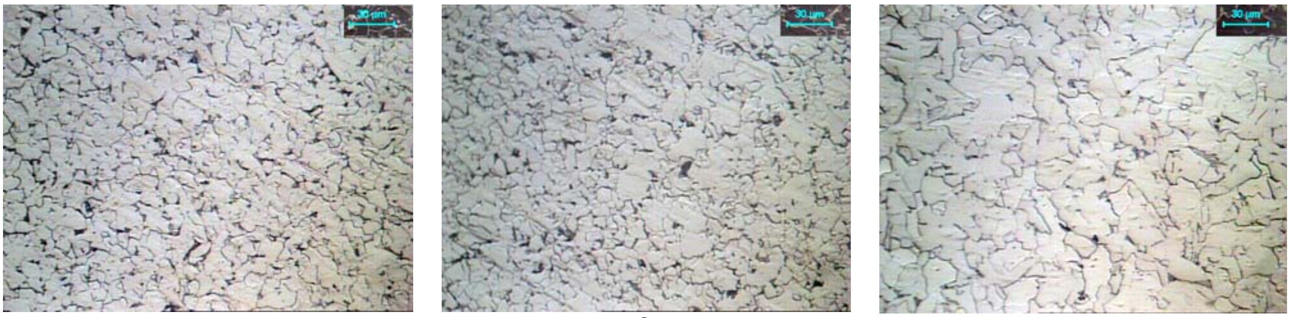
Figure 1. CTOD test: (a) obtaining the force-displacement record; (b) breaking the specimen.

3. RESULTS AND DISCUSSION

The results are presented and discussed in the following sections: microstructural analysis, tensile tests, impact tests and CTOD fracture toughness measurements.

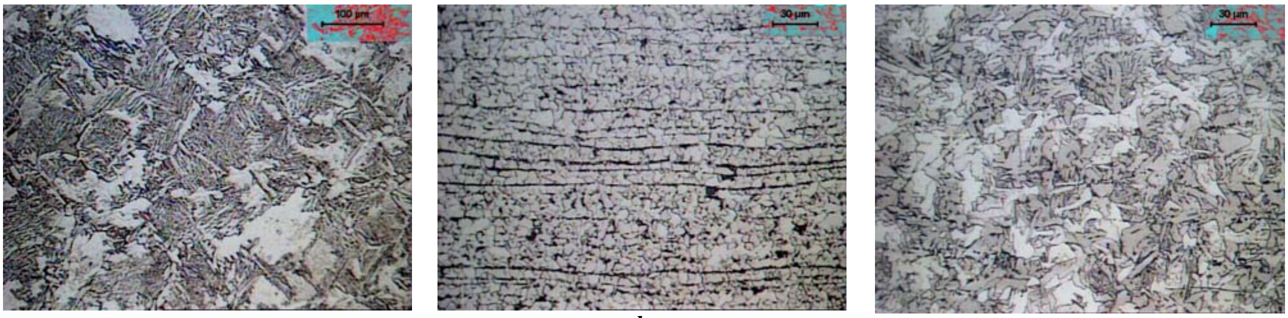
3.1. Microstructural analysis

Figure 2 shows representative micrographs of the weld (a), HAZ (b) and base metal (c) of SAE 1010 steel. The microstructure is ferritic, with perlite in the grain boundaries. A partial microstructural refinement is observed in the HAZ. The S275JR steel presents a more complex microstructure, as shown in Fig. 3. Acicular ferrite coexists with polygonal ferrite in the weld region (a). A microstructural refinement of the HAZ (b) is observed, as well as aligned segregation, which is possibly related to the compressive stresses developed during the welding process. As for the RD480 steel, Fig. 4 shows that the microstructure of the welded region (a) is slightly more refined than that of the S275JR steel and combines ferrite with aligned second phase, grain boundary ferrite and polygonal ferrite. The HAZ (b) presents microstructural refinement and the base metal (c) shows polygonal grain morphology. The microalloying elements (Nb, Ti) contribute to the formation of small size grains in the hot rolled material.



a *b* *c*

Figure 2. SAE 1010 steel, optical micrographs: (a) weld, (b) HAZ, (c) base metal (500 ×)



a *b* *c*

Figure 3. S275JR steel, optical micrographs: (a) weld (200×), (b) HAZ, (c) base metal (500 ×)

a *b* *c*

Figure 4. RD480 steel, optical micrographs: (a) weld, (b) HAZ, (c) base metal (500 ×)

3.2. Tensile tests

From the tensile tests, the following properties were obtained for each material after welding process: yield stress (σ_y), tensile strength (σ_t) and percent elongation (ΔL). The results (average from 6 tests) are presented in Tab. 2. According to these results, RD480 steel shows, after welding, higher mechanical strength and lower ductility than the other steels evaluated in this work. On the other hand, S275JR and SAE 1010 steels present the same ductility level, although the former shows higher tensile properties. It should be noted that no significant variation was observed in the tensile properties, whatever was the position of the fracture (inside or outside the welded region).

Table 2. Tensile test results.

Steel	σ_y (MPa)	σ_t (MPa)	ΔL (%)
SAE 1010	317 ± 24	429 ± 10	29
S275JR	350 ± 16	487 ± 14	26
RD480	439 ± 5	527 ± 16	18

The sharp-notch tension testing results are presented in Tab. 3. The RD480 steel shows also higher values of the maximum stress in this test. It can be noted that, for all of the steels, the maximum stress achieved for the notch tip inside the HAZ is slightly higher than in the case of the notch tip in the welded region. This result is indicative that the HAZ region is tougher than the weld metal. A remarkable result is that the maximum stress obtained in the notch tension testing is higher than the tensile strength for each of the steels, shown in Tab. 2. This is because the latter property is obtained after a significant plastic deformation was occurred, which means a reduction in the cross sectional area of the specimen, not taken in account in the engineering properties calculation.

Table 3. Sharp-notch tension testing results.

Steel	Maximum Stress (MPa)	
	Notched Weld	Notched HAZ
SAE 1010	530	535
S275JR	550	588
RD480	674	704

3.3. Impact tests

The impact test results are shown in Tab. 4. The general behavior is that the absorbed fracture energy corresponding to notched HAZ is higher compared to notched weld. A significant drop in the absorbed energy occurred for the tests conducted at low temperature, especially for the notched weld, indicating a ductile-brittle transition. It is also remarkable that, despite the differences in the tensile properties of these steels, the impact test results indicate that their toughness is equivalent.

Table 4. Impact test results (average of 6 tests).

Steel		Energy (J)	
		- 25,0 °C	23,5 °C
SAE 1010	Weld	8 ± 5	76 ± 41
	HAZ	83 (1)	59 (1)
S275JR	Weld	7 ± 1	42 ± 9
	HAZ	10 ± 1	113 ± 5
RD480	Weld	5 ± 1	79 ± 21
	HAZ	81 ± 10	97 ± 12

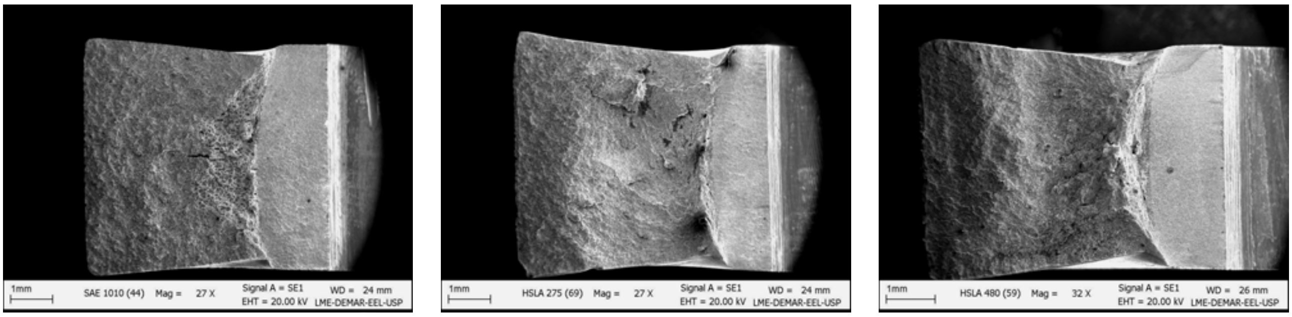
(1)Average of 3 tests.

3.4. CTOD fracture toughness measurements

Table 5 presents the validated critical CTOD values sorted in ascending order. From these results, a tendency is observed of the HAZ CTOD values being higher than those corresponding to the weld metal for a given steel. It is also remarkable that the SAE 1010 data are more scattered than the corresponding to the HSLA steels, for both the weld metal and the HAZ. Figure 5 shows SEM observations of representative fractured CTOD specimens of the three studied steels. It must be stated that, despite the slight differences in CTOD values, no distinction was found in the fracture appearance of the weld metal and HAZ. On the other hand, it can be observed in Fig. 5 (a) that a huge amount of stable crack extension occurred in SAE 1010 steel, accompanied by the formation of cavities characterizing a ductile fracture. This feature was not observed in the HSLA steels, see Fig. 5 (b) and (c), probably due to the presence of microalloying elements that contributed to carbide formation that inhibited crack extension. It can be inferred from the CTOD data that the HSLA steels are equivalent from the toughness point of view and the welding process in these steels produces more reliable joints.

Table 5. Critical CTOD results (mm).

Notch positioned in weld metal			Notch positioned in HAZ		
SAE 1010	S275JR	RD480	SAE 1010	S275JR	RD480
0.227	0.337	0.312	0.169	0.452	0.468
0.263	0.340	0.339	0.403	0.456	0.586
0.564	0.388	0.450	0.693	0.540	0.608



a *b* *c*

Figure 5. Fracture surfaces of CTOD specimens: (a) SAE 1010 AA, (b) S275JR, (c) RD480

4. CONCLUSION

The microstructure and mechanical properties of two flash-welded microalloyed steel plates, designated as S275JR and RD480, were evaluated and compared to those of the conventional low carbon SAE 1010 steel, employed in automotive wheel rims. The microalloyed steels presented more complex microstructures, and the presence of the elements Nb and Ti contribute to a microstructural refinement of RD480 steel. Both microalloyed steels showed higher tensile strength than the low carbon steel. The CTOD results, along with the sharp-notch tension and impact tests indicated that, although showing higher strength, the microalloyed steels toughness is comparable to that of the low carbon steel. Moreover, it can be inferred from the CTOD data that the welding process in the HSLA steels produces more reliable joints. RD480 steel, due to its microstructural and mechanical characteristics, shows a better combination of strength and toughness. Therefore, from the point of view of the mechanical properties of the welded joints, RD480 steel should be preferred to replace the low carbon steel in the production of wheel rims.

5. REFERENCES

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