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Laser welding of dissimilar steels: Maraging (18Ni) and 300 M

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Abstract

In this work welded joints made of dissimilar steels: Maraging (18Ni) and 300M-ESR steel by the laser beam welding process (LBW) was evaluated. After the laser welding, different heat treatments were applied with the purpose to approximate the hardness of both steels in the fusion zone and heat affected zone. Subsequently, the joints were submitted to tensile and microhardness test for mechanical properties evaluation. Metallographic analyses of the welded joints were also performed and the microstructure and mechanical properties were correlated. The heat treatments applied after welding proved to be convenient for improvement of the hardness and the tensile strength. The increase in tensile strength due to the heat treatment applied after the welding was about 400 MPa. The laser welding process proved to be efficient to achieve the union of the proposed dissimilar steels and the heat treatment applied contributed to improve the mechanical properties.

Keywords: maraging steel; dissimilar welding; 300M steel; laser beam welding (LBW), microstructural characterization.

1. Introduction

In the aerospace industry, in order for a rocket or missile to have the desired behavior during operation, it is necessary to fabricate structures using materials with high mechanical resistance combined with low density. For instance, the VLS-1, Brazilian Satellite Launch Vehicle, is a project of the Institute of Aeronautics and Space (IAE) that uses ultra-high strength. Two important types of steels used for this purpose are: the 300M and Maraging 300 steel (Silva and Mei, 2006; Abdalla et al., 2006; Fanton et al.2014).

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The rocket motor case (propellant) commonly used by the aerospace industry consists of a cylindrical casing made up of calendered and welded metal structures (ferrules), closed with a front hemispherical dome and a semi-closed rear, thus forming the combustion chamber (pressure vessel) for burning the solid propellant. Figure 1, the main components of a propellant space and site of welding are shown.

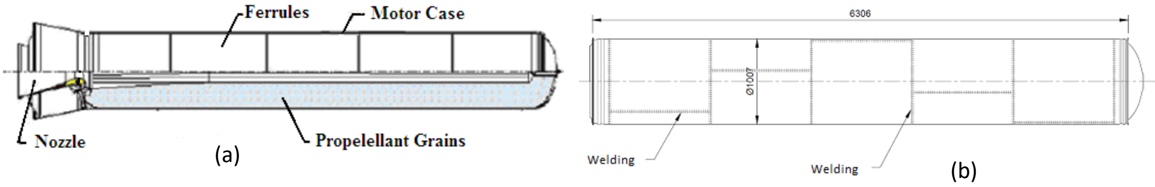


Fig. 1. (a) basic components of rocket motor; (b) positions of welding in cylindrical metal structures (Brazilian VLS-1).

In similar metal parts, the welding and heat treatment processes to be applied to 300M or Maraging 300 steels are known. However, dissimilar welding is often avoided, since greater care is required in the selection of materials and procedures involved, such as: greater control in the welding parameters and in the heat treatments. The processes must be satisfactory for both steels.

In dissimilar welding, the fusion of two different types of steel occurs, creating a region with variable chemical composition, thus presenting different properties of the preceding metals. After welding of two pieces, three distinct regions are expected to emerge: the fusion zone (FZ), the heat affected zone (HAZ) and the base metal (BM - where there was no change in the original microstructure). In carbon steels, as in the case of 300M steel, there is a tendency to form a martensitic phase with high hardness in the FZ and HAZ. In the case of Maraging 300 steels, where the carbon element content is very low, there is a tendency of reduction in the hardness and strength of the steel in the FZ regions and HAZ, making necessary a thermal treatment strategy to recover and equalize the mechanical properties in these regions.

Fanton et al. (2016) and Sakai et al. (2015) have observed that in Maraging 300 steel there is a reduction in hardness to about 300 HV in FZ due to welding, but after a temper aging treatment of about 3 h at the temperature of 480 °C the hardness values can be raised to values in the order of 500 HV.

On the other hand, Joshi et al. (2016) and Cardoso et al. (2014) observed that in steel samples such as 300M and AISI 4340, after the laser welding process, there is an increase in hardness due to the formation of the martensitic phase. In this case, a heat treatment after welding can recover part of the ductility lost due to the formation of the hard phase in the ZF and ZTA. Cardoso et al. (2014) observed that a tempered treatment at 500 °C reduced the ZF hardness values from 650 HV to 480 HV for 300 M steel and to 4340 steel the value of hardness of this region was reduced from 550 HV to 440 HV.

The main objectives of this work are: (a) to achieve a good quality in the laser welding, adjusting the laser parameters properly and (b) to perform heat treatments capable of equalizing the mechanical properties in the fusion zone (FZ) and heat affected zones (HAZs) of both steels. During the analysis the microstructural characteristics were evaluated by optical and scanning electron microscopy as well as the mechanical performance by the use of hardness and tensile tests.

2. Materials and Methods/Experimental

In Table 1, the compositions of Maraging 300 and 300 M steels, obtained after the chemical analysis are shown. Plates of both steels were cut to the dimensions of 200 x 200 x 3.3 mm; the surfaces were sanded and the place where the wedding was performed was cleaned with acetone.

Table 1. - Chemical composition of 300 M and Maraging 300 steels (weight percent).

Element (wt %)	C	Mn	Si	P	S	Cr	Ni	Mo	Co	Ti	Al	V
300 M	0,379	0,824	1,670	0,009	0,0004	0,77	1,59	0,39	-	-	-	0,06
Maraging 300	0,007	0,013	0,08	<0,004	0,001	-	18,58	4,67	8,79	0,61	0,079	-

2.1 Laser welding

The welding was performed by Laser Beam Welding (LBW) with a fiber laser, IPG - model YLR2000, with maximum power of 2 kW, with an output fiber of 100 µm in diameter and 5 m in length. The welding was done without the addition metal (autogenous), a power of 1,800 W with a lower surface behavior, a focal length of 160 mm and a speed of 3,000 mm/min was used. For the protection of the weld region a flow of argon gas over a liquid pool at a rate of 6 liters/minute was applied. Two laser beam paths were made for welding, one on each side of the plate. The laser parameters used in this study were based on the results of other researchers that worked with maraging and 300 M steels (Fanton et al., 2016, Sakai et al., 2015, Joshi et al., 2016, Cardoso et al., 2014).

2.2 Heat treatment

The heat treatments applied to 300 M and Maraging 300 steels had the objective of improving the mechanical properties of the welded steels. In order to compare different heat treatments that could contribute to improve the characteristics of the welded region, thermal treatments were applied before and after the welding process. The times and temperatures were chosen to give an adequate treatment to both steels (quenching and tempering in 300 M carbon steel for and solubilization followed by aging for the maraging 300 steel). The following heat treatments had been applied:

a) Heat treatment before welding:
- HTo: Maraging and 300 M steel without heat treatment;
- HT1: Quenching (980 °C - 1 h, cooled in oil) and tempering (280 °C - 4 h) in 300 M steel, and
  Aging heat treatment in Maraging steel (480 °C - 3 h);

b) Thermal treatments applied after welding:
- HTo’ - welded joints in the condition HTo was subjected to a Quenching (980 °C - 1 h, cooled in oil) and tempering (480 °C - 3 h);
- HT1’ - welded joints in the condition HT1 was subjected to Aging treatment (480 °C - 3 h).

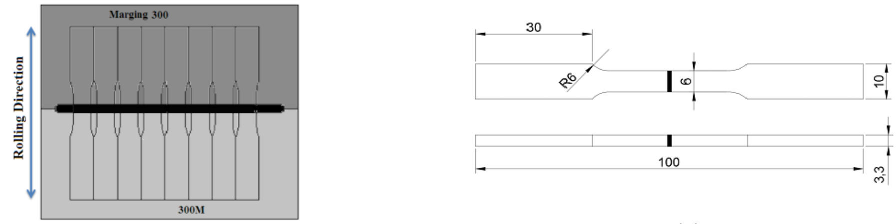
2.3 Microstructural Characterization

For the microstructural analysis, samples were prepared in resin (bakelite); each sample was sanded and polished with diamond paste. After preparation they were etched with 2% and 5% natal solution. The samples were analyzed by Optical Microscopy (OM).

2.4 Tensile Test

The tensile specimens were produced in accordance with ASTM E8M-11 (2011), with rectangular cross section. In Fig 1.a it is shown how the specimens from the welded plate were cut by Electrical Discharge

Machining (EDM) process and in Fig 1.b the final dimensions of the specimen are shown. The tensile tests were performed on a servo-hydraulic tensile machine type MTS, model 810.23M.



(a) (b)

Fig. 1. – (a) Cuts of specimens in the welded plate and (b) tensile specimens final dimensions (mm).

2.5 Microhardness Test

The measurements were performed on a microhardness tester model FM-700 from the Company Future Tech, using a load of 300 gf with the penetration time of 15 s. The measurements were carried out in the transverse region of the weld with a spacing of 0.10 mm distance, until it crossed the base material of the 300 M steel until it reached Maraging steel.

3. Results

3.1 Microstructural Characterization

In Figs 2a and 2b the microstructures of the steels in the initial condition before they are welded or receive heat treatment are shown. The microstructure of 300 M steel is basically ferritic/perlitic (Fig 3a) and the grains of Maraiging steel are composed of martensite of low hardness (no carbon).

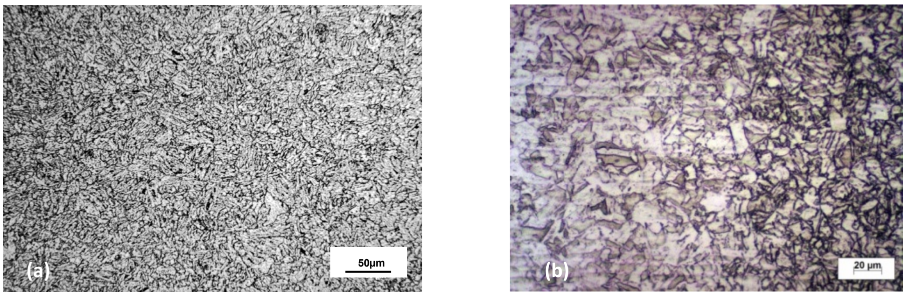


Fig. 2. – Optical Microscopy: (a) microstructures of materials as received: (a) 300 M steel, (b) Maraging 300. Etching - nital 2%.

In Figs 3a and 3b the microstructure of the studied steels is shown, after the thermal treatments for hardening of the base materials. The 300 M steel was quenched and tempered (Fig. 3a) and acquired a martensitic structure, its hardness increased from about 260 HV to 600 HV. The Maraging 300 steel (Fig 3.b) was aged increasing its hardness from about 340 HV to 540 HV. This increase was due to the precipitation process (Reis et al., 2017).

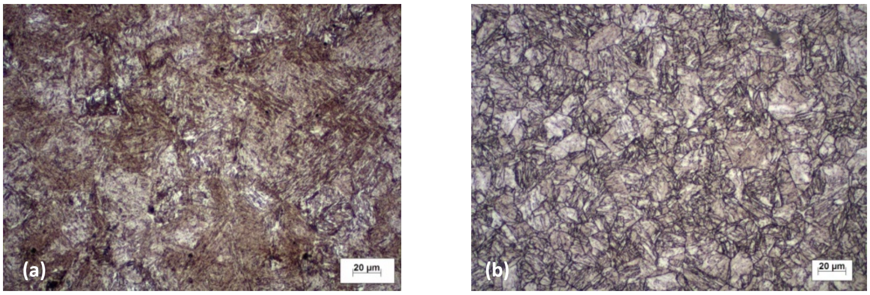


Fig. 3. – Optical Microscopy: (a) microstructures of materials heat treated: (a) 300 M steel quenched and tempered, (b) Maraging 300 temper aged. Etching - nital 2%.

In Fig 4 the welded joint in condition HTo (without heat treatment) and the micrographs of the main regions of the union between the dissimilar steels are shown schematically. The fusion zone (FZ - black), the heat affected zone (HAZ) and the base material (BM) of Maraging steel are shown in Fig. 4.a. Details of HAZ and MB are shown in images 4.b and 4.c. The fusion zone (FZ - white), the heat affected zone (HAZ) and the base material (BM) of the 300 M steel are shown in Fig. 4d. In Fig. 4e an enlargement of this region is shown.

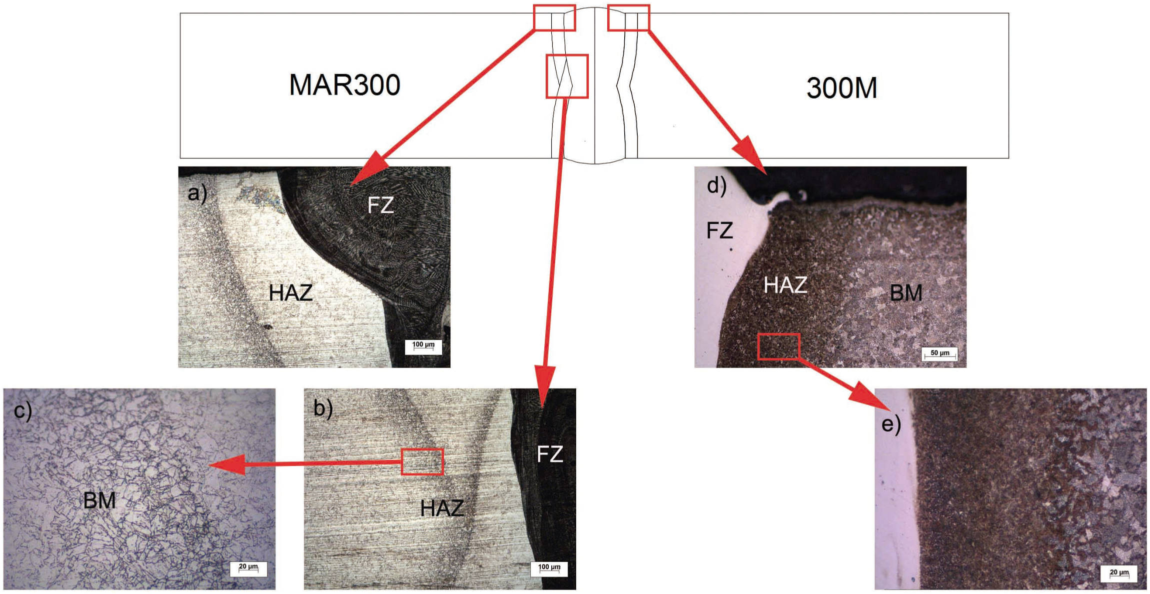


Fig. 4. - Weld joint micrograph of HTo condition, Maraging and 300 M steel without heat treatment: showing the morphology of the regions: (a) Fused zone (FZ); (b) Heat Affected Zone (HAZ) in Maraging; (c) Transition region of base metal (BM) and HAZ in Maraging; (d) Heat Affected Zone 300M (HAZ)in 300 M and (e) Transition Region of Base Metal (BM) and HAZ in the 300M. Optical Microscopy.

The weld made to join the steels in the HTo condition showed an FZ of about 1 mm and a HAZ of similar size. In the HAZ of the Maraging steel, near the FZ partial aging occurs in the microstructure, due to the heat of the welding process. On the side of the 300 M steel, the formation of hard martensite occurs in FZ and HAZ due to the rapid heating in the region of austenitization and rapid cooling after the passage of the laser.

In Fig 5 the microstructure of the welded region of the HT1 condition is shown. In this case the base material (BM) of the 300 M steel has a martensitic structure because it was quenched before welding. In Fig. 5.d, it is shown that the fused zone (FZ) and heat affected zone (HAZ) have martensitic microstructures, but with different morphology of the base material, due to the fusion and rapid cooling. The FZ structure becomes dendritic. The base material on the side of the Maraging steel that had been previously hardened by the aging treatment shows changes that reduce the hardness in FZ due to melting and in HAZ due to partial solubilization (Fig 5a). In Figures 5b and 5c the enlarged details of the HAZ region are shown. It is also observed that in the center of the FZ there are some pores in both steels (black circle). These localized defects may cause an increase in the standard deviation in the mechanical properties of the material.

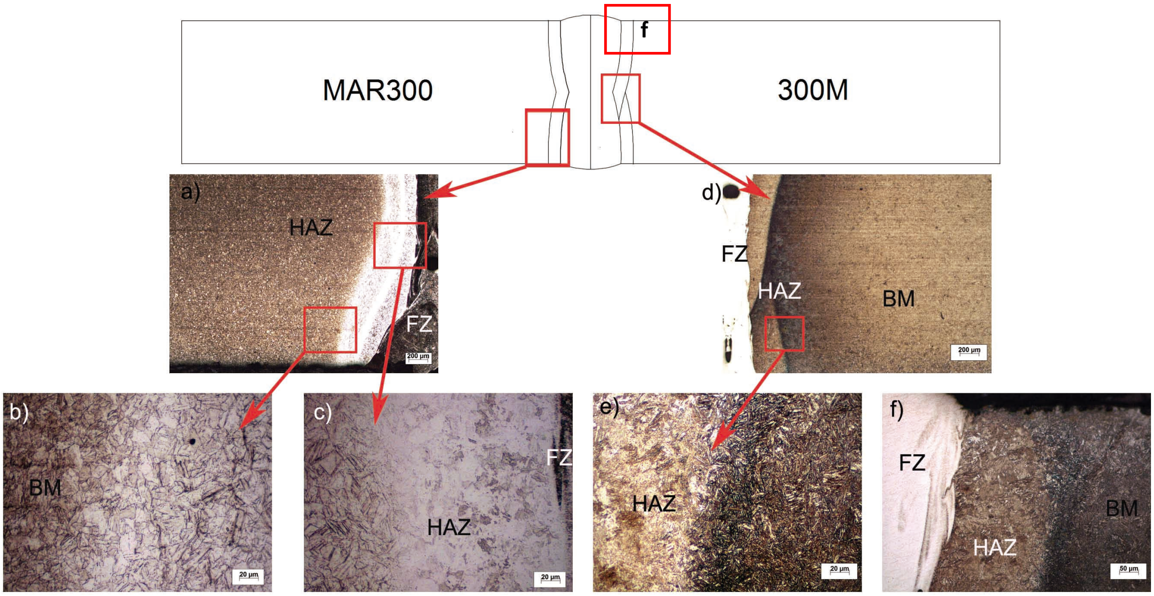


Fig. 5. - Weld joint micrograph of HT1 condition: Maraging steel quenched and temper aging and 300 M steel quenched and tempered, showing the morphology of the regions: (a, b and c) Fused zone (FZ), Heat Affected Zone (HAZ) and Basic Material in Maraging steel; (d and e) Fused Zone (FZ), Heat Affected Zone (HAZ) and Base Material (BM) in 300M steel, (f) FZ and HAZ in 300 M steel, near the surface. Optical Microscopy.

In Fig 6, the microstructures formed after the heat treatment of quenching and tempering subsequent to welding are shown. Due to the quenching performed from 980 °C, a new phase transformation occurred in the HAZ and FZ. After the HTo' heat treatment, the HAZ regions of the 300 M or Maraging steels have similar structure, as can be seen in Figs. 6a and 6d. Due to the low hardness of the martensitic phase of the Maraging steel after quenching, the aging treatment (480 °C for 3 hours) of the steel was required to recover the hardness.

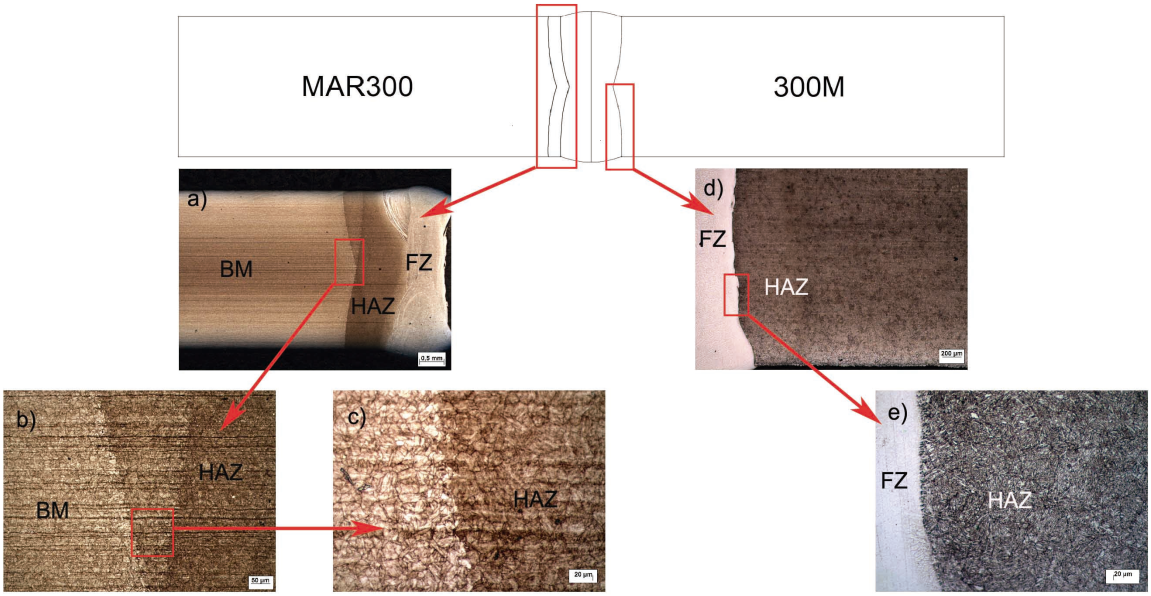


Fig. 6. - Weld joint micrograph of HTo' condition: welded joint in the HTo condition and subsequently tempered and aged. Showing the morphology of the regions. Fig 6.a, 6.b and 6c in Maraging steel: (a) Fused zone (FZ) and base material (BM); (b) Heat Affected Zone (HAZ) modified and (c) detail of grain near Transition to FZ. Fig 6.d and 6.e in 300 M steel: (d) FZ region (white) and martensite formed near in 300 M steel; (e) expanded detail of the region. Optical Microscopy.

The microstructure presented after heat treatment in the HT1' condition is similar to the HT1 condition, because in this case, after welding, the joint was subjected to only an aging treatment at (480 °C for 3h) without phase transformation due to the low temperature of the heat treatment.

3.2 Microhardness Test

In Figure 7a shows the hardness values measured along the weld joint for the HTo condition are shown. On the side of the Maraging steel of the interface between the HAZ and the base material there is a small increase in the hardness due to the precipitation effect during the welding, at the interface between the HAZ and the FZ there is a reduction in the hardness due to the melting and solidification of the steel. On the side of the 300 M steel there is an increase in hardness due to the formation of martensite during the rapid cooling after the welding process.

Analyzing the graph of Fig 7b, for the condition HT1 it is observed that there is an increase in the hardness of the base material in the case of 300 M steel due to the rapid cooling after austenitization at 980 °C and in the case of Maraging steel due to the aging at 480 °C for 3 h. It is also noted that there is an increasing gradient of hardness in the FZ, from the Maraging steel towards the 300 M steel, this phenomenon is related to the higher carbon content that is higher nearby of the 300 M steel. Despite the large increase in the hardness value of both steels, the hardness profile in FZ remains similar to the HTo condition. This fact indicates that the fusion and subsequent solidification due to laser welding occurred in a similar way in both cases (HTo and HT1 condition), forming similar microstructures in FZ and HAZ.

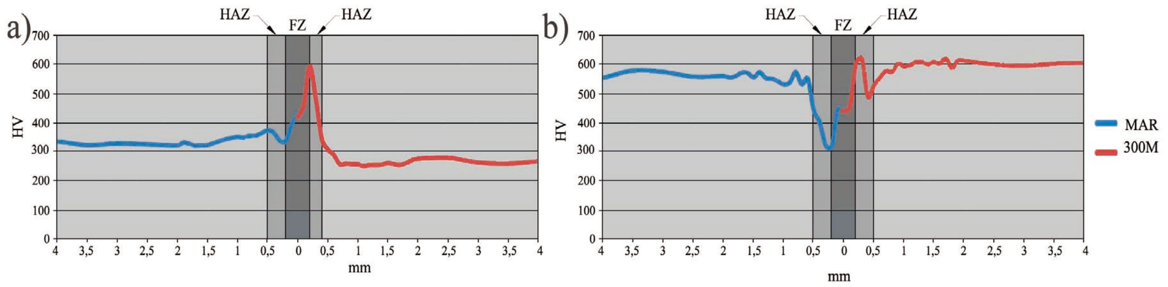


Fig. 7. - Microhardness tests in the weld region: (a) HTo condition - no heat treatment; (b) Condition HT1 - previously aged magaring steel and quenched 300 M steel.

The hardness values presented in Fig. 8a refer to the HTo' condition, where an additional treatment of quenching and aging after welding of the steels in the HTo condition was applied. In Figure 8b the hardness values for the condition HT1' are shown, where after welding only one aging treatment has been applied. It is noticed that the microhardness profile is very similar to that observed in Fig. 8a. In both conditions a hardness increase occurs, on the side of the 300 M steel there is the formation of hard martensite, with tetragonal structure due to the carbon content; on the side of the Maraging steel, hardening is obtained because of precipitation of intermetallics during the temper aging in both cases.

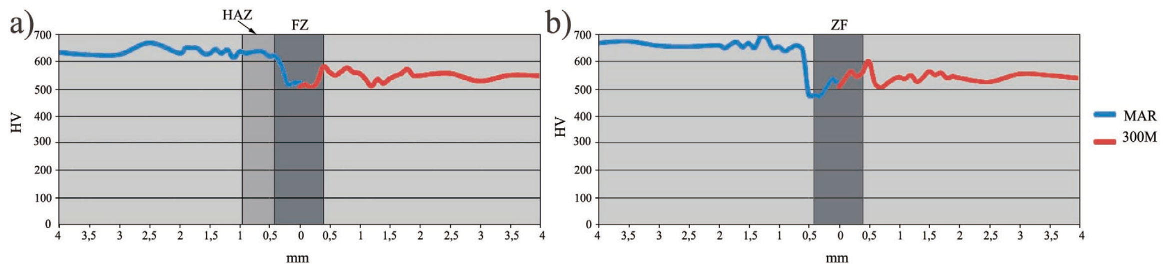


Fig. 8. - Microhardness tests in the weld region: (a) HTo' condition: without heat treatment before welding + quenching and temper aging post welding; (b) Condition HT1' - previously aged Maraging steel and quenched 300 M steel + temper aging post welding.

3.3 Tensile Test

The steel 300 M in the condition as received (annealed) presented a tensile strength of 840 ± 20 MPa and after receiving the quenching and tempering treatment, this value increased to 1,330 ± 10 MPa. For the Maraging steel in the condition as received (solubilized), the obtained tensile strength was about 1.024 ± 9 MPa and after temper aging heat treatment it was elevated to 1890 ± 10 MPa. The changes in the tensile strength after the welding process of dissimilar steels for each condition studied are shown in the graph of Fig 9.

In the HTo condition (without heat treatment before or after welding) the tensile strength levels were lower than those observed in the other conditions. This fact is related to the initial microstructure of the steels, which in the case of Maraging steel consists of an untreated martensite of low hardness and for the

300 M steel is of a ferritic-pearlite structure. The tensile strength found is slightly lower than that observed for 300 M steel without treatment around 740 ± 6 MPa.

After the application of the HTo' treatment there was an increase in the levels of tensile strength. The quenching and temper aging applied allowed the formation of high hardness martensite in the 300 M steel (around 600 HV) and a rise in hardness of the Maraging steel (around 580 HV) due to the precipitation of hard particles. In this case, the tensile strength of the welded joint has risen to about 1340 ± 20 MPa.

For the HT1 condition, where the quenching and aging heat treatments were applied before the laser welding process, the microstructure of the base material of both steels has a higher hardness, close to 600 HV. After the welding, the Maraging steel will form in the fusion zone (FZ) and in the heat affected zone (HAZ), near the FZ, a structure without the hardening precipitates, with less hardness. It is noticed, however, that the tensile strength levels are similar to those observed in the post-weld heat treatment conditions (HTo’ and HT1’), around 1,500 ± 50 MPa.

When the welded set in the HT1 condition receives the annealing heat treatment, passing to the HT1’ condition, a reduction in the tensile strength (about 1400 ± 100 MPa) occurs due to the martensite tempering in 300M steel (Fig 9). It is noticed that heat treatments applied, both before or after the welding, are important to increase the tensile strength.

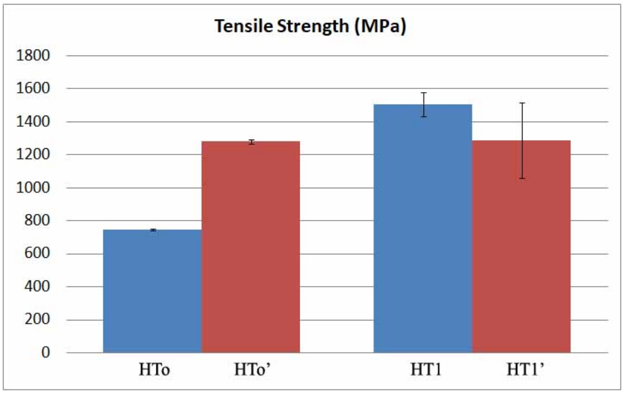


Fig. 9. - Results of tensile tests for the four conditions studied: HTo; HTo’; HT1 and HT1’.

3. Conclusions

The results showed that it is possible to weld the dissimilar steels: 300 M and Maraging (18Ni). It has also been observed that the heat treatments can improve the hardness and the tensile properties.

The 300 M steel with a carbon content of around 0.4 % needs to undergo a quenching and tempering heat treatment to increase its properties and for Maraging steel the aging heat treatment is enough.

Adjustment of the quench temperature for the 300 M steel with the aging temperature of the Maraging steel (480 °C) allowed the structure of both welded steels to have increased in hardness value.

Acknowledgements

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