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Similar and dissimilar welding effect on the mechanical properties of 5383 H34, 5754 H34 and 6005 T6 aluminum alloys

Efeito da soldagem nas propriedades mecânicas de ligas similares e dissimilares de alumínio 5383 H34, 5754 H34 e 6005 T6

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ABSTRACT

Aluminum alloys are not covered by their specific weight. Each class of aluminum alloy presents a set of properties that are favorable to a given function in the same product, just as the alloys may be present in the same vehicle. However, it is necessary to know the changes in the mechanical properties that occur with the union process of these aluminum alloys. The objective of this study was to evaluate the mechanical and morphological properties of alloys 5383 H34, 5754 H34 and 6005 T6 similarly welded and dissimilar by the MIG process. Six combinations of these alloys were characterized by mechanical tensile, folding and Vickers micro-hardness tests, as well as scanning electron microscopy (SEM) and optical microscopy (OM). Among the results obtained, a decrease in tensile strength was observed for all welded alloys. In addition, the microhardness was affected in the melt line, in the weld bead and in the HAZ (heat affected zone). The main causes of the reduction of the mechanical resistance of the welded alloys were the grain growth and the precipitate dissolution. The data obtained in this study contribute in a very positive way to the development and dimensioning of new projects and technologies involving aluminum alloys.

Keywords: microstructure, dissimilar welding, mechanical resistance, grain morphology.

RESUMO

As ligas de alumínio são amplamente aplicadas no setor de transporte devido ao seu baixo peso específico. Cada classe de liga de alumínio apresenta um conjunto de propriedades que são favoráveis a uma determinada função a qual a peça irá exercer no produto, assim diferentes ligas podem estar presentes em um mesmo veículo. Entretanto, faz-se necessário conhecer as mudanças nas propriedades mecânicas que ocorrem com o processo de união dessas ligas de alumínio. Este estudo teve por objetivo a avaliação das propriedades mecânicas e morfológicas das ligas 5383 H34, 5754 H34e 6005 T6 soldadas de forma similar e dissimilar pelo processo MIG. Seis combinações destas ligas foram caracterizadas por ensaios mecânicos de tração, dobramento e microdureza Vickers, além de análises de microscopia eletrônica de varredura (MEV) e microscopia óptica (MO). Dentre os resultados obtidos verificou-se uma diminuição na resistência à tração para todas as ligas soldadas. Além disso, a microdureza foi afetada na linha de fusão, no cordão de solda e na ZTA (zona termicamente afetada). As principais causas da redução da resistência mecânica das ligas soldadas foram o crescimento de grão e a dissolução de precipitados. Os dados obtidos neste estudo contribuem de forma muito positiva para o desenvolvimento e dimensionamento de novos projetos e tecnologias envolvendo ligas de alumínio.

Palavras-chave: microestrutura, soldagem dissimilar, resistência mecânica, morfologia dos grãos.

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1. INTRODUCTION

Aluminum alloys have advantageous properties if compared to other metals like steel, such as resistance to weather, high mechanical resistance, low specific weight, high malleability and easy processing [1]. One of the most explored characteristics is the low specific weight, mainly in the transportation sector [2].

Each aluminum alloy class has a set of properties that are favorable to a certain function at which the part will have on the product. Once the complexity of the existing functions in a transportation vehicle is known, it is necessary to use more than one aluminum alloy for the development of a project.

Regardless of the joining process type used between parts of different aluminum alloys, such process will cause changes on the mechanical behavior of the joint [3, 4, 5]. Therefore, it is necessary for the product designer to know them, to allow the use of adequate calculations and considerations to develop the project [6]. This joint can be carried out by means of welding, allowing the assemblage of products with an efficient weight reduction [7]. Among the various existing welding processes, one of the most commonly used is the MIG process, because of its versatility and performance. MIG weld (Metal Inert Gas) or GMAW (Gas Metal Arc Welding), or according to the designation given by European standards EN 131, is characterized by the fusion of the base metal by an electric arc caused by the current that crosses the consumable wire, protected by a flow of inert gas [8, 9]. However, this process has the disadvantage of not presenting the same results for all the types of alloys [10].

Studies show that each dissimilar combination of alloys in aluminum under different heat treatments will have a distinct mechanical behavior after they are welded by MIG process [11,8]. It is necessary, thus, to study specifically each new alloy developed with its respective treatment, for the scaling of a project.

In order to know the behavior of the joint between those alloys and allow the projects that use them to be developed with the consideration of the properties and characteristics of those joints, this work proposes the study of alloys 5383 H34 and 5754 H34 and 6005 T6, welded by MIG process, with the optical microscopy (OM), scanning electron microscopy (SEM), traction trials, bending and Vickers micro-hardness techniques, previously chemically characterized by optical spectrometry. The data obtained by means of different methods were analyzed and compared, in a way that they can be relevant for the development of new projects and technologies involving those alloys.

2. MATERIALS AND METHODS

The aluminum alloys 5754 H34, 5383 H34 and 6005 T6 had their chemical composition determined by optical spectrometry with plasma coupled by Spectro device, Spectromaxx model.

The three alloys were welded according to Figure 1, by double pulsed MIG process, executed manually with the preparation in a 45° angle. The weld was done with the horizontal displacement in favor of the melting puddle, at the speed of 0.45 mm/s, with torch tilt at 60°. The machine used was of the brand Castolin Eutectic, model MigPulse 3001 DP, in alternating current of 111 A, under 21.8 V tension. The addition metal used was in accordance with the European standard AWS A5.10: ER5356, with 1.2 mm diameter, made of aluminum, and of chemical composition of Si: 0.25%, Fe: 0.4%, Cu: 0.1%, Mn: 0.2%, Mg: 5.0%, Cr: 0.2%, Zn: 0.1%, Ti: 0.2%. The gas used was argon, at 99.99% purity level. All the welding parameters were kept constant during the whole process.

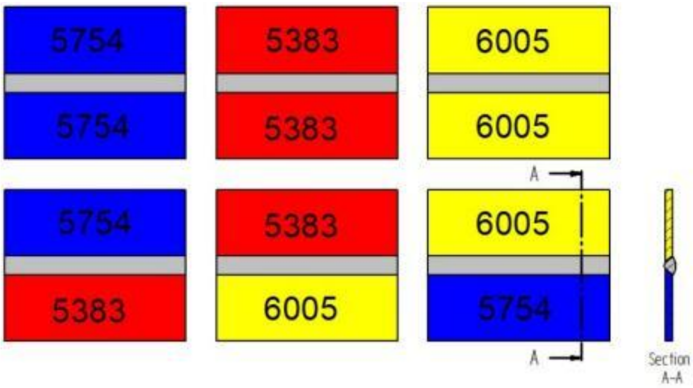

Figure 1: Combination of aluminum alloys used for the tests.

After the test pieces were welded, they were subjected to a traction test, according to the standard ASTM E8/E8M 2009, with test pieces machined in accordance with the referred standard. The test was carried out in a tests universal machine EMIC DL 10.000, with load cell of 100 kN.

The samples for microhardness profiling were extracted from the cross section of the parts, according to detail A-A of Figure /l1. After polished, the micro-hardness profile was elaborated by means of the machine Vickers Hardness Tester, model HVS-5. The load used for the test was of 0.2 kg; it was kept for 10 s until it was released.

For the analyses by OM and SEM, the surface of each sample was sanded with sander granulations at 200, 400, 600, 800, 1000 and 1200; after that, they were polished with polishing cloth, with Diapol diamond paste and lubricant (Panambra – Brazil) of 6 µm, 3 µm and 1 µm. The final polishing was carried out with colloidal silica of 0.04 µm (Struers – Denmark). The chemical attack was carried out with two reagents at different concentrations: 60% of HCl, 20% of HNO_3, 10% of HF and 10% of distilled water (Reagent 1) and 2.5% of HNO_3, 1.5% of HCl and 1% of HF (Reagent 2). The polished and chemically attacked samples were observed with an optical bench microscope, brand ZEISS, model AXIOSCOP 2 MAT and with a scanning electron microscope, brand Shimadzu, model SS-550, with acceleration of 15 kV.

3. RESULTS AND DISCUSSION

Table 1 presents the result of the optical spectrometry for the alloys 5383 H34, 5754 H34 and 6005 T6. Magnesium is the element that is present in the biggest quantity in alloys 5383 and 5754. The highest hardness and resistance to aluminum is a solid solution of Mg_2Si, $Al_6(Fe,Mn)$ and Al_3Mg_2 is attributed to that element [12]. In alloy 6005, the most abundant element, besides aluminum, is silicon, present at 1.15%; it has low solubility in aluminum [12], but increases the alloy resistance when combined with magnesium (present at 0.54% in alloy 6005) and heat treated, forming precipitates of Al-Mg-Si in GP phases Zone Mg_2Si, β Mg_5Si_6, β' Mg_9Si_5 e β'' Mg_2Si [13].

Table 1: Chemical composition of samples.

	Si (%P/P)	Fe(%P/P)	Cu(%P/P)	Mn(%P/P)	Mg(%P/P)	Cr(%P/P)	Zn(%P/P)	Ti(%P/P)
5383 H34	0.1326	0.2731	0.0136	0.6178	5.0413	0.0893	0.007	0.0333
5754 H34	0.154	0.2925	0.032	0.3644	2.8714	0.0581	0.007	0.0155
6005 T6	1.1558	0.2103	0.1182	0.1474	0.537	0.0007	0.0053	0.0131

The traction test was carried out in the samples the way they were received and after the welding process. The samples as they were received, i.e., without welding, had the following results in the traction test: 210, 278 and 155 MPa of yield strength for 5754, 5383 and 6005, respectively. The results for ultimate tensile stress were 160, 270 and 150 MPa, respectively. Figure 2 presents the result of the traction tests for the test pieces welded in similar and dissimilar ways.

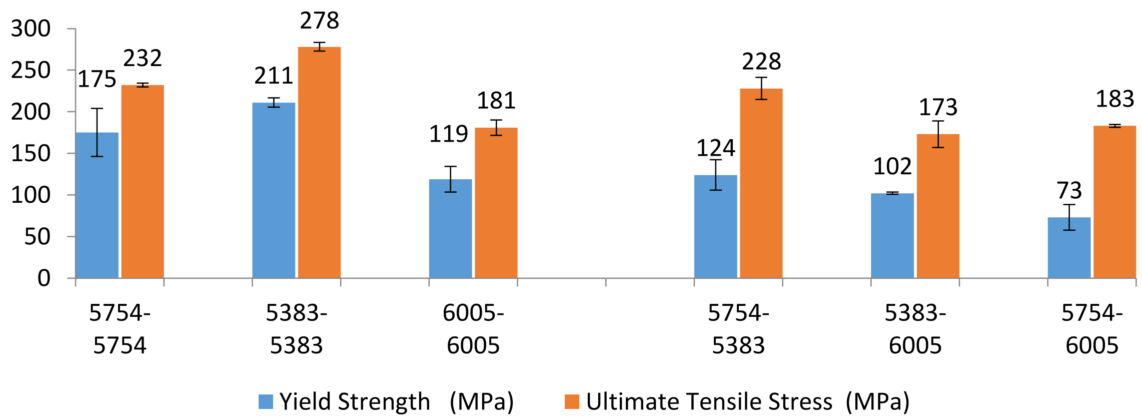

Figure 2: Results of the traction tests of welded test pieces considering engineering tensile.

By comparing the result of the traction tests of alloys TPs the way they were received (without welding) to the similar alloys after welded, one could notice a decrease on the maximum tension and on the yield strength for all the samples. The resistance to traction and the yield strength of alloy 5754 reduced around 16%, due to the welding process. For alloy 5383, this reduction was more evident, presenting a reduction of 24% on the yield strength and of 26% on the values of ultimate tensile strength. Alloy 6005 had a reduction of 23% on the values of yield strength and of 14% on the ultimate tensile strength, always being compared to the results of alloys without welding. This way, it could be noticed that there was a loss of mechanical resistance caused by the welding process in alloys of similar materials. The decrease in maximum stress and yield strength is caused by the heat input generated by welding, which generates loss of strength in 6XXX and 5XXX family alloys [20]

For dissimilar samples, it is believed that the joint between different materials results in the loss of mechanical resistance with the welding process, i.e., it is expected that the joint resistance is equal or inferior to the resistance of the alloy with the lowest flow limit and the lowest resistance to traction. The weakest joint location is the cause of the reduction in mechanical strength, the HAZ [18] .

In order to verify this supposition, the result obtained for the traction test with TPs welded in a dissimilar way was compared to the result obtained from the alloy with the lowest resistance (without welding). Nevertheless, a reduction of 41% was observed for the values of yield strength and of 18% on the values of maximum tension for the joint of welded alloys 5754-5383, when they were compared to the values presented by alloy 5754 (the alloy least resistant to traction). Joint 5383-6005 lost 34% on the yield strength and 17% on the maximum tension, when compared to alloy 6005. The union 5754-6005 had a reduction of 53% on the yield strength and of 13% on the maximum tension, when it was compared to alloy 6005.

When we compare the results of ultimate tensile strength and of yield strength (Figure 2) of the dissimilar samples with similar welded alloys, it is not possible to notice a significant difference on these values. Therefore, it can be concluded that the resistance of the dissimilar alloy is equivalent to the resistance to the material with the lowest resistance, similarly welded.

Aiming to evaluate the alterations of mechanical properties on butt weld and on diverse joint areas, micro-hardness profiles were elaborated to each dissimilar union. Figure 3 presents results on the Vickers micro-hardness and co-relate them, through graphics background image, to the location in which the indentations were done on the test pieces.

Alloys 5754 and 5383 as received have the hardness of 84.02 $HV_{0.2}$ and 102.27 $HV_{0.2}$ respectively. For the welding of alloy 5754 with alloy 5383, it could be observed that there was loss of micro-hardness in the weld seam, when compared to alloy 5754. The micro-hardness decreases on alloy 5383, near the weld seam. Thus, the heat generated by the welding affected the micro-hardness of alloy 5383 and 5754.

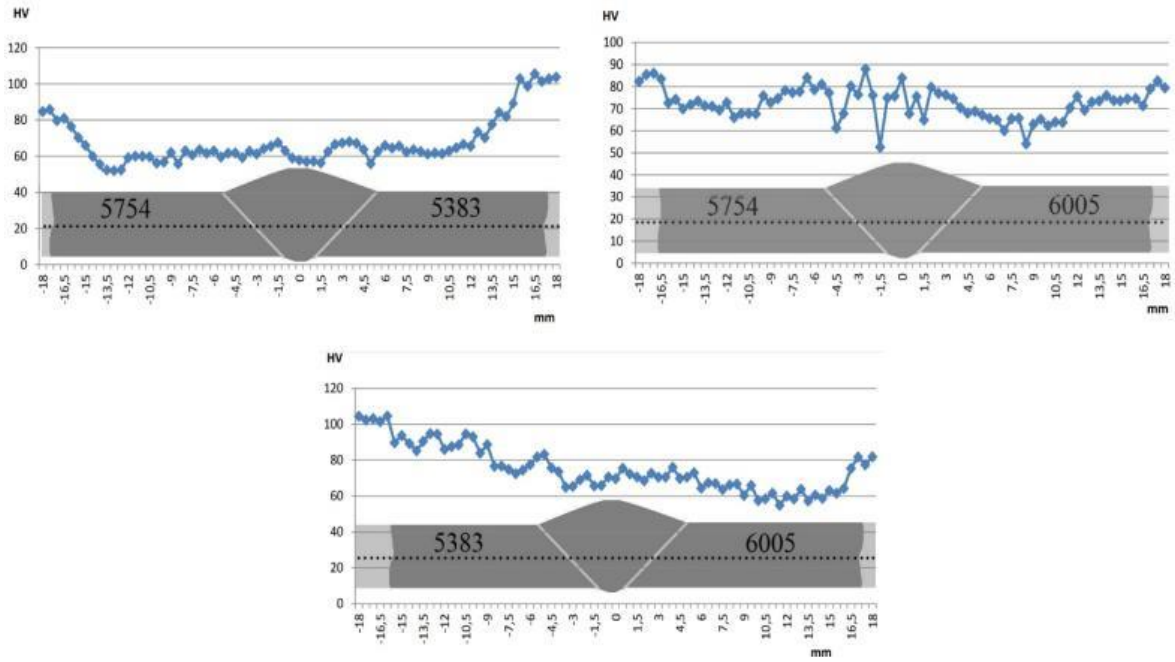

Figure 3: Result of Vickers micro-hardness for alloys 5754 - 5383, 5383 – 6005 and 5754-6005.

For the dissimilar alloys 5754-6005, there was a slight increase on the micro-hardness values for alloy 5754 by a few points, the probable cause is that they are high AL_2O_3 sites, which are particles present in aluminum and magnesium alloys and significantly increase the hardness of the material [19]. It could be perceived that there were some oscillations on the values measured in the fusion lines and on the weld seam, possibly generated by the presence of micropores, located under the surface where the indentation was done, due to vaporation of Mg and Zn elements [21]. For alloy 6005, there was a decrease on micro-hardness on HAZ when compared to the alloy as received, with 83,32 $HV_{0,2}$; it spread up to a distance of 16,5 mm from the weld seam center. This effect was also found in a similar way by GUNGOR, *et al.* [14] in the welding of other alloys of the family 6XXX.

For the hardest alloy, 5383, after welding with the least hard one, 6005, a reduction on the hardness values was noticed, beginning at 4 mm from the fusion line on alloy 5383. The weld seam had less variation on the measurements, and a gradual reduction of the joint micro-hardness was noticed.

Optical microscopy was used to investigate how the alloys' microstructure was affected by the heat and how this influenced on the modification of the mechanical properties of tensile strength and micro-hardness. Figure 4a presents the optical micrography of alloy 6005 T6 as-received condition, and, on Figure 4b, after it was welded, at a distance of 7.5 mm from the center of the butt weld. One can notice an increase of the average grain size; the alloy as it was received presented an increase on the grain average size. The alloy, as-received condition, had a grain average size of 0.015 mm; after the welding process, this size went up to 0.096 mm. As alloy 6005 T6 has the grain size controlled by thermal treatment, and it was modified by the action of the welding heat, this phenomenon can be attributed to the loss of resistance, as observed in the traction tests. Figure 4c presents the micrograph at 6 mm from the joint center for alloy 6005, done in the interface area between the HAZ and the butt weld. It can be observed that the precipitates on grain boundaries start to dissolve, and the linear continuity observed in Figures 4a and 4b was lost. In Figure 4d the micrograph of the butt weld center is presented. In that area, there was a dissolution of precipitates characteristic of β-Mg_2Si, which contributes to the reduction on resistance to traction in this alloy family [15].

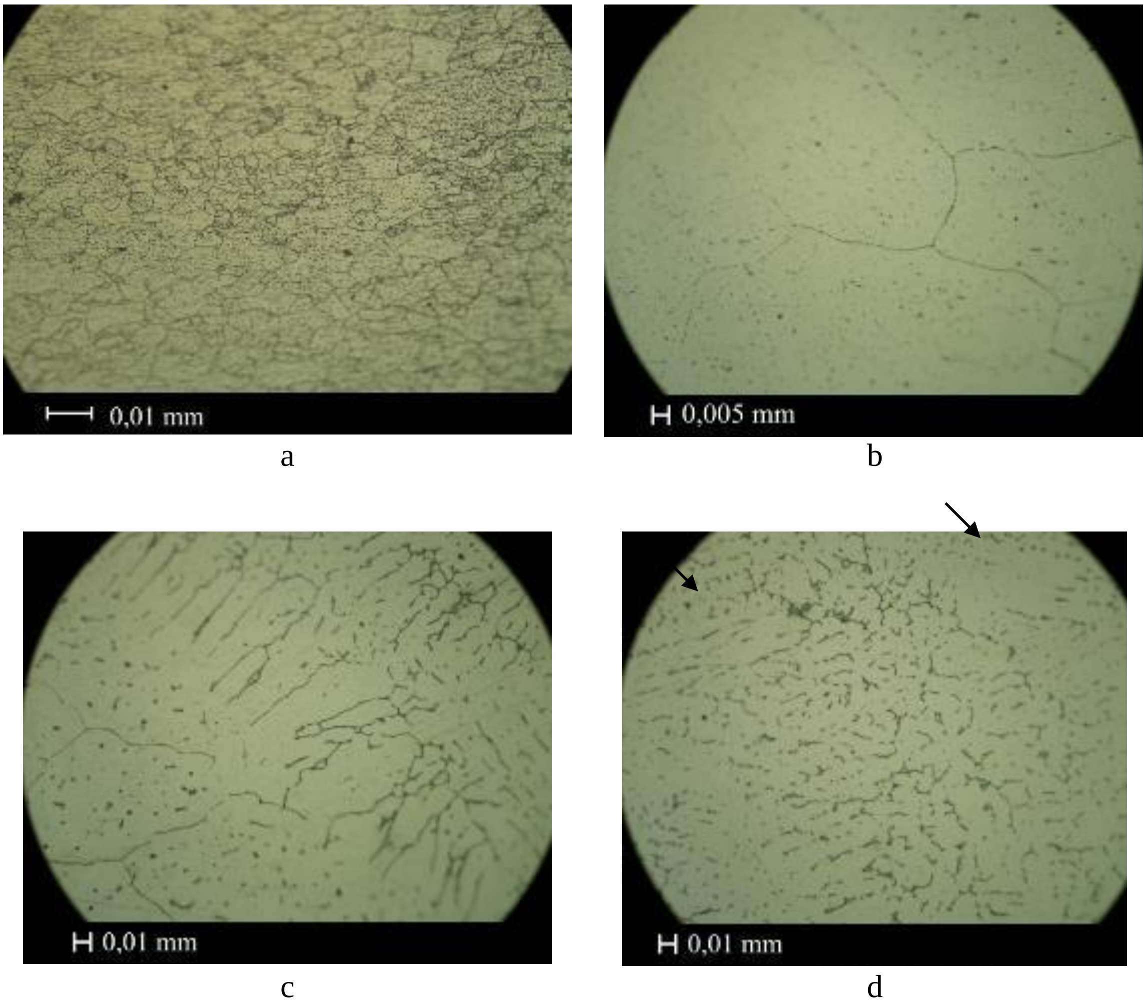

Figure 4: Micrographs of alloy 6005 T6 as it was received attacked by Reagent 2. As it was received, with 10x of magnification (a), after the welding, at HAZ, with 50x (b); of butt weld and HAZ interface, with 50x (c); of the butt weld with 50x (d).

The micrographs of Figures 5a and 5b have the same magnification and were taken in different positions in relation to the weld seam, which allowed the comparison of the microstructure at 18 mm (5a) and at 8 mm (5b) from the butt weld center. With the distance of 18 mm from the butt weld, the material microstructure was not altered; at 8 mm from the butt weld center, there were not modifications on grain morphology either. The elongated grains, characteristic of rolled alloys, were affected by the heat, which is noticed since 12 mm of distance from the butt weld center, and then the grains start to have morphology that resembles the equiaxial.

Near the weld seam, the grains start to have a less elongated form, but they still present a reduced size. A huge modification on the grain size happens at 6 mm from the weld seam center. The average size of the grain went up from 0.0011 mm to 0.0083 mm. In this area, there was a microstructural change. In places where there were not alterations caused by the heat, the grains were horizontally elongated; on the weld seam, the grains increased considerably, and became diagonally-oriented, as can be seen in the image of Figure 5d. An increase of 7.5 times of the average grain size could be noticed. Such change in microstructure can be related to the reduction of the micro-hardness average value of 19 HV.

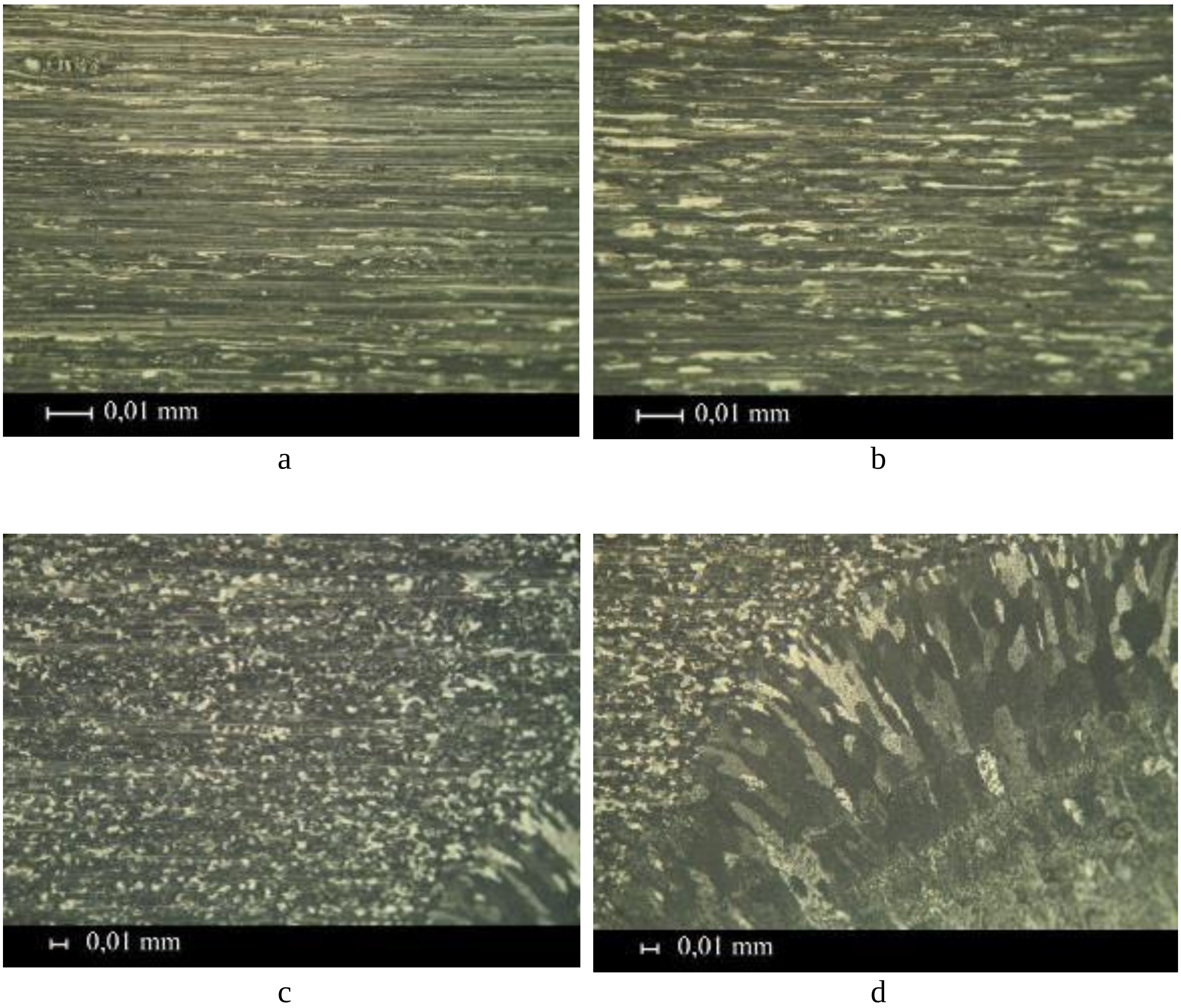

Figure 5: Optical Micrographs of welding of similar alloys 5383 with, attacked by Reagent 1. At 18 mm from the butt weld center (a), at 8 mm from the butt weld center (b). Figure 9: at HAZ (c), and at the fusion line with the butt weld (d).

In Figure 6, it is possible to observe how the resistance increase mechanism of alloy 5383 was altered. One can observe the detail of the formation of unconformities' movement lines [16], and notice that entire blocks were displaced, a characteristic of cold work hardening [17]. In Figure 6 it can be noticed that this mechanism of resistance increase was modified when there was the fusion of the material with the additional metal, by the change of crystals orientation, for they lost the horizontal fibrous orientation, which provides resistance to that alloy. In Figure 6, one can observe the loss of morphology of elongated grains, a characteristic of laminated materials after the welding, once that in the butt weld area, such morphology was altered. This can explain the decrease on the values of resistance to traction and hardness observed in the mechanical tests.

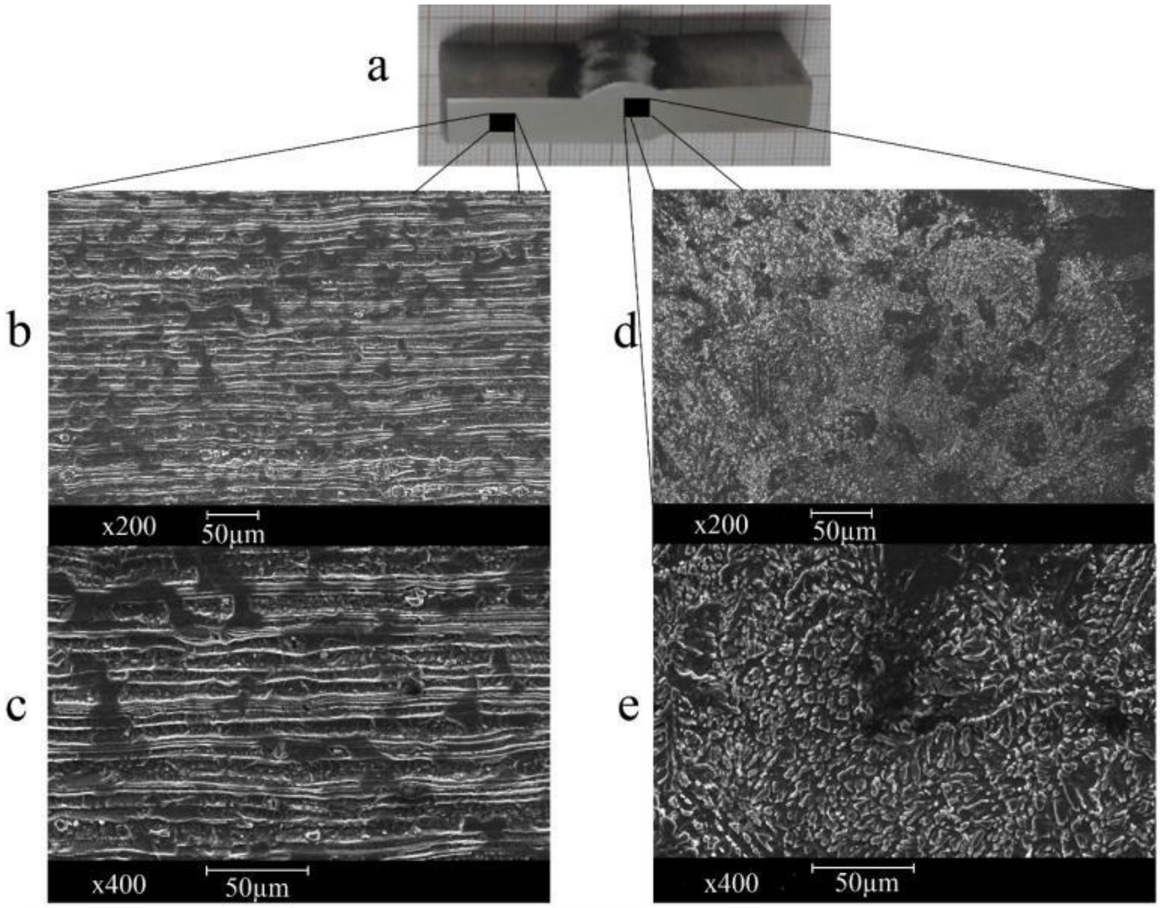

Figure 6: Micrograph of the welding of dissimilar alloy 5383 as received, attacked with Reagent 1 (b, c), of the alloy as it was received, and on the butt weld (d, e).

4. CONCLUSION

Alloys 5383 H34, 5754 H34 and 6005 T6 are compatible with MIG welding and do not lose resistance to traction when they are similarly welded. It means that the total resistance of this combination can be considered as the alloy resistance that is the least resistant when welded. Even though alloy 5383 presents a decrease on micro-hardness after it was welded, the areas that present lower micro-hardness were the fusion line and the HAZ in the dissimilar alloy at 5383. Therefore, those joint points can be considered the most susceptible to failures. The main cause of the reduction on resistance to traction and on the micro-hardness of alloys 5383 and 5754 was the loss of morphology of elongated grains and grain growth.

The data obtained from this study contribute in a very positive way to the development and the scaling of new projects and technologies involving those alloys.

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