

Effect of surface modification by Agitation Friction (FSA) on the hardness and wear of the aluminum alloy of the 6000 series

Efecto de la modificación superficial por Fricción Agitación (PFA) en la dureza y el desgaste de la aleación de aluminio de la serie 6000

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Abstract

This article presents the results obtained from the evaluation of the effects of the surface modification by Friction Stir Processing (FSP) on an aluminum alloy of architectural use of the series 6063 are reported. The behavior of the material in the state of supply and of the modified material by FSP, microhardness analysis, metallographic analysis at macro and micro levels, wear analysis and coefficient of friction were performed using the Pin on Disk dynamic test. It was found that in general the surface modification produces a substantial improvement of the mechanical properties such as hardness when passing from 42 HV to 62 HV in the samples modified by (FSP) and the wear resistance in terms of mass loss was reduced in a 39% offering an important technological alternative to improve the in-service performance of these materials subjected to similar operating conditions.

Keywords: pin on disk; metallographic; friction

Introduction

The high demands of components in the automotive and aeronautical area stimulates the development of components more it proves to be lightweight (Cavaliere, 2005). The aluminum alloys included the series 6000 have a great demand due to No. the low density and high resistance to the corrosion (Charit & Mishra, 2003). For certain applications it is needed that the components have superficial special conditions such as high resistance to the wear (Karthikeyan, Senthilkumar, Balasubramanian & Natarajan, 2009; Nascimento, Saints, Vilaça, Miranda & Quintino, 2009), the superficial modification for friction agitation PFA has turned into a technology of solid-state

processing for the superficial modification of materials with a base to the beginning of the weld for friction agitation (SFA) (Darras, Khraisheh, Abu-Farha, & Omar, 2007; Wang & Mishra, 2007). The superficial modification as friction agitation (PFA) has the aptitude to improve diverse properties of the material as the resistance to the wear, the corrosion, the fatigue and the hardness (Mahoney, Rhodes, Flintoff, Bingel, & Spurling, 1998) what gives an advantage on traditional processes of superficial modification as some thermal treatments where on having improved a property there gets lost other one (Poggie & Wert, 1992).

The friction coefficient and the behavior to the wear of the different aluminium types in conditions of not lubrication they are associated with the mechanical properties, as well as with the reactivity of the surface, the first approximation supposes that an increase in the hardness will be translated in an increase in the resistance into the wear (Elangovan, & Balasubramanian, 2007).

Experimental Development

The superficial alloy modification of the series 6063, was realized on sheets of 60 mm, 200 mm, 4,7 mm, extracted from a slide obtained by extruding 25,4 cm of width by 6 meters of length and 4,7 millimeters of thickness. The tribology characterization was realized on the cord surface; while they were effected microhardness measurements and the metallography analysis on the section of the transverse cord.

Welding process

The superficial sheets modification was realized generating a cord on one of the faces of the sheet with the help of a conventional milling machine brand JHONFORD of 4HP, with the parameters that appear in Table 1.

Table 1. Parameters of PFA and speed relation

Muestra No.	Rotation speed (RPM)W	Forward speed (mm/min)V	Relación de Relación of (rev/mm)
1186	1120	86	13
1163	1120	63	17.7
1686	1600	86	18.6
1663	1600	63	25.3

Source: the authors

It was used as a tool made with steel H13 moderate and re-come for a minimum hardness of 50HRC, with the flat shoulder of 18 mm of diameter, with a cylindrical screwed pin 6 mm of diameter and 3,3 mm of height. The cords were done by the tool's rotation in the anti-hourly sense. Figure 1.

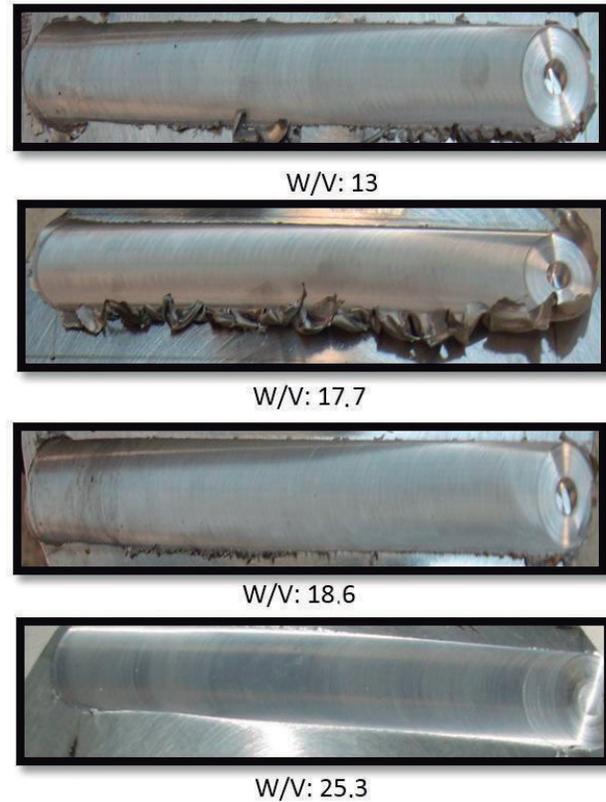


Figure 1. Aluminium cords processed for FSP. Source: the authors

Characterization Test

The sheets modified by friction-agitation process, were characterized by means of the mechanical microhardness tests, wear tests and the metallographic analysis to determine the size of grain and the microstructural changes structural generated mikes.

The analysis of metallographic was realized on the transversal section of the modified face by PFA; the samples were refined by sandpapers up to the number 2000, then polished in cloths using alumina of 0,05 microns and finally they were stuffed with Poulton reagent to reveal and to analyze the microstructure of the different material zones modified in an optical Olimpus microscope.

As the samples for metallographic the microhardness profiles were realized on the transversal section of every

surfaces' cord modified by PFA, a longitudinal and transversal sweep was done on the samples to determine the microhardness in a Mike – hardness tester Zwick/ Roell Indentec ZHV1-m with a load of 100 g and time of maintenance of 15 s.

The resistance to the wear and the coefficient of friction was evaluated by means of Pin-on-Disk's test on the surfaces modified by PFA, as well as for material base.

The test was realized under the following parameters: a tour of 1000 m, load applied 10N, diameter of the fingerprint 1 cm and a pin of steel to the hard chrome with a diameter of 6 mm.

Results

Characterization

In Figure 2 it appears the microstructure of the aluminum alloy superficially modified by FSP. Figure 2a corresponds to the transversal cut of the modified surface by PFA, can appreciate the typical zones: a rough zone (ZA), the affected thermic zone (ZAT), the affected thermo mechanically zone (ZATM), and material base, MB. In Figure 2b one presents the thick microstructure of material base MB, characteristic of the smelting aluminum with a dendritic formation with incorporations and segregation in the edges of grain. The rough zone ZA, appears in Figure 2c, composed of thin grains and equiaxials with a size of average grain of 6,7µm, resultant of the dynamic recrystallization in comparison with material base. As we approach the zone of transition ZATM, to see Figure 2d, is observed the presence of elongated grains orientated in the flow direction of the material, product of the high deformation that takes place in this zone and the insufficient heat gain that brings like proved a partial recrystallization of the grains (Elangovan & Balasubramanian, 2007).

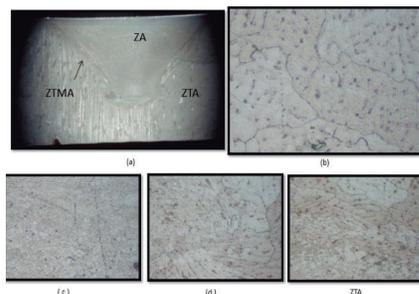


Figure 2. (2a) Micrographies of the transversal section of the surface modified by FSP, (2b) zone waved to 50X (2c) zone of transition to 50X (2d) Microstructure of Metal base s50X.

Source: the authors

Microhardness

The evolution in the microhardness material base (MB) with and without superficial modification presented in Figure 3. It is appreciated that on having diminished the speed relation during the PFA an increase takes place in the microhardness of the modified material, as result of the refinement size of grain for phenomena recrystallization that takes place during the process PFA. The samples modified by PFA reach values of maximum microhardness of 62 HV, very over the values of material base that ranged in 42 HV.

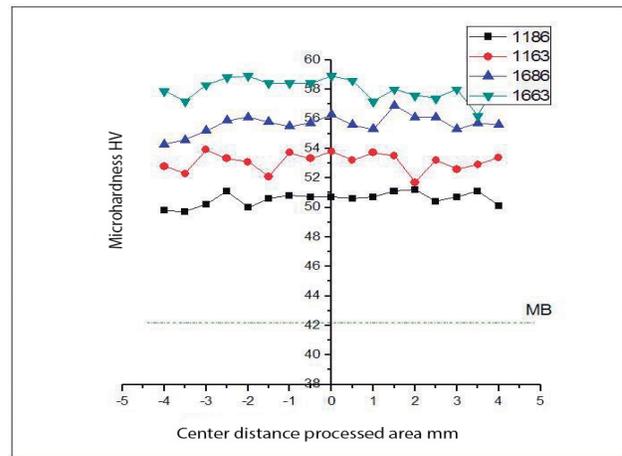


Figure 3. Profile of microhardness in the transversal section of surfaces modified by PFA

Source: the authors

The superficial effect of the modification PFA on the microhardness in aluminum alloys has been studied widely. Rajakumar, Muralidharan, and Balasubramanian (2011) examined the profiles of microhardness associated with the microstructure in the rough zone (ZA) of Al's alloys 6063-T5. And they have brought that the microhardness profile saw strongly affected by the distribution of precipitates in regions with small size of grain in the weld.

Recently, Zahmatkesh, Enayati, & Karimzadeh, (2011) investigated the effect of the PFA in the microstructure of the aluminum alloy 7050-T7451. Bringing that the process SFA has a direct effect on the size of the subgrains in the border of the thermally affected zone (ZAT), provoking a thickening of the precipitates and hardenings, causing the microhardness variation in this zone of border. Similar observations were done also by Siddiqui, Abdullah, and Al-Belushi (2000) in an examination detailed with TEM of the SFA in Al's alloy 7050-T651. The thickening of the precipitates and (FSP's) extension are evident (Morgado, Branco, & Infante, 2007).

Wear

In Table 2 the behavior shows itself of material base and modified by PFA in the test of pin on disk; observes a slight decrease of the friction coefficient in the samples modified superficially in relation to the samples of material base (MB). The samples modified by PFA showed an initial slope of more pronounced friction coefficient, which the material presents it without any treatment or material base, the average coefficient friction of the samples with PFA was 0,7, minor that MB's samples that presented a friction coefficient of 1,2.

Table 2. The behavior of the friction coefficient depending on the speed relation for every sample

Sample	Rotation speed (RPM)/W	Relation speed (rev/mm)	Friction coefficient
1186	1120	13	0.58
1163	1120	17.7	0.68
1686	1600	18.6	0.64
1663	1600	25.3	0.7
MB	N/A	N/A	1.2

Source: The Authors

The initial increase in the friction coefficient of the MB can owe to the increase of the necessary friction force to overcome the highly adhesive contact between the Pin and the surface of the test (Padmanaban and Balasubramanian, 2010). The differences in the plastic strain amplitude located in royal areas of contact that can lead to the difference in the friction coefficient provided that the surfaces are more difficult to separate (Chowdhury, Chen, Bhole, & Cao, 2010; Perez, Ortiz Albuixech, Moglioni & of Vedia, 2003).

This decrease in the friction coefficient was more well-known for the speed relations related to a major heat gain, which obtained the values of microhardness in more high places. The hardening of the surface strengthens and re-accommodates the royal areas of contact between the tribology couple favoring this way not only the friction coefficient but also the wear of the surface like it is reported by Zahmatkesh, Enayati, & Karimzadeh (2010).

In the images of sweep electronic microscopy SEM, phenomena of wear were observed in figure 4, since of lamination and ruts of graze in material base or without superficial modification (Figure 4a and Figure 4c) while the samples modified superficially by PFA presented cracks and delamination (Figure 4b and Figure 4d).

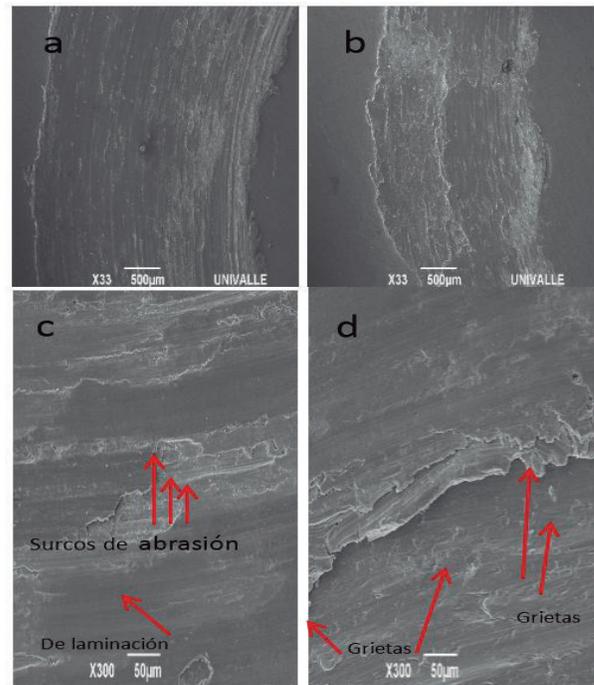


Figure 4. Sweep of electronic microscopy, fingerprint of wear, (to and c material bases) (c and d) speed relation (25,3)

Source: the authors

The presence of cracks and delamination in the samples superficially modified by PFA it obeys principally the difference of hardness between the tribology couple, though the process of superficial modification for PFA improves the superficial hardness of the material in relation with material base, the hardness of the pin is top and during the dynamics of wear the progressive detachment of material and the constant deformation of the same one produces the generation of cracks for fatigue (Alidokht, Abdollah - Zadeh, Soleymani, Saeid, & Assadi, 2012).

In the Figure 5 shows how it changes the loss of mass with regard to the relation speed, appreciates a notable decrease in the loss of mass in the samples modified superficially by PFA as it increases the speed relation, reaching a reduction in the loss of mass of 39 % in the samples with speed relations of (25,3) in comparison to the MB; this owes to that it presents major microhardness which diminishes the wear. Is it observed that for a rotation speed of the constant pin the increase in the speed of advance provokes an increase in the loss of mass. Similar behavior has been brought by Ren, Ma and Chen (2007), in aluminum To 390 reinforced with graphite by (FSP).

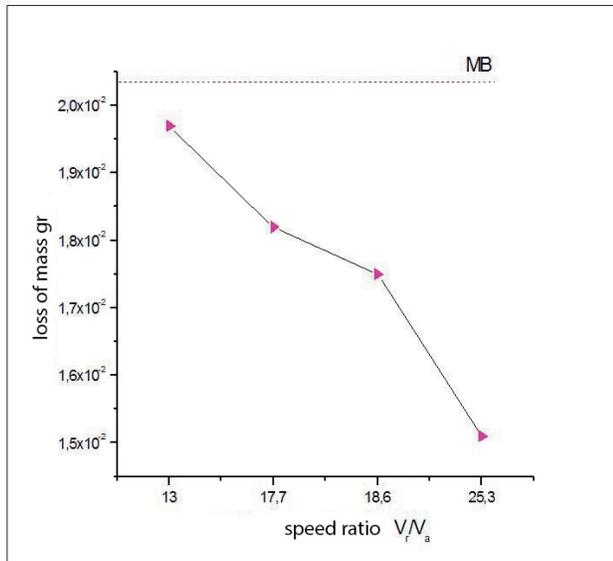


Figure 5. Loss of mass with regard to the speed relation for MB and samples with FSP
Source: the authors

The minor time of the material exhibition with the pin, it is translated in fewer heat gain. This affects the refinement of grain that has a preponderant effect in the resistance to the wear of the material.

Argument

It is concluded that the superficial modification has a charitable effect on the microhardness of aluminum alloys 6063 in condition of smelting, going from 42 HV to 62 HV, associated principally with the refinement of the grain size for the superficial modification of the material for PFA.

Conclusions

The loss of mass and the coefficient of wear diminished for the samples modified superficially by PFA with regard to material base. What allows us to think that the dissolution of precipitates and the refinement particles that take place during PFA's process has a major effect on the tribology behavior of the material that the microhardness by conferring a more ductal behavior to the aluminum matrix.

References

Alidokht, S. A., Abdollah-zadeh, A., Soleymani, S., Saeid, T., & Assadi, H. (2012). Evaluation of

microstructure and wear behavior of friction stir processed cast aluminum alloy. *Materials Characterization*, 63, 90-97. doi: <https://doi.org/10.1016/j.matchar.2011.11.007>

Cavaliere, P. (2005). Mechanical properties of friction stir processed 2618/Al 2 O 3/20p metal matrix composite. *Composites Part A: Applied Science and Manufacturing*, 36(12), 1657-1665. doi: <https://doi.org/10.1016/j.compositesa.2005.03.016>

Charit, I., & Mishra, R. S. (2003). High strain rate superplasticity in a commercial 2024 Al alloy via friction stir processing. *Materials Science and Engineering: A*, 359(1), 290- 296. doi: [https://doi.org/10.1016/S0921-5093\(03\)00367-8](https://doi.org/10.1016/S0921-5093(03)00367-8)

Chowdhury, S. M., Chen, D. L., Bhole, S. D., & Cao,X. (2010). Tensile properties of a friction stir welded magnesium alloy: Effect of pin tool thread orientation and weld pitch. *Materials Science and Engineering: A*, 527(21), 6064-6075. doi: <https://doi.org/10.1016/j.msea.2010.06.012>

Darras, B. M., Khraisheh, M. K., Abu-Farha, F. K., & Omar, M. A. (2007). Friction stir processing of commercial AZ31 magnesium alloy. *Journal of materials processing technology*, 191(1), 77-81. doi: <https://doi.org/10.1016/j.jmatprotec.2007.03.045>

Elangovan, K., & Balasubramanian, V. (2007). Influences of pin profile and rotational speed of the tool on the formation of friction stir processing zone in AA2219 aluminium alloy. *Materials Science and Engineering: A*, 459(1), 7-18. doi: <https://doi.org/10.1016/j.msea.2006.12.124>

Karthikeyan, L., Senthilkumar, V. S., Balasubramanian, V., & Natarajan, S. (2009). Mechanical property and microstructural changes during friction stir processing of cast aluminum 2285 alloy. *Materials & Design*, 30(6), 2237-2242. doi: <https://doi.org/10.1016/j.matdes.2008.09.006>

Mahoney, M. W., Rhodes, C. G., Flintoff, J. G., Bingel, W. H., & Spurling, R. A. (1998). Properties of

- friction-stir-welded 7075 T651 aluminum. *Metallurgical and materials transactions A*, 29(7), 1955-1964. doi: <https://doi.org/10.1007/s11661-998-0021-5>
- Morgado, T. L. M., Branco, C. M., & Infante, V. (2007). Previsão de vida à fadiga dos engates (rabetas) dos vagões de transporte de carvão. *Revista da Associação Portuguesa de Análise Experimental de Tensões ISSN*, 1646, 7078, 14, 35-43
- Nascimento, F., Santos, T., Vilaça, P., Miranda, R. M., & Quintino, L. (2009). Microstructural modification and ductility enhancement of surfaces modified by FSP in aluminium alloys. *Materials Science and Engineering: A*, 506(1), 16-22. doi: <https://doi.org/10.1016/j.msea.2009.01.008>
- Padmanaban, G., & Balasubramanian, V. (2010). Fatigue performance of pulsed current gas tungsten arc, friction stir and laser beam welded AZ31B magnesium alloy joints. *Materials & Design*, 31(8), 3724-3732. doi: <https://doi.org/10.1016/j.matdes.2010.03.013>
- Pérez, C. R., Ortiz Albuixech, M., Moglioni, A., & de Vedia, L. A. (2003). Evaluación de tensiones residuales en soldadura de aluminio AA6061-T6 obtenida por el método de fricción-agitación (FSW). *Simposio Materia 2003*. Red Latinoamericana de Materiales. Bariloche, Argentina.
- Poggie, R. A., & Wert, J. J. (1992). The role of oxidation in the friction and wear behavior of solid solution Cu-Al alloys in reciprocating sliding contact with sapphire and D2 tool steel. *Wear*, 156(2), 315-326. doi: [https://doi.org/10.1016/0043-1648\(92\)90225-W](https://doi.org/10.1016/0043-1648(92)90225-W)
- Rajakumar, S., Muralidharan, C., & Balasubramanian, V. (2011). Influence of friction stir welding process and tool parameters on strength properties of AA7075-T 6 aluminium alloy joints. *Materials & Design*, 32(2), 535-549. doi: <https://doi.org/10.1016/j.matdes.2010.08.025>
- Ren, S. R., Ma, Z. Y., & Chen, L. Q. (2007). Effect of welding parameters on tensile properties and fracture behavior of friction stir welded Al-Mg-Si alloy. *Scripta Materialia*, 56(1), 69-72. doi: <https://doi.org/10.1016/j.scriptamat.2006.08.054>
- Siddiqui, R. A., Abdullah, H. A., & Al-Belushi, K. R. (2000). Influence of aging parameters on the mechanical properties of 6063 aluminium alloy. *Journal of Materials Processing Technology*, 102(1), 234-240. doi: [https://doi.org/10.1016/S0924-0136\(99\)00476-8](https://doi.org/10.1016/S0924-0136(99)00476-8)
- Urbano Bedoya, L., & Arnaldo Ávila, J. (2011). Evaluación de la resistencia a la tensión de las juntas soldadas de la aleación de aluminio 6261-T5 por el proceso de soldadura por fricción-agitación. *Informador Técnico*, 75, 1517- 22. doi: <https://doi.org/10.23850/22565035.15>
- Wang, Y., & Mishra, R. S. (2007). Finite element simulation of selective superplastic forming of friction stir processed 7075 Al alloy. *Materials Science and Engineering: A*, 463(1), 245-248. doi: <https://doi.org/10.1016/j.msea.2006.08.118>
- Zahmatkesh, B., Enayati, M. H., & Karimzadeh, F. (2010). Tribological and microstructural evaluation of friction stir processed Al2024 alloy. *Materials & Design*, 31(10), 4891-4896. doi: <https://doi.org/10.1016/j.matdes.2010.04.054>

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