Development of the Bobbin-Tool for Friction Stir Welding

Characterization and analysis of aluminum alloy processed AA 6061-T4

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Abstract

The process of Friction Stir Welding (FSW) has been assumed as a cutting-edge technology in the binding of various metallic materials, which focuses on aluminum alloys, and materials of low weldability widely used in the aerospace and navy. Thus, the potential use of the FSW process in the structure and components of aircraft and ships is extremely high. It allows significant weight reductions and productivity increases replacing other welding technologies previously used.

This research focuses on the production and development of a tool known as a FSW Bobbin Tool that will provide some portability to the process of Friction Stir Welding and eliminate some common defects of conventional Friction Stir Welding, because it increases the production rate and field of utilization. The analysis was based on the study of the weldability of the alloy AA6061-T4 with 4.8mm thickness, typically used in accessories for aircraft and ships due to their high corrosion resistance, easy workability and its wide availability. To this end, the parameters for the process of FSW Bobbin Tool were developed followed by a risk assessment of the behavior of the joints on the shear strength of welded joints, made under static tensile and bending. A study of welding temperatures along a welded joints. The mechanical efficiency of the welded joints was calculated in order to check the influence of the parameters studied. A metallographic analysis of the joints was developed through various tests and their respective characteristics, complemented with technical non-destructive testing(visual analysis) and destructive techniques (analysis of hardness). The results demonstrate the influence of the process parameters in the quality obtained from the joints and allow to access the level of influence on the mechanical behavior of welded joints.

Key-Words

FSW Bobbin Tool, AA6061-T4, Mechanical Efficiency, Influence of parameters.

Introduction

Friction Stir Welding (FSW) Bobbin-Tool, is a variant of the FSW process, it is also a solid state welding, that is taking place below the melting temperature of the materials in order to connect them. A non-consumable tool with animated rotation and consisting of two bases and pin geometries capable of some complexity is introduced in the plates until it reaches the thermal conditions needed to compose the rotation with linear movement forward during which the tool will go through the line defined by joining these same plates. Thus, the connection of the solder material is obtained from a combination of extrusion, forging and chaotic mix [1],the heat generated mainly from the visco-plastic deformation zone of the welded materials, but the friction interfacial zones of sliding between the tool and the materials [2]. The technological relevance of this process within the manufacturing technologies, both for the scientific community and for the industry, it can be demonstrated by the important industrial applications where you can apply SFL Bobbin-Tool and the intense activity of research that resulted in new publications and patents [3], [4], [5], [6], [7], [8]. Also the Department of Mechanical Engineering of Instituto Superior Técnico, accompanied the development of this new concept, performing the first study in Portugal for experimental analysis SFL Bobbin-Tool. To use this new tool it was necessary to create new conditions of operation, including a new table setting, capable of withstanding the loads inherent in the process of SFL without suffering deflections which affect the welds. This work happens during the application and development of process SFL Bobbin-Tool link in aluminum alloy AA6061-T4, widely used in accessories and components in the aircraft industry and shipbuilding.

The development and Experimental Procedure

In order to design and build a new Bobbin Tool and to investigate the potential of this new method of SFL, the conception tool was based on certain characteristics of the conventional tools [9]. The simplicity, ease of handling and robustness were the three concepts always present in the design of the tool.

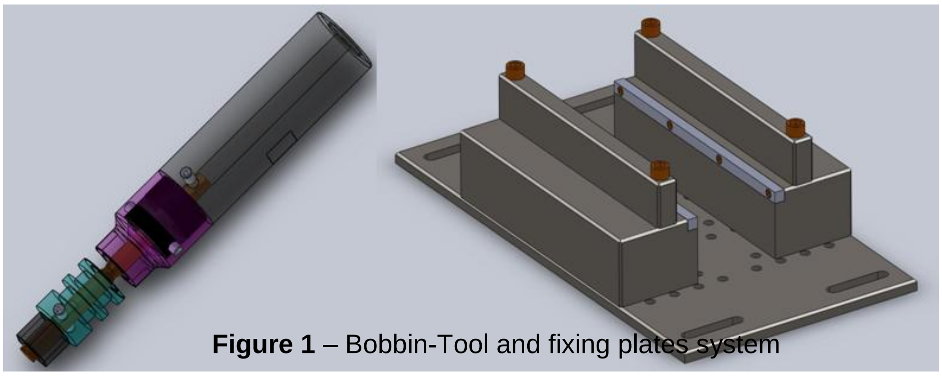

Figure 1 – Bobbin-Tool and fixing plates system

The material chosen for the FSW Bobbin-Tool has a steel H13, with an alloy for hot work, with an initial hardness of 240HV after a quench to about 400 ° C under vacuum, which is about the maximum temperature that the aluminum alloys reach at the time of welding while the hardness increases up to 540HV. Then the surfaces are cleaned to be targeted by a hardening treatment. Such cleaning involves shooting small balls that will remove the surface oxides. The heat treatment applied after this cleanup is a nitriding, which will again increase its hardness up to 1200HV . Finally an oxidation treatment is applied to surfaces in the tool using a water vapor at approximately 500 °C. The purpose of this treatment is to reduce friction and adhesion between the tool and the plates to be welded.

The new fixing system for the use of FSW Tool Tool Bobbin does not have to comply with geometric precision as careful adjustment of the plates. The big difference is that the plates are fixed at an interval previously defined and not as close as possible to the cord, because the joint welded plates have to be suspended for the Flyer Shoulder to pass without hitting any face. The fixation system has been designed to be used in the equipment available LEGIO TM FSW 3U- and also to be able to install it in a conventional milling machine. The system consists of a base thickness of 10mm which is all perforated so that it is possible to vary the interval between the two blocks that will hold the plates. These blocks were machined inside to reduce their weight for easier transport. The vertices of the two blocks were placed 2 rules consumables that after a few hours of use will be subject to wear due to the temperature gradient reached in that area, where more push-ups will be performed by alternating plates. The tool requires pre-defined procedures for the proper installation to ensure all operating conditions without damaging the machine and the tool. and as the very integrity of the operator below is represented a mounting procedure Tool and preparation of plates to be welded.

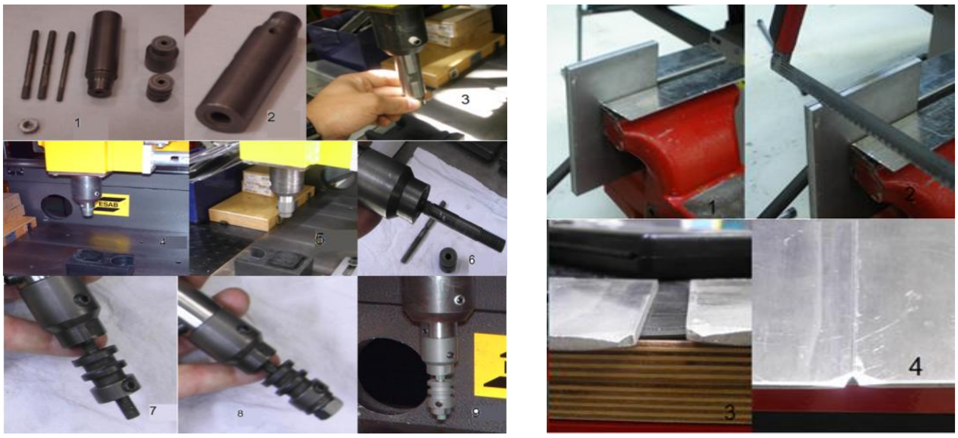

Figure 2 – Mounting Procedure Tool and preparation of plates

Was selected a group of samples to assess the influence of welding parameters on the properties of strings obtained. The samples carried out in order to establish groups of parameters that remained constant and groups of parameters that varied, as well as to assess their influence, are described below.

The parameters which remained constant during the tests are as follows: rotation speed, Ω = 800 rpm, with a clockwise direction so that the pins can "push" the material of the plates to be welded in the opposite direction to the shoulders, angle of attack, α tool = 2º, all the cords were performed with control of position, the length of the strings was approximately 150mm. Below is a table with the parameters used in the 6 samples chosen.

Description	Pin [7mm]	Gap [mm]	Advance Speed [mm/min]
Sample 1	Cylindrical	4.8	100
Sample 2	Tapered	4.8	160
Sample 3	Tapered	4.55	100
Sample 4	Tapered	5.05	100
Sample 5	Tapered	4.8	100
Sample 6	Cylindrical	4.8	160

Table 1 – Welding parameters

Results and Conclusions

The visual analysis indicates that with GAP's difference, there are changes in the appearance of welded joints. For example Samole 4 that has a GAP of 5.05 mm shows that it is the upper permissible limit because of the difficulty in filling the joint. Initially welding has some cracks showing lack of strength in forging, yet there was a small burr with the possibility of manual removal, this was seen only from the top because in the bottom the thickness increased . Test 3 was produced with a GAP of 4.55 mm. At the top were not properly trim only decreases in thickness, while at the bottom there was a lot of trimming and consequent reduction in thickness. In other cords with GAP 4.8 mm, this range is the thickness of the plate, it was found that no material changes happened in thickness either at the top or at the bottom. Only the appearance of slightly irregular chips that are due to the passage pin within the joint-repellent material to the outside due to the incompressibility of the material. Looking at the difference of pins, denotes that the cylindrical pin is a decrease in the appearance of scrap compared to the flask.

Analyzing the macrographs in the posterior Samples, there is the nugget It does not cover all the samples of the thickness of the plates welded, mainly testing pin cylinder where it is found that the nugget in these trials is thinner than the tests with the cylindrical pin, but there is a full completion of the nugget in the thickness of the plates, the test is 3 due to the lower GAP tool.

The results of Vickers hardness tests performed on the samples are presented in the form of a graph that traces the evolution of the hardness along the welded joint from the nugget to the base material of the sample (87.7 MB = HV0.5)

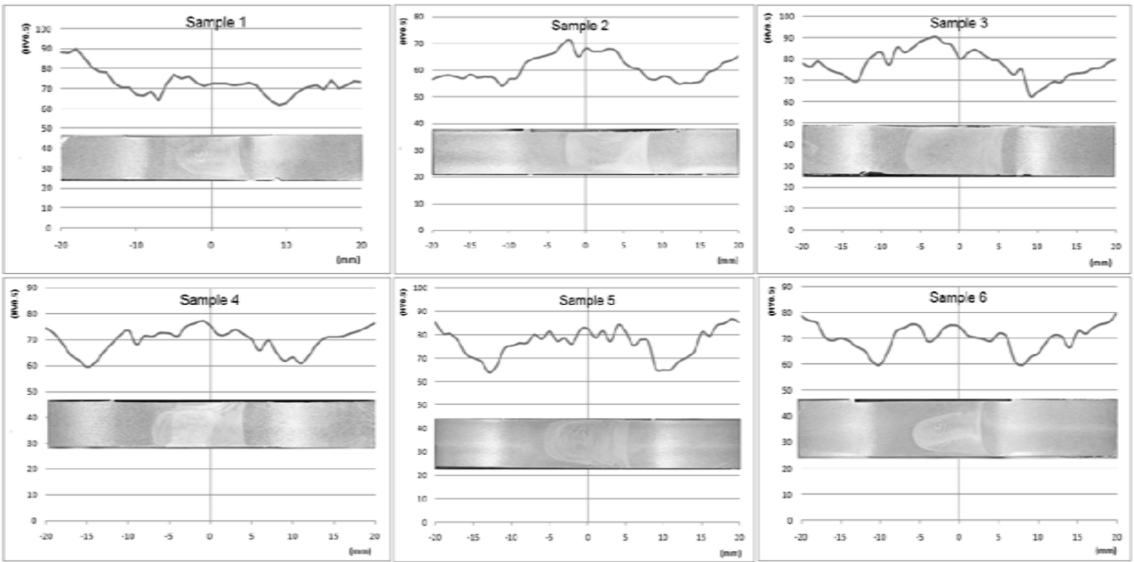

Figure 3 - Vickers hardness profiles

Analyzing the graphs presented above we can say that:

The hardness of Base Material is higher in all cases except test 3, where the hardness of the nugget turned out to be higher. Due to this reason GAP of 4.55 mm in this case carries a increased load of forging which increases the hardness, as the grain size provided by the dynamic recrystallization of the nugget decreases. The remaining hardness are lower compared to BM due to the smaller amount of forging that is not enough to "pack" the nugget as expected for a conventional FSW. The lower hardness in each profile is located at the interface between heat affected zone by thermomechanically affected zone due to be the warmest area, with no dynamic recrystallization or deformation of the grain. Another possible justification for the point of absolute minimum hardness is located at the interface between heat affected zone and thermomechanically affected zone is that correspond to the area without undergoing plastic deformation, suffers the highest rate of cooling (temperature), coming of temperatures (+450 º C) in which there was a partial redissolution of the precipitated second phase in the solid phase of aluminum, followed by an aging insufficient precipitation of new intermetallic. Note that the plastic deformation of the crystal structure in thermomechanically affected zone promotes the retention of energy, which promotes the increase of the hardness of the structure in question.

From this absolute minimum, and with increasing distance from the center of the nugget, the maximum temperature decreases, but increases the time period in which the temperature is typical of activating the mechanisms of aging. Probably the local minimum that exists within the heat affected zone, before reaching the base material, due to an over-aging, and the resulting coalescence of precipitates.

Finally it is concluded that the speed gap between the shoulders is an important factor in determining the hardness, since the samples 2, 4 and 6 was found where the absolute minimum of hardness, in sample 2 and 6 due to the higher speed advance and sample 4 due to the increased GAP.

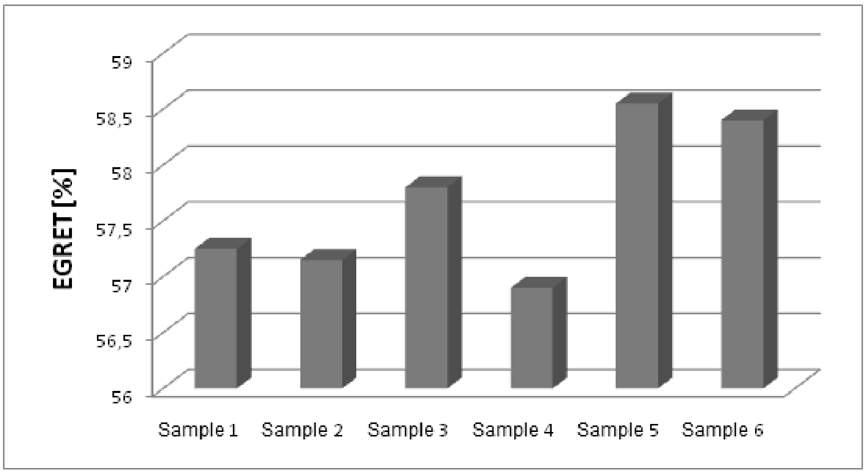

Figure 4 - Factor EGRET obtained for Samples

In general we can prove the vicinity of mechanical properties in all samples, since the EGRET(Efficiency Global Resistance Estatic Traction) factor never exceeded 2%, which is to show the repeatability in the quality of FSW Bobbin Tool in the presence of changing parameters.

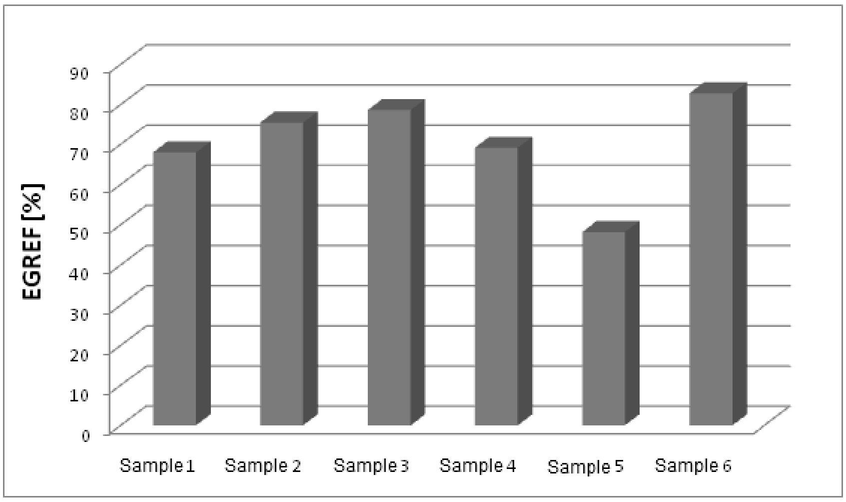

Figure 5 - Factor EGREF obtained for Samples

In this particular case we can see a greater divergence in the EGREF(Efficiency Global Resistance Estatic Flexion) factor that prove the influence of changing parameters, which reached around 30%.

Conclusions

Referring in particular all the work in the AA6061-T4 alloy 4.8mm thickness with the conclusions drawn were as follows:

• It was proven increased productivity as the time to settle plates is reduced and the security of smaller differences in the joints, because the FSW Bobbin Tool are more likely to repeatedly under identical welds.

• It was found and proved that it is only necessary robustness in the xx axis and yy zz as in the forging force is exerted on the tool itself between the Flyer Shoulder and Shoulder Body.

• The gap between the Shoulders can not be greater than the thickness of the sheets because of the difficulty of forging and waste of material which presents the beginning of the weld as it has difficulty in "forging" completely and doesn´t occor a healthy welded joint, it should also not be lower due to the reduction of section area of the cord and due to the large amount of scrap resulting from excessive penetration of the Shoulders, it was thus that the recommended interval is the GAP equal to the thickness of the plates because it is the one with better properties.

• On Flyer Shoulder is recommended cooling because the overheating of the time and difficulty in welding to cool the same, since the convection cooling even with the fins is not sufficiently effective at operating temperatures of the tool was tested with a cooling liquid cooling and found major improvements in cooling of the tool and all the equipment, for even the adapter sleeve SFL Bobbin Tool suffered a higher thermal gradient on the SFL Conventional and substantially improved the stability of the weld.

• Another aspect is to focus attention on cleaning tool, that after the second weld, it was the filling of the spiral grooves Shoulders the threaded pin, is thus advisable to clean these areas to increase tool life and facilitates the flow visco-plastic.

In general, the cords FSW Bobbin Tool perform better flexural strength than the best result for the tensile factor EGRET never exceeded 58% while the factor EGREF the best result came to the order of 83%.

References

[1] Thomas, W. M., Nicholas, E. D., Needham, M. G., Templesmith, Dawes, C. J., *Friction stir butt welding,* International patent Application PCT/GB92/02203, GB Patent Application 9125978.8, US Patent 5.460.317, 6 December 1991;

[2] Pedro Miguel dos Santos Vilaça da Silva, *"Fundamentos do processo de soldadura por fricção linear – Análise experimental e modelação analítica –"*, IST, Setembro de 2003;

[3] M. Skinner and R.L.Edwards, Improvements to the FSW Process Using the Self-Reacting Technology, Mater,Sci. Forum, Vol. 426-432, 2003, p2849-2854;

Sammy Nabors, Tool for Two Types of Friction Stir Welding, *Marshall Space Flight Center, Alabama*, 2006;

[4] *Richard Venable, Joseph Bucher,* Mechanism for Self-Reacted Friction Stir Welding, *Marshall Space Flight Center, Alabama,* 2004

[5] *Robert Carter, Kirby Lawless,* Gimballed Shoulders for Friction Stir Welding, *Marshall Space Flight Center, Alabama,* 2008;

[6] Jonathan Martin, Ian Norris; Assessment of Bobbin Friction Stir Welding for the Joining of Aluminium Alloys, September 2008;

[7] F. Marie, D. Allehaux, and B. Esmiller, Development of the Bobbin Tool Technique on Various Aluminum Alloys, Proceedings of the Fifth International Conference on Friction Stir Welding, September 14- 16, 2004 (Metz, France), TWI, Paper on CD;

[8] G. Sylva, R. Edwards, and T. Sassa, A Feasibility Study for Self Reacting Pin Tool Welding of Thin Section Aluminum, Proceedings of the Fifth international Conference on Friction Stir Welding, September 14-16, 2004(Metz, France), TWI, Paper on CD;

[9] Instituto Superior Técnico, PATENTE DE INVENÇÃO NACIONAL Nº 104072, 2008