

CONSIDERATIONS REGARDING FRICTION STIR PROCESSING OF AL7B04 ALUMINUM ALLOY

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Abstract: Friction stir processing is an environmentally friendly process of solid-state processing on well-defined areas of metallic materials, with the aim of local modification of the microstructure and mechanical properties. The process is of current interest to researchers and specialists in the field of metallic materials processing, being in continuous development regarding application possibilities to various metallic materials. The paper presents aspects regarding friction stir processing in different working medium of the aluminum alloy Al7B04, based on an analysis of the specialized literature. The study shows the possibility of applying friction stir processing for this aluminum alloy, as well as the modification of its microstructure and mechanical properties after processing.

Key words: friction stir processing, Al7B04 aluminum alloy, water cooling, processing conditions, microstructure, mechanical properties

1. INTRODUCTION

Friction stir processing (FSP) is an innovative, environmentally friendly, energy-efficient and versatile solid-state processing process for metallic materials, being of interest in applications in various industrial fields (e.g. the production of components and structures for the aeronautics, aerospace, shipbuilding, railway and automotive industries, etc.). Friction stir processing is derived from the friction stir welding process, having the same working principle, being applied on a single plate of base material.

Friction stir processing is a cutting-edge technique in the field of surface engineering, the use of which is investigated by researchers and specialists from priority industrial fields, with the aim of modifying the microstructure of the processed material, the hardness and roughness of the processed surface, increasing plasticity in certain well-defined areas and improving the properties of various metallic materials (e.g. aluminum alloys, copper, etc.) [1]-[5]. The application of FSP processing to metallic materials is aimed at local modification of material characteristics and properties, refinement of microstructure grains, as well as improvement of mechanical properties, fatigue and corrosion resistance, etc. [3], [6] and [7]. Friction stir processing (FSP) can be carried out in ambient -air, as well as in liquid medium (Submerged Friction Stir Processing - SFSP) [1], [2], [7] and [8].

Submerged friction stir processing is current and of interest to the scientific community and for industry, being an environmentally friendly and innovative technique for surface processing of metallic materials, which represents a progress in surface engineering. Research on Submerged Friction Stir Processing (SFSP) aims to evaluate the potential of using this technique to obtain fine-grained metallic materials, microstructure modification to improve surface quality and reduce porosity of the material to be processed [2]. The studies and experimental investigations envisage that by using FSP/SFSP processing it is possible to obtain materials with more refined microstructures than those specific to unprocessed materials.

Studies and research have shown that FSP processing performed in air, without additional cooling, is a good method to refine grain size and improve ductility of metallic materials, but starting from the idea that much more refined structures could be obtained by reducing the temperature of the processed material by increasing the cooling rate during FSP processing, complex studies and research have been carried out on submerged friction stir processing (SFSP), as a variant derived from FSP. Some studies have shown that SFSP has great potential to obtain fine and ultrafine grain sizes in aluminum alloys [2], [7]-[9].

The use of a liquid working medium during processing or a cooling medium for the processed material has the role to avoid overheating of the material to be processed as well as of the processing

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tool, thus contributing to improving the mechanical properties of the processed materials and increasing the service life of the processing tool.

Research on the possibilities of applying FSP/SFSP processing is primarily focused on aluminum alloys, given that they represent an important category of metallic materials with widespread use in various industrial fields. One of the aluminum alloys used in various industrial applications is Al 7075 due to its mechanical characteristics and properties. Researches on increasing the performance of this alloy have led to the development of a new alloy (7B04) that has increased corrosion resistance [10]. This paper presents some general aspects, based on specialized literature data, on the FSP processing of aluminum alloy 7B04, where the cooling of the processed material was carried out in ambient as well as with water.

2. EXPERIMENTAL DATA

2.1. Material

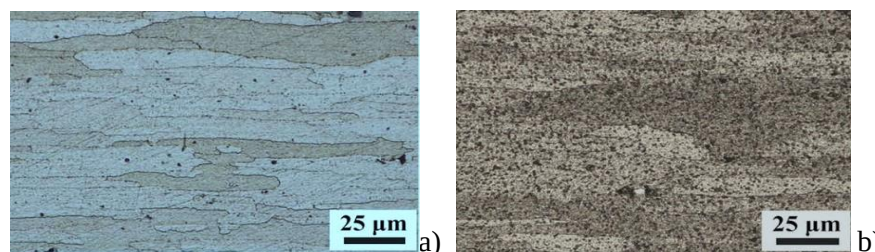
The Al7B04 aluminum alloy is developed from the 7075, aluminum alloy the alloying elements Fe and Si being quantitatively reduced to improve the corrosion resistance of the alloy [10]. Al-7B04 is an aluminum alloy which, in addition to aluminum as the main constituent element, contains Zn, Mg and Cu as the main alloying elements (Al-Zn-Mg-Cu). Given that it is a lightweight and high-strength material, it is widely usable in industry to produce various component parts for aircraft and flight vehicles [11]. The chemical composition of aluminum alloy Al7B04 [10] is shown in Table 1.

Table 1 – Chemical composition of aluminum alloy Al 7B04

Zn	Mg	Cu	Mn	Fe	Si	Cr	Al
5,8-6,5	1,8-2,6	1,4-2,0	0,2-0,6	0,05-0,25	< 0,1	0,1-0,25	rest

Aluminum alloy Al-Zn-Mg-Cu (Al-7B04) has been used in studies and experimental research programs of friction stir welding/processing [10]-[18]. The current work aimed to analyze the possibilities of applying friction stir processing in one pass for the 2mm thick 7B04 aluminum alloy in two heat treatment (temper) conditions of the material, namely: artificially aged (7B04-AA) and with an annealing structure (7B04-O), respectively [10], [12].

The appearance of the microstructure of the base material in the two temper conditions is presented in Figure 1 [10]. It was observed that, for the base material, at the microstructural level, the differences between the two material's conditions are not significant, given that the microstructure is mainly composed of elongated grains, which are specific to a material structure obtained by rolling.



*Figure 1 – Microstructure of the base material Al 7B04 in different surface conditions:
(a) – AA- artificial aging condition; (b) O- annealed condition.*

2.2. Processing experiments. Results

Research on friction stir processing investigations for Al-Zn-Mg-Cu aluminum alloy (Al-7B04) in the two aforementioned temper conditions: artificially aged (7B04-AA) and with annealed structure (7B04-O) was identified [10].

In the specialized literature, research on friction stir processing of the aluminum alloy Al 7B04 under different working conditions and different temper conditions [10], [12]-[17], also analyzing the effect of cold-water cooling (processing in a liquid medium) on the behavior of the Al-7B04 alloy during FSP processing, have been identified. Some studies and research [12], [14]-[18] in relation to friction stir processing of this aluminum alloy show that the initial temper condition of the base metal can significantly influence its behavior, both in the case of FSW welding and FSP processing. Also, the effect of water cooling of the welded or processed material (as the case may be) could be influenced by the initial temper condition of the base metal.

Positive results of experimental research [10] on the friction stir processing of rolled sheets of 7B04 aluminum alloy, in their rolling direction, have been obtained using a processing tool with a tapered pin made of tool steel and the following combination of processing parameters: processing tool rotation speed of 800 rpm and a processing speed of 200mm/min. The processing was carried out in two variants in terms of the cooling medium of the processed material. One variant used cooling of the processed material in the ambient environment (air), and the other variant used water cooling by spraying water on the surface of the material to be processed, in the processing area. Water cooling has a beneficial effect on the material to be processed, but also on the processing tool, by avoiding their overheating during the work process.

The evaluation of the processed material included structural analyses, hardness measurements and mechanical tensile tests. The samples taken from the processed material for structural analyses were prepared by cleaning, grinding, polishing and subsequently etched with Keller reagent. The macroscopic appearance of the samples taken from the processed material are shown in Figure 2 [10].

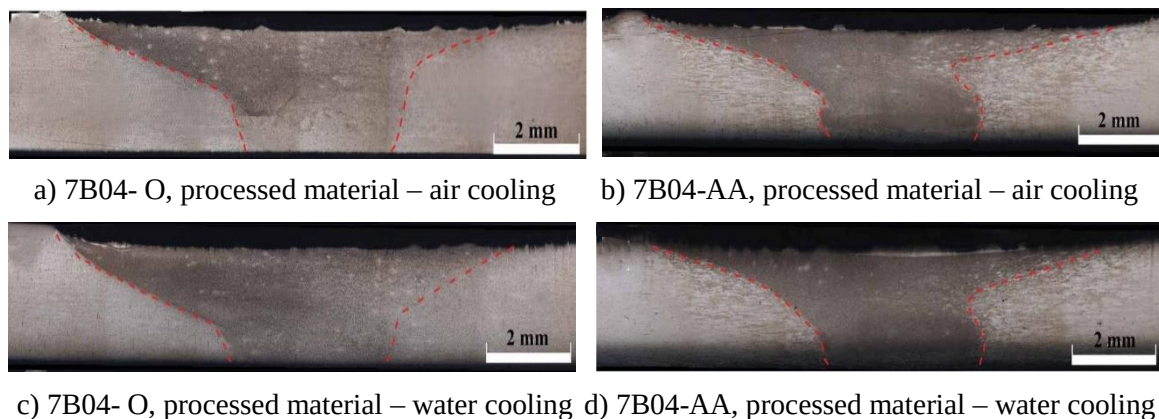


Figure 2 – Macroscopic appearance of FSP processed samples under different process conditions

In the images in Figure 2, no defects such as cavities or cracks were observed in the stir zone SZ of the processed material. The geometry of the stir zone SZ of the plasticized material is influenced by the initial temper condition of the material, as well as by the cooling method of the processed material. For the material in the annealed temper condition, the geometry of the stir zone is relatively symmetrical, regardless of whether the cooling was performed with air or water (Figure 2 a, c). For the material in the artificially aged temper condition, the geometry of the stir zone does not have the same symmetry (Figure 2 b, d).

At the microstructural analysis of the processed material grain changes compared to the microstructure of the base material have been identified, the processed area containing recrystallized equiaxial fine grains. Figure 3 [10] shows the appearance of the microstructures for the annealed (7B04-O) and artificially aged (7B04-AA) aluminum alloy Al 7B04, in the case of air cooling and water cooling, respectively.

In order to see how the working/cooling medium (air, respectively water) influences the microstructure of the processed material (in the two material temper conditions analyzed: annealed and artificially aged), a comparative analysis of the grain size was performed. The data [10] in Table 2

show the grain size values, finding that for both temper conditions, water cooling of the processed material led to obtaining smaller dimension grains compared to the use of air cooling.

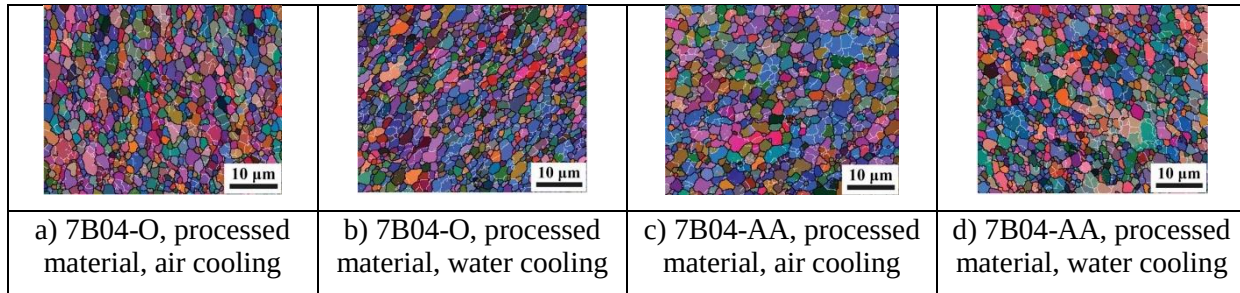


Figure 3 – Microscopic appearance of FSP processed samples under different process conditions

Table 2 – Grain sizes of processed Al 7B04 alloy – air and water cooling, respectively

7B04- O, processed material		7B04- AA, processed material	
air cooling	water cooling	air cooling	water cooling
1.62 µm	1.47 µm	2.11 µm	1.77 µm

Comparative analysis of the grain size of the processed material showed that in the case of water cooling, their dimensions are smaller than in the case of air cooling, due to the fact that water reduces the amount of heat in the processed material, avoiding its overheating which would lead to an increase in grain size. Obtaining a finer grain microstructure can lead to changes in the hardness of the material in the processed area.

The hardness measurements made in cross-section of the samples taken from the processed materials were performed on the median line of the material thickness. The graphs of the hardness variation of the processed material (7B04-O and 7B04-AA), in the two cooling variants (with air and with water, respectively) are presented in Figure 4 [10].

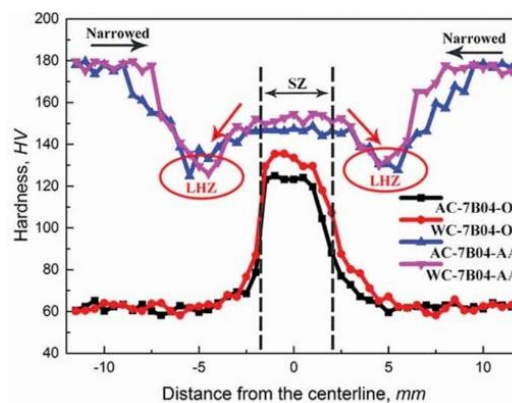


Figure 4 – Hardness variation graphs of FSP processed 7B04 under different process conditions

It was observed that the hardness values of the annealed material (7B04-O) are lower than those of the artificially aged material (7B04-AA). The hardness profile of 7B04-O is different from that of 7B04-AA. In the case of 7B04-O, a significant increase (doubling) of the hardness values was observed in the stir zone compared to the adjacent zones and the base material, while water cooling led to an increase in the hardness values compared to air cooling. In the case of the artificially aged material 7B04-AA, a “W”-shaped hardness profile was observed, a softening of the material in the adjacent areas to the stir zone and an increase in hardness in the stir zone due to the grain refinement

in the processed area. The average hardness values in the base materials and in the processed materials [10] are presented in Table 3. The data in Table 3 shows that in case of water cooling, the average hardness of the processed material is higher than in the case of air cooling, for both temper conditions (7B04-O and 7B04-AA).

Table 3 – Average hardness values of processed 7B04-O and 7B04-AA – air cooling, water cooling

Material	7B04-O	7B04-AA
Average hardness base material, (HV)	62	177
Average hardness processed material, air cooling (HV)	120	145
Average hardness processed material, water cooling (HV)	130	150

The results of mechanical tensile tests performed on samples taken from the base materials and processed materials [10] are presented in Table 4.

Table 4 – Tensile strength of 7B04-O and 7B04-AA processed specimens – air cooling, water cooling

Material	7B04-O	7B04-AA
Tensile strength base material, Rm (MPa)	220	560
Tensile strength processed material Rm, air cooling (MPa)	325	510
Tensile strength processed material Rm, water cooling (MPa)	385	528

The data presented in Table 4 shows that the values of tensile strength have a similar variation profile to the hardness values. For the annealed material 7B04-O, an increase in the values of tensile strength was observed in the processed area compared to the base material, the values being higher in the case of the processed material cooled with water. For the artificially aged 7B04-AA, it was observed that to the tensile test, the processed material broke at lower values of tensile strength compared to the base material. The tensile strength of the processed material is higher when cooled with water than with air, for both analyzed temper conditions (7B04-O, 7B04-AA).

3. CONCLUSION

For the 7B04-O and 7B04-AA aluminum alloy, the analysis of studies and research in the specialized literature showed that FSP/SFSP processing can be applied with positive results, in both process conditions (air and water cooling of the processed material, respectively), concluding that:

- areas of processed material without visible defects upon macroscopic analysis can be obtained, both for 7B04-O and 7B04-AA;
- the friction stir processing led to a significant refinement of the microstructure. Water cooling of the processed material led to a finer-grained microstructure compared to cooling in ambient conditions (air), for both temper conditions of the 7B04 aluminum alloy (annealed, artificially aged). It was observed that the smallest grain size in the microstructure was obtained in the case of the artificially aged 7B04-AA material, cooled with water;
- the hardness in the stir zone of the processed material was much higher in the case of the 7B04-O aluminum alloy, compared to the adjacent zones and the base material. For 7B04-AA, a "W"-shaped hardness profile was observed, with a material softening in the adjacent areas to the stir zone and a hardness increase in the stir zone due to the grain refinement in the processed area;
- the tensile strength in the processed area for 7B04-O was higher compared to that of the base material, the values being higher in the case of water cooling of the processed material. For 7B04-AA, the break of the processed material occurred at lower values of the tensile strength compared to the base material. The tensile strength of the processed material is higher in the

case of water cooling than in the case of air cooling, for both temper conditions of the material (7B04-O and 7B04-AA);

- water cooling of the processed material led to higher hardness and tensile strength compared to air cooling;
- in the case of water cooling of the processed material, better results were obtained for the annealed 7B04-O aluminum alloy compared to the artificially aged material 7B04-AA.

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