Friction stir processing in multiple passes of cast aluminum alloy EN AW 5083 (AlMg4.5Mn0.7)

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Keywords

Friction stir processing, multiple passes, cast aluminum alloy, EN AW 5083 (AlMg4,5Mn0,7), experiments.

1. Introduction

Friction stir processing FSP is a current process for surface processing, which can bring significant contributions to the important field of surface engineering, being internationally developed [1], [2].

Experimental researches have shown that in some cases, through the application of the FSP procedure, spectacular local modifications of mechanical characteristics can be obtained, especially for cast alloys, including aluminum ones [3]-[8].

Compared with other already well-known processes used to obtain functional layers with special properties, such as deposition by using electric arc [9], [10], thermal spraying [11], [12], that are pollutant processes, FSP processing is a purely mechanical process, which takes place at approx. 70-80% of the melting temperature of the materials to be processed, being environmentally friendly. These aspects recommend the FSP process for implementation in industrial activities.

Cast aluminum alloys have a wide use due to their high corrosion resistance and very good casting properties, which provide a good casting, even in complex shapes, where the minimum mechanical properties obtained in reduced sections are greater than those obtained at casting of high-strength alloys, but with low casting properties.

In the paper there are presented some results obtained by ISIM Timisoara in an experimental program developed for applying of the FSP process to the cast aluminum alloy EN AW 5083 (AlMg4.5Mn0.7).

2. Material to be processed

The base material used to be friction stir processed is the cast aluminum alloy EN AW 5083, with the chemical composition shown in Table 1.

Table 1. Chemical composition of cast aluminum alloy EN AW 5083 (AlMg4.5Mn0.7)

Chemical composition, (%)									
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others	Al
0.4	0.4	0.15	0.4÷1.0	4÷4.9	0.05÷0.25	0.25	0.15	0.05	balance

The EN AW 5083 (AlMg4.5Mn0.7) alloy is used in various industrial applications in the fields of shipbuilding, equipments and tanks for the chemical industry, pressure vessels, structural components, body elements in the automotive industry, etc.

The cast aluminum alloy EN AW 5083 (AlMg4.5Mn0.7), in the state of delivery, is characterized by a coarse microstructure and possible casting defects, as well as by mechanical characteristics specific to those microstructure. A solution for finishing of the casting microstructure, as well as for the elimination of casting defects and for improving/modifying some of properties and mechanical characteristics of the mentioned aluminum alloy, consist in the application of the friction stir processing method.

3. Experimental program. Results

3.1. Experimentation technique

The experimental program for friction stir processing in multiple passes of aluminum alloy EN AW 5083 (AlMg4.5Mn0.7) having 8 mm thickness, was carried out using the FSW experimentation technique from ISIM Timisoara (figure 1), consisting of:

- friction stir welding machine, type FSW 4-10 (pos.1) with the following main characteristics:
  - adjustable feed rate in the range: 10÷480 mm/min;
  - rotational speed of the processing speed, adjustable in the range: 300÷1450 rpm;
  - useful stroke (processing): 1000 mm.

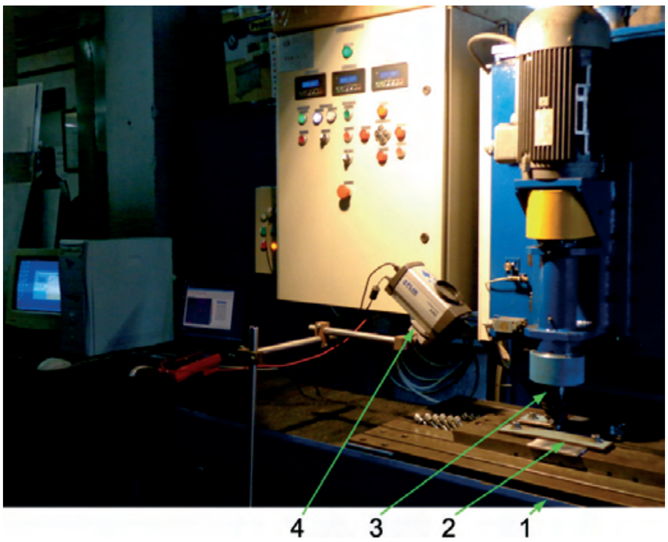


Figure 1. FSW experimental technique from ISIM Timisoara

- positioning and fastening device (pos. 2);
- tools and welding device designed and made by ISIM Timisoara (pos. 3);

- FSP process monitoring system using infrared thermography (pos. 4);
- related devices - support for experiments.

3.2. Technological data

Table 2 presents technical data for FSP processing experiments in multiple passes of the cast aluminum alloy EN AW 5083 using different types of processing tools.

The material undergoes to FSP processing was a cast aluminum alloy EN AW 5083 having 8.0 mm thickness.

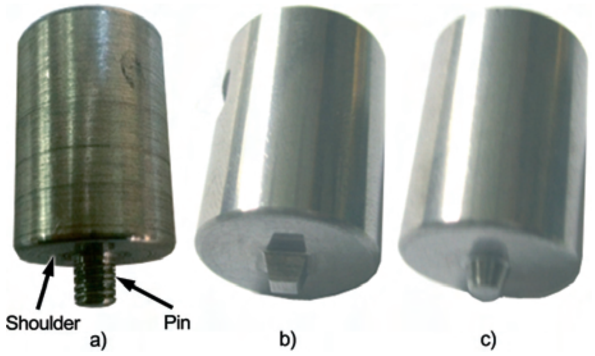


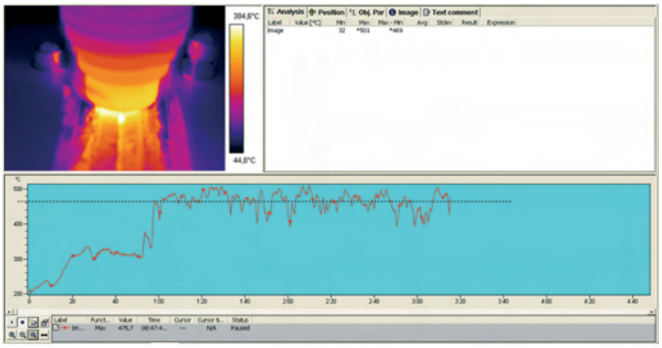
Figure 2. Processing tools used in the experimental program: a) Threaded cylindrical pin tool; b) Conical pin tool with 4 flat bevels; c) Smooth conical pin

The FSP processing tools shown in Figure 2 were made as follows:

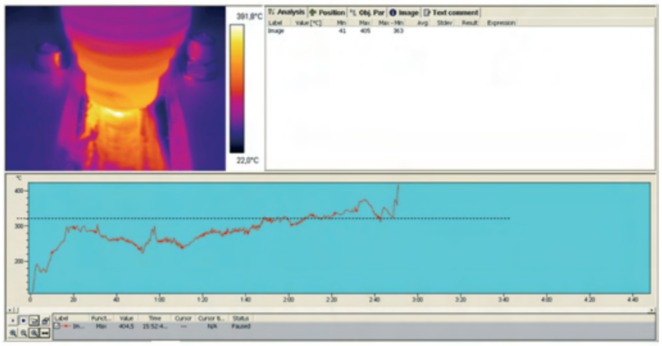
- threaded cylindrical pin tool - made of X38CrMoV5 steel, treated at about 40÷42 HRC, with shoulder diameter $Ø_{shoulder}$ = 22.0 mm and threaded cylindrical pin M6, the pin length being L_{pin} = 5.5 mm;
- the conical pin tool with four flat bevels - made of P20S tungsten sintered carbide with a shoulder diameter $Ø_{shoulder}$ = 20.0 mm and the pin length being L_{pin} = 5.0 mm;
- conical pin tool - made of sintered tungsten carbide, with shoulder diameter $Ø_{shoulder}$ = 20.0 mm and pin length L_{pin} = 4.6 mm.

The process parameters used for the multiple-pass FSP processing experiments (five passes with a partial overlap having pitch p = 5 mm) were: tool rotational speed n = 1450rpm, horizontal tool speed on the material to be processed v = 100mm/min, the direction of rotation being anticlockwise.

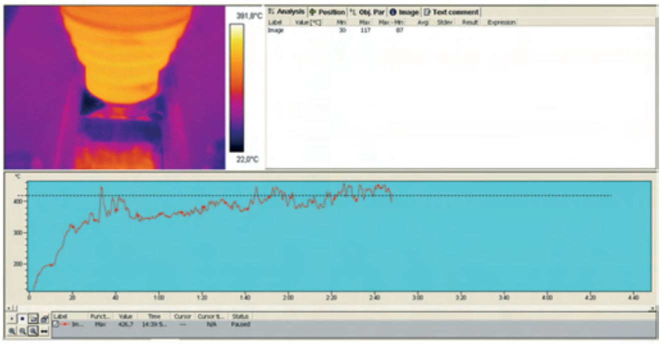
From the point of view of the temperatures developed on the processing tool shoulder area, the FSP process monitoring was performed for each FSP pass (processed row). For example, the temperature evolution during FSP processing for pass R3 of each experiment is shown in Figure 3.



a) R3 - Exp. 1 ($T_{R3\ max}$~500^{0}C; $T_{R3\ med}$~460^{0}C)



b) R3- Exp. 2 ($T_{R3\ max}$~420^{0}C; $T_{R3\ med}$~320^{0}C)



c) R3 - Exp. 3 ($T_{R3\ max}$~ 455^{0}C; $T_{R3\ med}$~ 420^{0}C)

Figure 3. Temperature evolution during FSP processing

The temperature differences that occur depending on the process parameters used and the type of the FSP processing tool pin (threaded cylindrical, conical with 4 flat bevels, smooth conical) have been observed.

4. Results. Discussions

Table 3 shows analyze of the temperature evolution after stabilizing of the FSP process for the three experiments (Figure 3).

Table 2. Technical data – FSP processing experiments for EN AW 5083 cast alloy

Exp. No.	Base material		The processing tool				No. of passes [Row]	Processing parameters		
	Type	BM thickness [mm]	Material	Pin type	Shoulder diameter, $Ø_{shoulder}$ [mm]	Pin length, L_{pin} [mm]		Rotational speed, n [rot/min]	Processing speed, v [mm/min]	Rotation sense
1	EN AW 5083	8.0	X38CrMoV5	threaded cylindrical M6	22.0	5.5	R1÷R5	1450	100	counterclockwise
2			P20S	conical with 4 flat bevels	20.0	5.0				
3			P20S	smooth conical	20.0	4.6				

Table 3. The temperature evolution after stabilizing of the FSP process

Exp. No.	The average temperature / processed rows [°C]	Maximum values of the recorded temperature [°C]	The average temperature / full process – 5 processed rows [°C]
1	350÷500	480÷520	463
2	300÷320	420÷450	324
3	380÷420	400÷480	399

The surface aspect of the processed material for one of the experiments (Exp. 2) is shown in Figure 4. Partial overlapping of the processed rows, with step p = 5 mm (set in correlation with the tool pin dimensions), can be observed, so that processing of the material in the pin action area to have continuity, thus avoiding the occurrence of unprocessed material areas that could have been formed in the interference area between passes.

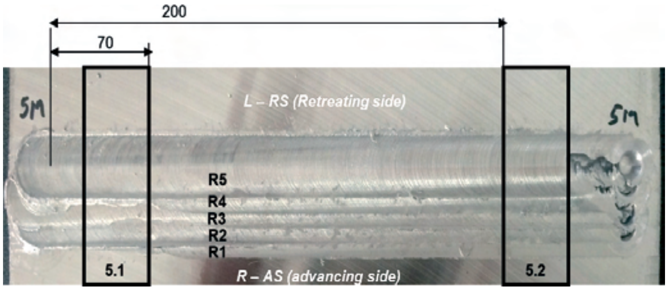


Figure 4. Appearance on the surface of the processed FSP material

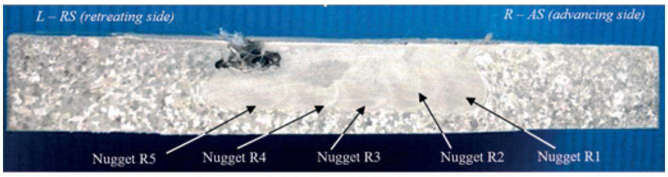
In experiments Exp. 1 and Exp. 3, at the surface of the last processed row, a channel has been formed on the entire length of the processed material. This type of defect has been observed at FSW welding of several alloys which have magnesium as alloying element (e.g. laminated sheet of EN AW 5754).

This type of defect has not formed when the conical pin tool with four bevels was used.

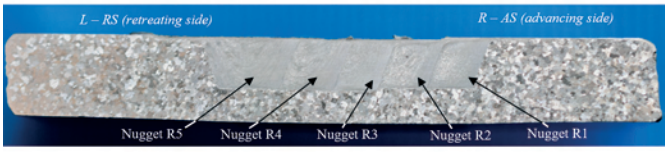
For the evaluation and characterization of the processed materials (macroscopic and microscopic analyzes, hardness), two samples were taken for each experiment. The areas where the macroscopic analysis was performed were situated at about 70 mm and 220 mm from the starting point of the FSP process. Examples of the macroscopic appearance of the samples taken for the three experiments are shown in Figure 5.

Visual and macrostructures analyze of the processed materials, shows that:

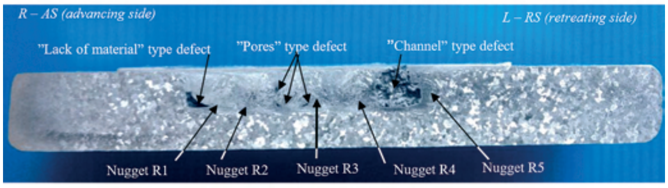
- defects have been formed on the processed surface, visible on the last processed row, at Exp. 1 and 3, (Figure 5 a and c);
- it is noted that from the point of view of the welding tool geometry, the most favorable geometry of the FSP tools was the conical pin with four bevels (Figure 5b). Note that the processed area is very well consolidated by overlapping of the nuggets (approx. 25% of its volume) resulted at each pass (row). The processed area under the influence of the FSP tool, the well consolidated nugget for each pass (R1÷R5 rows), as well as the continuity, compactness and uniformity of the processed area on its entire size, can be observed;
- from a macroscopic point of view, processed areas without defects were also obtained for the other two types of FSP tools (Exp. 1 and 3), except the last processed row (R5 row). For samples 1.2 and 3.1 (Exp. 1 and 3), the nuggets for each pass can be observed, but also important defects in the processed area, especially on the last processed row. This defect may have been as large in the R1÷R4 rows, but by applying FSP by overlapping, in multiple passes, this defect have been resolved by mixing the material.



a) Exp. 1 (sample 1.2)



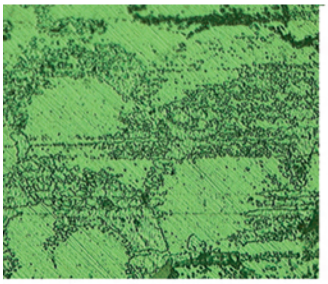
b) Exp. 2 (sample 2.2)



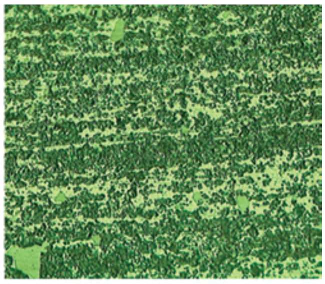
c) Exp. 3 (sample 3.1)

Figure 5. Macroscopic appearance of the samples

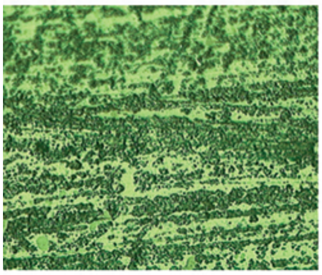
Figure 6 shows the microstructure analysis for the base material and the processed area.



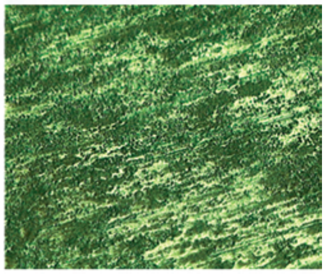
a) BM



b) the processed area



c) interference area between BM and the processed area



d) flow lines of the material

Figure 6. Microstructural analysis for the base material and processed material

The base material has a coarse grains structure, which is specific to the cast materials. Analyzing the microstructures obtained by FSP processing of the EN AW 5083 alloy, using three different types of processing tools, the finishing of the grains of the processed material is observed, with visible material flow lines during the FSP process.

The HV1 hardness measurements, for experiments 1, 2 and 3, were performed horizontally on a line placed at 3mm below the top surface of the material to be processed. The distance between the measuring points was 2mm, the measurements being made from left to right. Analyzing the hardness evolution, it has been observed that the values are generally in the range of 85÷92 HV1, close to the values recorded in the base material. The average values of hardness on the processed area was ~76HV1 (Exp.1), ~94 HV1 (Exp.2) and ~81 HV1 (Exp.3), the average hardness value recorded in the base material being ~81 HV1. A higher average hardness value in the area processed was observed at Exp. 2, where the tool with four flat bevels was used.

Samples from the base material (T.4BM, T.5BM) and from the processed area were taken: longitudinal (along the processed area - T.L.4.4, T.4.2 and T.L.5.2) and transversal (T.5.1), to perform mechanical tensile tests. Due to the limited size of the processed area (L×l×h ~ 220×30×4mm), small size test specimens were taken for the tensile tests, as outlined in the sketch from Figure 7.

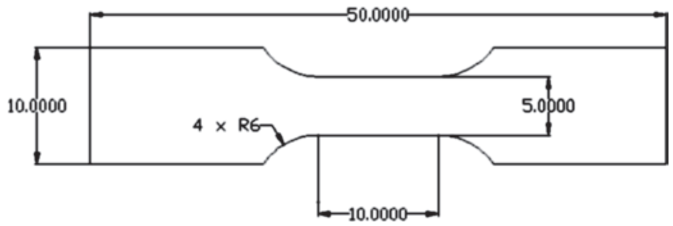


Figure 7. Sketch of small dimensional specimen for tensile test

The appearance of the samples after the tensile and bending tests is shown in Figure 8.

The mechanical strength of the base material - EN AW 5083 cast aluminum alloy is R_m = 255 N/mm^2 and the specimens taken from the processed material (Figure 8a) have broken at R_m = 245 N/mm^2 (cross sectional specimen) and at R_m = 255 N/mm^2 (specimen taken in the longitudinal direction).

It can be seen that the mechanical strengths have values close to those of the base material, with approx. 5% lower on specimens taken transversely on the processing direction.

Elongations at break on the longitudinal direction had slightly higher values (12%) compared with base material (10%).

The bending test of the specimens (Figure 8b) taken from the base material and from processed materials (longitudinally and transversely to the processing direction) showed that:

- the BM breakage (specimen B.5 BM) was produced at a small bending angle (46°), which is specific for the cast materials;
- the breakage in the processed materials was produced at a bending angle of 74° (on the longitudinal direction– specimen B.5.2. Long.), on the transversal direction (specimen B.5.2. Transv.) the bending angle at which breakage occur, being similarly with BM bending.

5. Conclusions

To be as relevant as possible, experiments for processing in multiple passes were performed using the same values for the processing speed, rotational speed and rotation sense of the FSP tools, as well as the same step (the same space between passes or rows).

FSP processing in multiple passes highlighted the following process aspects / phenomena:

- the use of the threaded cylindrical pin and of the smooth conical pin have as result the formation, at the last pass, of a “tunnel” type defect, along the entire processed length, the processed areas corresponding to the other passes being without defects. Similar defects occurred to the friction stir processing of each row, these being “repaired” by processing of the next row;
- the conical pin tool with four flat bevels has led to obtain very good quality, compact and without defects processed areas.

In all experiments, process temperature records were made using the infrared thermographic technique. Due to the geometric characteristics, the lowest average process temperatures were recorded with the use of the four bevels conical pin tool (in this case the friction phenomenon was also accompanied by the cutting phenomenon).

Macro and microstructural analyzes, respectively sclerometric analysis, were performed. In all cases, it was observed that under the action of the FSP tool and of the process dynamics there was a “burst” of the thicker grains specific to the cast alloys and much more homogeneous microstructures made of fine grains were obtained.

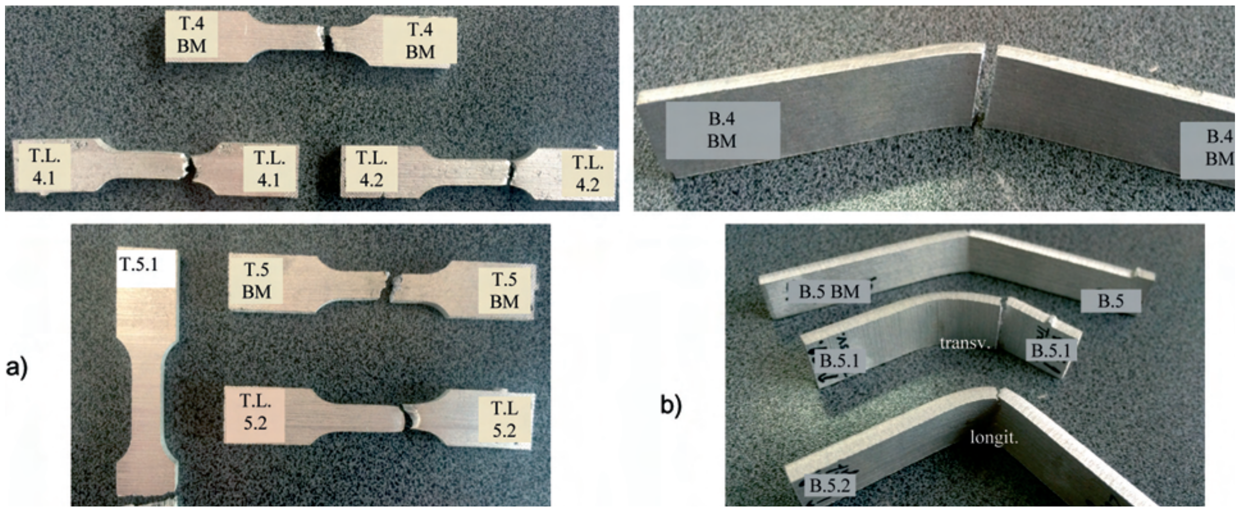


Figure 8. Appearance of specimens taken from the processed material and BM (Exp.1, 2) tested at:
a) tensile tests (T); b) bending tests (B)

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