Nonconventional Technologies Review
Romania, September, 2018

FRICTION STIR PROCESSING OF THE CAST ALUMINUM ALLOY EN AW 5083 (AlMg4,5Mn0,7)

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ABSTRACT: The paper presents the analysis of the behavior of the cast aluminum alloy EN AW 5083 (AlMg4,5Mn0,7) to the friction stir processing (FSP), which is applied in order to locally modify some properties / characteristics of the base material. This method of metallic materials processing is currently an important research direction in the field of surface engineering. Some general data on the FSP processing and preliminary results obtained by ISIM Timisoara regarding FSP application on the cast aluminum alloy EN AW 5083 are presented. For the FSP processing experiments, three types of processing tools with different geometries, steel and tungsten sintered carbides, were used. The paper contains information on the development of the experimental program, data on FSP tools and technological parameters used, data on process monitoring using infrared thermography, as well as analysis and characterization of processed material. The obtained results about behavior to friction stir processing in a single pass of the cast aluminum alloy EN AW 5083 in correlation with the types of tools that are used, have been compared.
KEYWORDS: friction stir processing FSP, cast aluminum alloy, EN AW 5083 (AlMg4,5Mn0,7), experiments

1. INTRODUCTION

The development of new processes and techniques for the processing and joining of the metallic materials has been determined by the continuous development of the scientific and technological priority fields of research at European level. These areas are focused on developing and implementing of new manufacturing processes, new materials, restructuring and upgrading some industrial areas to adapt them to the current performance and quality requirements.

The use of technically and economically efficient processing processes of lightweight materials (e.g. aluminum alloys) contributes to the development of the product manufacturing techniques in various priority industrial fields (e.g. automotive, aeronautics, aerospace, naval, public transport, etc.).

The processing processes must meet current technical requirements (materials, shapes, sizes, structures, loads), economic (productivity, consumption, cost) and environmental requirements (pollution, noxious) imposed by the accelerated development of priority industrial fields.

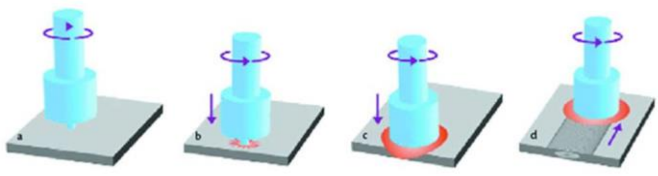
In the last years, ISIM Timisoara has carried out numerous own researches for the development and implementation some of unconventional processing methods of materials: ultrasonic welding [1], HVOF thermal spraying [2], water jet cutting [3], laser beam processing [4], friction stir welding and processing [5], [6].

The topic of welding and friction stir processing has been approached by ISIM since year 2000, a number of FSW research projects have been developed until now by the institute.

In this context, ISIM Timisoara intends to develop the materials processing technique using friction stir processing FSP, aiming the development of FSP technologies for cast metallic materials from the category of aluminum alloys used in industrial applications, the promotion of a environmentally friendly technique for materials processing, with a high degree of innovation, applicable in different industrial fields.

The Innovative Friction Processing Process (FSP) has been developed from the FSW friction stir welding process with possibilities to be applied to a wide range of metallic materials, in order to obtain microstructural changes and improve the properties in the processed area.

The friction processing with the rotating active element is applied to a material (base material BM), the process sequences (Figure 1) consisting of: rotating of the processing tool with a certain speed (a), penetration of the tool pin into the material to be processed (b), until a firm contact between the tool's shoulder and the base material surface (c) is achieved, followed by the movement of the rotating tool, on a determined path - the processing direction (d).



a) b) c) d)

Figure 1. Friction stir processing – process sequences [7]

The heat generated by the friction between the tool shoulder and the surface of the base material with which it comes into contact, respectively by the friction between the tool pin and the base material in which it plunges during the process, dissipates in the processed material, causing rising of the temperature and plasticizing of the material. [7] - [11].

By applying of the friction stir processing, it is possible to modify some of properties and mechanical characteristics of the materials, which may be useful for different industrial applications.

2. MATERIALS AND PROCESSING TOOLS

The paper analyzes the behavior to friction stir processing FSP of the 8 mm thick EN AW 5083 cast aluminum alloy with the chemical composition shown in Table 1. The analysis refers to the single pass / actuation of the FSP tool on the base material.

Table 1. Chemical composition of EN AW 5083 cast aluminum alloy

Chemical composition, (%)									
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	other	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 cast aluminum alloy EN AW 5083 has a large grain microstructure, specific to the cast materials. During the FSP process, under the action of the processing tool, the material undergoes important plastic deformations, which are leads to the modification of the microstructure and the properties / characteristics of the processed material.

Casting alloys may have some disadvantages, such as lower operating characteristics, possible casting defects, non-metallic inclusions, inhomogeneities, rough structure, a.o.

Friction stir processing may be a useful solution in various industrial applications where it is necessary to modify some local mechanical properties of the materials or to eliminate some casting defects, but also to improve the exploitation properties and increase the quality of the parts made by casting [12]- [13].

The paper presents some preliminary results obtained by friction stir processing of the 8 mm thick EN AW 5083 cast aluminum alloy, processed using three different types of processing tools, shown in figure 2.

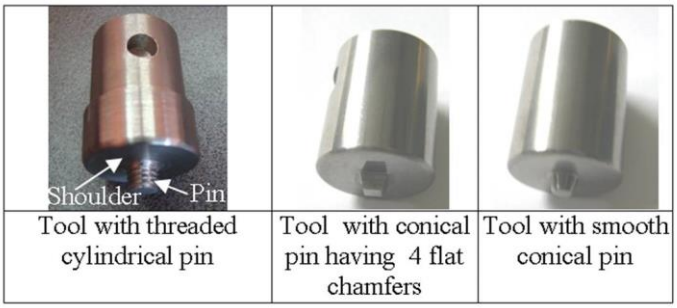


Figure 2. FSP processing tools used in experimental program

The FSP processing tools presented in Figure 2 are made of different materials (X38CrMoV5 steel as well as tungsten sintered carbide, P20S type), the geometrical characteristics of the tools being presented in Table 2.

Table 2. Characteristics of the FSP tools

Tool type	Pin type	Material	Shoulder diameter ∅(mm)	Pin length L_{pin}(mm)
U 1	M6 Threaded cylindrical pin	X38CrMoV5	22	4,5
U 2	Conical pin having 4 flat chamfers	P20S	20	5,0
U 3	Smooth conical pin	P20S	20	4,5

3. EXPERIMENTAL PROGRAM. RESULTS

Preliminary research programs of friction stir processing have been performed to study the processing behavior of the EN AW 5083 cast aluminum alloy (8 mm thick), using the types of processing tools mentioned in chapter 2 and the same experimental conditions. The friction stir processing process has been accomplished in a single pass (figure 3).

Figure 3. Surface appearance of the processed material (single pass)

The FSP experiments were carried out using the equipments shown in the Figure 4:

- FSW 4-10 friction stir welding machine (pos.1),
- positioning and fixing device of the material to be processed (pos.2);
- tool and port-tool device (pos.3),
- system for monitoring the pressing force of the tool shoulder on the base material during the FSP process, with a force transducer (pos. 4a) mounted in a device on the FSW machine, using a data

logger, a modular voltage source and a PC for acquisition, storage and data processing (pos.4b),

- temperature monitoring system (pos.5) at the surface of the base material (BM) to be processed in the tool shoulder area , using an infrared thermography camera mounted on a fixing and positioning device, as well as a PC for acquisition, storage and data processing.

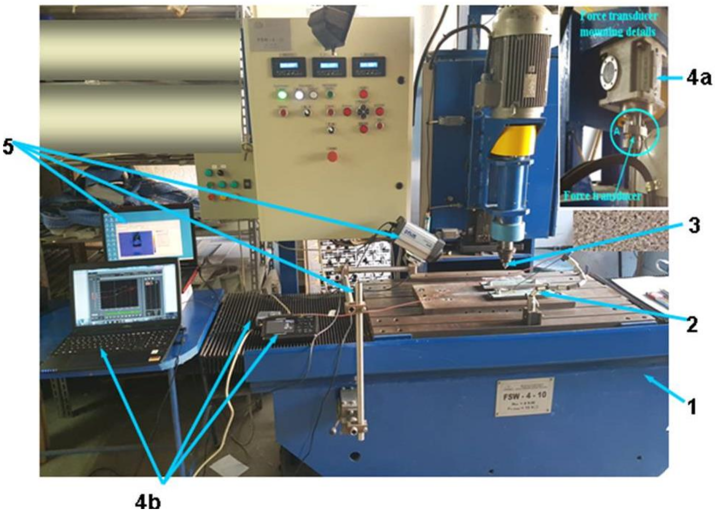


Figure 4. Work equipments for FSP processing

Table 3 presents the technical data for the FSP processing experiments of the EN AW 5083 cast aluminum alloy, with information on the material to be processed (base material), type of FSP tool and the technological parameters that are used.

Table 3. Technical data for FSP experiments – EN AW 5083 cast aluminum alloy

Experi-ment no.	Base material	FSP tool type	Process parameters		
			Rotational speed n (rot/min)	Processing speed v (mm/min)	Direction of rotation
A.1	Cast EN AW 5083 (s=8 mm)	U1	1450	100 and 200	counter clockwise
A.2					
B.1		U2			
B.2					
C.1		U3			
C.2					

To analyze the behavior of the 8 mm thick EN AW 5083 alloy cast aluminum to friction stir processing, three experimental programs have been performed, corresponding to the three types of FSP tools specified in Table 2. In all experiments performed, constantly have been maintained: the rotational speed of the processing tool n = 1.450 rpm and the counter clockwise direction of rotation for the processing tool. For each type of processing tool, FSP experiments were performed with two values of the processing speed on the processing direction, i.e. v = 100 mm / min and v = 200 mm / min, respectively.

After processing, the program for evaluation of the processed materials area included the following steps:

- visual examination of processed FSP material;
- FSP process analysis from the point of view of the process temperatures and the values of the force of the tool shoulder pressure on the surface of the material to be processed;
- sampling from base material and processed FSP material;
- macroscopic and microscopic structural analysis;
- hardness and roughness measurements for base material and FSP processed material;
- analysis of results by comparison of the processed material FSP with the base material.

The aspect of the processed material surface can be observed in Figure 3 and is specific to the use of the friction stir processing technique (no further mechanical processing was performed).

Figure 5 shows representative macroscopic images specific to the FSP processed EN AW 5083 cast aluminum alloy, using the processing tools and parameters specified in Table 3.

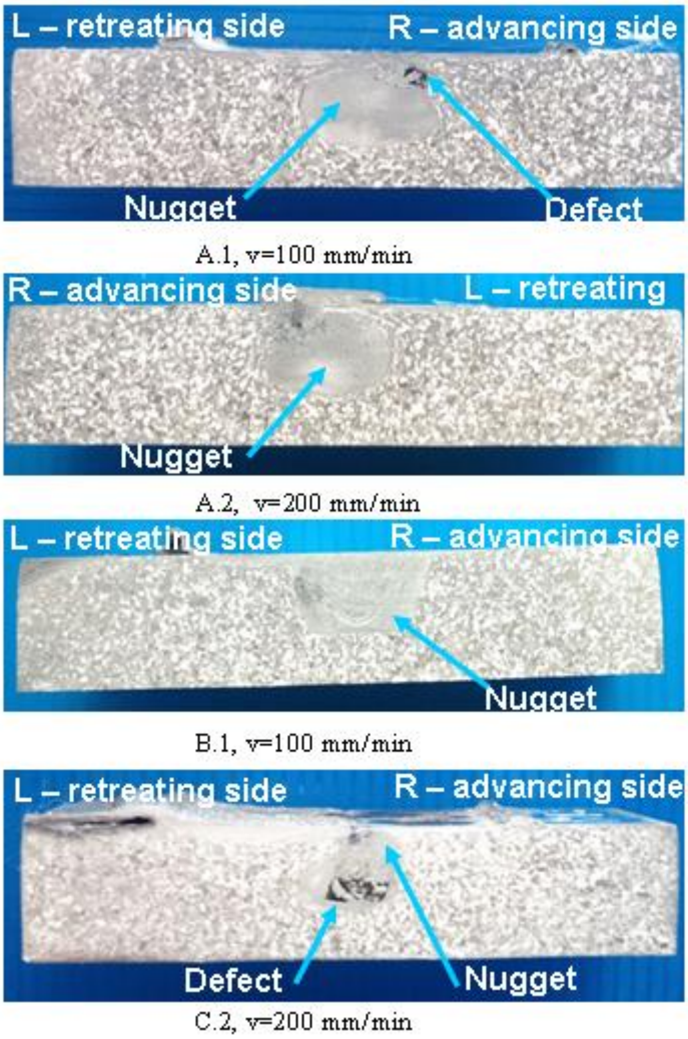


Figure 5. Macroscopic analysis –Exp. A, B, C

At the A1 and A2 samples, the processed area under the influence of the FSP tool and the well-consolidated core, characteristic for friction stir processing, can be observed.

At the A1 sample, a "void of material" type defect in the processed material was observed. This is located at approx. 1 mm from the surface, respectively 2-2,5 mm from the nugget axis. The size of the defect, in cross-section area is ~ 1,5 mm^2.

At the sample B1 (using a conical pin tool with four flat chamfers), the defect-free processed area with a well consolidated nugget is observed.

The conical pin tool has produced major defects (sample C2), dispersed in the action area of the pin tool relative to the BM, which recommends caution when choosing this tool to process EN AW 5083 aluminum alloy, or expanding the investigations using other combinations of the process parameters.

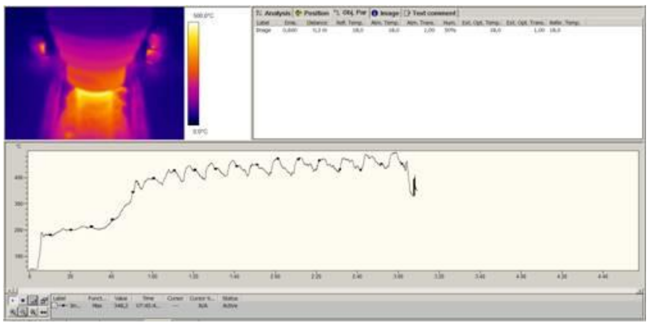
The FSP processes have been monitored from the point of view of the temperatures developed in the base material, at 1 mm behind the processing tool shoulder, as well as of the forces with which the processing tool presses on the base material.

The maximum recorded temperature (using infrared thermography) for the FSP processing of EN AW 5083 cast aluminum alloy, has ranged from 400-520^{0}C, depending on the tool type and the processing speed that is used (Table 4).

Table 4. FSP process monitoring

Exp. No.	Processing tool	Process monitoring	
		Maximum temperature (^{0}C)	Maximum force F_{max} (N)
A.1	U1	500	15.500
A.2		495	15.700
B.1	U2	430	12.100
B.2		400	10.200
C.1	U3	520	14.900
C.2		450	18.500

For example, Figure 6 shows the temperature evolution during the FSP processing for the A-experiments.


a)

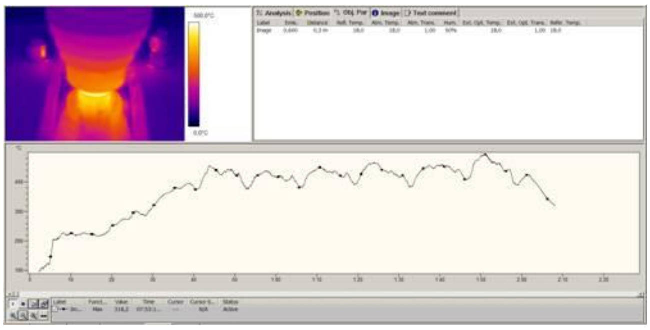

b)

Figure 6. Temperature evolution graphs for friction stir processing of EN AW 5083 cast aluminum alloy
a) v=100 mm/min; b) v=200 mm/min

The temperature evolution during the FSP process shows that using the processing speed v = 200 mm / min, the maximum recorded values of temperature (shown in Table 4) were slightly lower compared to the use of the processing speed v = 100 mm / min, as can be seen in Figure 6.

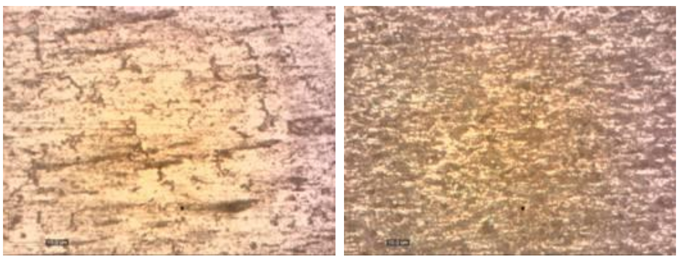
Similarly, the average values of the process temperature, after the process stabilization, were slightly lower (e.g. 420^{0}C using v = 200 mm / min compared to 440^{0}C using v = 100 mm / min).

Research on conventional FSW welding has shown that the process temperature evolves inversely in proportion with the welding speed, and in this case, with the FSP processing speed.

The maximum values for the pressing force of the tool were recorded during the penetration phase of it in the base material, when achieving a firm contact between the surface of the FSP tool shoulder and the base material, depending on the tool type and the shoulder diameter.

At the FSP processing experiments of the EN AW 5083 cast aluminum alloy, the maximum values of the pressure force of the tool on the BM varied between 10.200-18.500N (Table 4), indicating that these values are indicative, considering the experimental character of the force recording system during the process.

Figure 7 shows the microstructure images for the base material and processed material, observing the significant finishing of the granulation, resulting in a uniform structure with fine grains.



a) BM b) processed material

Figure 7. Microstructures – base material and processed material (EN AW 5083 cast aluminum alloy)

The HV1 hardness measurements were done according to the sketch from Figure 8: on the vertical line (corresponding to the pin axis) and horizontally, on the lines situated at 1 mm and 4 mm respectively below the upper surface of the material to be processed. The distance between the measuring points was 1 mm.

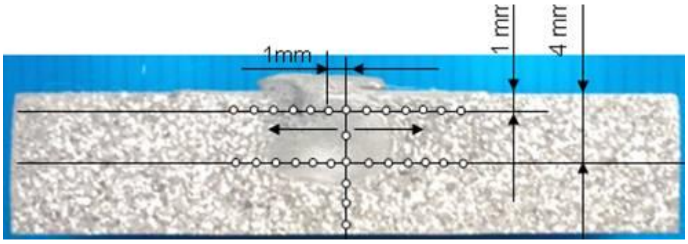


Figure 8. Sketch for the hardness measurements

For example, Figure 9 shows the graphs of hardness variation when using the tool with threaded cylindrical pin and processing speeds v = 100 mm / min (Figure 9a), respectively v = 200 mm / min (Figure 9b).

The hardness values, measured in a vertical plane, starting from the processed surface, are shown in Figure 9 in graphs a1) and b1), and in horizontal plane, hardness measurements are shown in graphs a2) and b2).

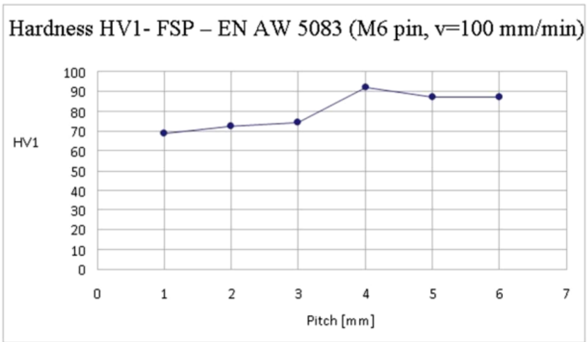
Analyzing the hardness evolution when use the processing speed v = 100 mm / min (figure 9a), it was found that the hardness values of 65-90 HV1 were recorded, the values around 82-83 HV1 being predominant in the nugget area.

In HAZ and TMAZ, higher values of hardness were measured on the advancing side of the processing tool, compared with other analyzed processed areas, the maximum value being 129 HV1.

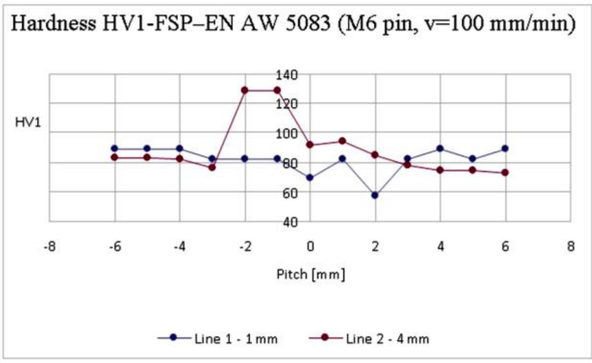
When using the processing speed v = 200 mm / min, the hardness in the processed area, measured vertically from the surface of the processed material (Figure 9b), had values of 98-100 HV1 (in the nugget, corresponding to the tool axis of rotation); 95 HV1 (in the interference zone from the bottom of nugget and BM), respectively 87 HV1 (in BM, below the nugget). There was a hardening of ~ 11-12% of the material in the tool pin action area.

The average value of the hardness horizontally measured at 1 mm below the tool shoulder (Figure 9b) was 112 HV1, up by about 12% relative to the hardness average of 100 HV1, measured at 4mm under the tool shoulder.

When using tools having conical pin with four flat chamfers, respectively smooth conical pin, the hardness values measured on the line that corresponding to the axis of rotation of the FSP processing tool were in the range 82,4 – 98,5 HV1, respectively 51 - 95 HV1, and in the horizontal plane the average hardness values measured at 1 mm and 4 mm below the tool shoulder, were 93,95 HV1 and 99,5 HV1, 92 HV1 and 95 HV1 respectively.

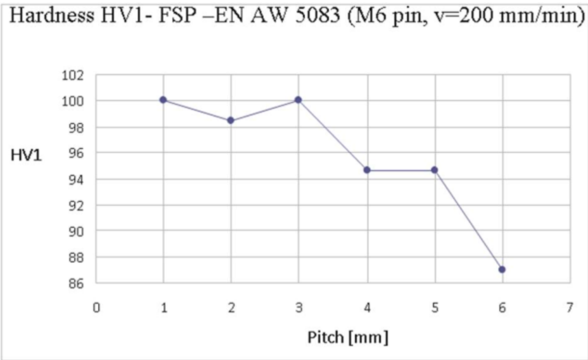


a$_1$)

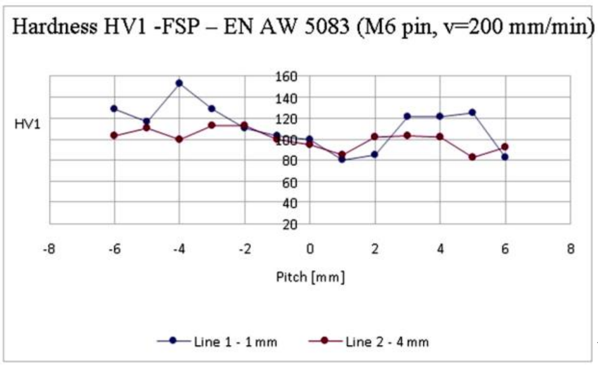


a$_2$)

a) v =100 mm/min



b$_1$)



b$_2$)

b) v =200 mm/min

Figure 9. Graphs of hardness variation–FSP processing of EN AW 5083 cast aluminum alloy

Measurements for determining the roughness of the processed surface were made on the processed surface, on the median line of the processed area, for each variant of the constructive solution of FSP tool that was used.

The roughness measurements revealed the obtaining of higher roughness of the processed surface (9,52-14,09 µm) using the FSP processing tool having threaded cylindrical pin and a processing speed v = 100 mm / min, compared with the values obtained using speed v = 200 mm / min (4,31-8,02 µm).

The processing tool shoulder that is made of steel does not have the surface that comes in contact with the base material as smooth as the tungsten sintered carbide tools.

In experiments performed with P20S sintered carbide tools, the roughness on the processed surface was lower (6,76 - 9,9 µm at v = 100 mm / min and 3,92-6,95 µm at v = 200 mm / min).

4. CONCLUSIONS

Friction stir processing FSP has been developed based on the friction stir welding process FSW, with application possibilities for a wide variety of metallic materials (e.g. aluminum alloys, copper, magnesium, titanium, steels, a.o.)

Cast aluminum alloys have multiple uses due to their high corrosion resistance and very good casting properties.

To obtain FSP processed materials with good mechanical properties and characteristics, the following aspects are very important:

- establishing the characteristics of the processing tool in terms of : the geometric configuration, the dimensions (correlated with the thickness of the material to be processed) and the material from which they are made;
- establishing the process parameters correlated with the material to be processed and with the type and geometry of the processing tool;
- the processing equipment as well as the positioning and fixing devices of the material to be processed, must ensure a rigid and robust fastening to avoid the occurrence of process disturbances.

Heat generation, plastic flow, the forces that are developed during the process and the uniformity of the processed material are influenced by the shape and design of the tool.

The greatest amount of heat in the process is generated by the tool shoulder (in contact with the material to be processed) which is rotating with a certain speed, which also has the role of preventing the expulsion of plasticized material from the material to be processed in the area undergoing processing.

Flow of material is a complex phenomenon, influenced by the geometry and dimensions of the shoulder and the pin of the processing tool.

The processing tool must keep its properties at high temperatures (thermal stability).

Processing tools made of alloyed and hardened steels as well as those made of W-sintered carbide can be used to develop research programs and to demonstrate the FSP process quality for cast aluminum alloys, more favorable results being obtained with tools having cylindrical threaded pin and conical pin with four plane chamfers.

When using tools with threaded cylindrical pin, respectively conical pin with four flat chamfers, for friction stir processing of EN AW 5083 cast aluminum alloy, consolidated and without defects areas have been obtained. The use of the tool having smooth conical pin has led to major "material voids" defects in the processed material.

5. ACKNOWLEDGEMENTS

The paper was developed on the basis of preliminary results achieved in the project PN 18.33.02.01 entitled "Researches on the development of innovative and environmentally friendly technologies for the processing of cast metallic materials from category of aluminum alloys used in industrial applications, by friction stir processing", financed by the Ministry of Research and Innovation within the Program Nucleu of ISIM Timisoara (contract 17N / 2018).

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