Tensile properties of friction stir welding of three dissimilar aluminium alloys, AA7075, AA2024 and AA6061 versus process parameters

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Abstract. Friction stir welding is a solid-state welding process with a lot of advantages comparing to the traditional arc welding. In the last years, this process was more and more used in industrial environment to joining by welding a large range of materials, similar and dissimilar. Applicability of this process was identified in automotive industry, aeronautics industry, aerospace industry, railway industry, metal working, research and development, electronic industry, machinery and equipment and others. The friction stir welding process is a simple, this are performed in three steps: a tool is rotated and plunge into the materials until the shoulder meets the surface of upper material, after that the tool keeps rotation, start translation movement and traversed along the direction of welding. At the end of welding seams, the tool has a vertically movement to get out of the plates. This paper presents an experimental study for the welding of three dissimilar aluminium alloys, with different mechanical and chemical properties and the results of it. These three materials are: AA7075, AA2024 and AA6061. The samples obtained with the friction stir welding were tested and analysed considering: process parameters and their influence on tensile properties

1. Introduction
Friction stir welding process was invented in year 1991 by Welding Institute – TWI. The first researches was performed on aluminium alloys, weld in similar and dissimilar combinations, therefore studies on FSW process of aluminium alloys are plentiful in past and recent speciality literature. The popularity of this process among researchers is due to wide range of applications envisaged worldwide [1] and flexibility of this welding process with which a wide range of materials can be combined such us: cooper, brass, magnesium, titanium, steel, polymeric materials or metal matrix composites (MMCs), such as Al₂O₃, SiC, Si₃N₄ or B₄C [2]. Until now was demonstrate that welding trough FSW for two similar materials show a better percentage of elongation compared to other combinations of the welded joints [3].

The success of performing welding through FSW process is dependent by the input parameters: welding speed and advancing speed, and in the same extent by the welding tool. Tool geometry significantly influence quality of friction stir welding (FSW) and it was demonstrated that tools with smaller pins improves the material mixing because increased the thermo mechanical action in welding.
seams, as well tools with threaded or taper pin gives a better weld. After analyses of mechanical properties of welding join was demonstrate that the maximum fracture load was produced for samples weld by tapered cylindrical tool against the straight cylindrical tool. [4].

The welding parameters listed above have as well influence of the welding seams and was obtained a better mixing of materials using a higher rotation speeds but in the same time the mechanical properties and joint efficiency decreased with increase in the rotation speed [5]. Higher advancing speed increase the hardness in thermo-mechanical affected zone and in heat affected zone and leads to better mechanical properties [6].

In concordance to the authors mentioned in the previous paragraphs the occurrence of the welding defects can be decreased by optimising the welding parameters and the tool geometry.

Aim of this work is to study the effect of process parameters on the mechanical properties of joining between three dissimilar aluminium alloys: AA7075, AA2024 and AA6061 weld together in overlap case by Friction Stir Welding process and to analyse possibility to optimize these parameters.

2. Experimental procedure

2.1. Friction Stir Welding process

The experimental stand used to perform the special welding process for all three materials is presented in figure 1. It is composed of: special device for fixing welding parts, tool fastener, thermographic camera, engine and machine spindle, laptop used to records output dates and machine control panel. The welding tool used is made of sintered tungsten carbide (P20+S), this is a cylindrical one, shape of pin is threaded M6, pin high by 5.3 mm and diameter of shoulder is equal with $\phi$22 mm, figure 2.

The FSW process is performed in three different steps: first of it is represented by vertically plunged through all three plates (completed in first two plates and partially in third plate), the second step is represented by travel of tool along of the welding seam and performing the welding plates and the last step is vertically extraction of the tool.

![Figure 1. Friction Stir Welding process](image1)

![Figure 2. Welding tool](image2)

![Figure 3. Friction Stir Welding process – front view](image3)

Dimension of each used plates are 200 mm x 250 mm and thickness of it are equal with 2 [mm]. The welding process is performed for three dissimilar aluminium alloy: AA2024, AA6061 and AA7075 in the overlapping configuration. The upper material is AA7075, in the middle is placed AA2024 and in the lower position is AA6061, like in figure 3.

2.2. Base materials

The materials used in this paper are three aluminium alloys: AA7075, AA6061 and AA2024. In Table 1 are displayed effective chemical composition and mechanical characteristics of these three different aluminium alloys.

2.3. Experimental plan

In actual paper are study the result of experiment performed with parameters presented in Table 2. The input parameters used in this special welding process are: the rotation speed [rpm] and the welding speed [mm/min].
Table 1. Chemical composition and mechanical characteristics of AA7075, AA2024 and AA6061

| Chemical composition [ weight %] | Mechanical characteristics |
|---------------------------------|-----------------------------|
| Si Fe Cu Mn Mg Cr Zn Ti Ti+Zr    | UTS [MPa] YS [MPa] E [%]    |
| AA7075 0.05 0.1 1.6 0.05 2.7 0.19 5.80 0.05 0.01 | 593 to 594 531 to 532 11 to 12 |
| AA2024 0.10 0.1 4.4 0.47 1.5 0.01 0.14 0.04 0.05 | 464 to 466 344 to 348 17 to 18 |
| AA6061 0.74 0.4 0.2 0.14 0.9 0.18 0.09 0.05 -   | 317 to 319 286 to 290 10 to 12 |

UTS - Ultimate Tensile Strength; YS - Tensile yield stress; E - Elongation

Table 2. Experimental plan for Friction Stir Welding

| Code of experiment | 4.3 |
|--------------------|-----|
| Position of materials | AA7075 – upper; AA2024 – middle; AA6061 – lower |
| Welding speed [mm/min] | 100 |
| Rotation speed [rpm] | 650 |

2.4. Cutting the specimens

After welding the specimens were extracted with a water jet cutting machine. The cutting plan and dimension of samples are exemplified in figure 4.

Each sample are identified with a code consisting of three digits: first of it, 4 – represent position of materials in welding system, the second, 3 – represent combination of input parameters and the last of it 1-4 represent position of sample on the welding seam.

For this experiment, the welding tool was broken at 60 mm before the end of the welding seam.

3. Experimental evaluation

As a result, further research is warranted. The FSW process is increasingly used, so it requires characterizations and studies through simulations and tests of various types of FSW assemblies. The present paper contains results of such research.

In this paper, the friction stir welding process was used to assemble three aluminium alloys plate, overlap like in figure 3 and specimens used to analyse all characteristic of welding seams was extract according to figure 4. These specimens was identified different according to their position on the welding seams, with the next: 4.3.1, 4.3.2, 4.3.3 and 4.3.4. Specimen 4.3.1 is the one at the beginning of the FSW process (closest to start welding), 4.3.4 being the last at the end of the welding process (farthest from start welding).

An important role in obtaining an optimal weld seams is the welding tool characteristics (dimension and profile of pin and shouM6older). For this assembly was used a cylindrical threaded M6 pin (figure 2) was used. Other important characteristics is direction of rotation of the tool, for this study was used the direction counter-clockwise.

The temperature recorded during the realization of the welding seams was recorded between 450 and 500 degrees. The temperature performing for each sample are represented in figure 5, the evolution is
stable, start with approximate 470 degrees for first sample (4.3.1), 460 degrees for second and third samples (4.3.2 and 4.3.3) and approximate 470 degrees for the last sample (4.3.4).

**Figure 5.** Evolution of temperature in FSW process for experiment 4.3

The tensile testing process has some different steps described in the next paragraphs:
- **preparation of surfaces, of interest, of specimens** - abrasive polishing, removal of the results with cloth soaked in acetone;
- **making coding**;

By isolating areas of interest, is applied in the background uniform matt white paint layer and then continue the process with the application by spray, fine and uniformly black paint, figure 6. This step has an important role.

**Figure 6.** Making coding – lateral and front view (left side) and front view (right side)

Coded surface should provide good contrast, required for the analysis phase. Making deformation fields, their characterization is done by a digital image correlation algorithm.
- **testing, recording and storing data.**

The tests were performed using a special "ISTRON 100 kN" testing machine. During the tests, for a deeper assay of FSW assembly, the following acquisition systems were also used:
- **3D GOM acquisition system**;
- **2D acquisition system - multiple recording camera**;

The results obtained by the system of the ISTRON test force versus time diagram are shown in the figure 7.
Figure 7. Graphs of the tensile forces for the four samples, depending on displacement

To specify, the time increment is 0.5 s. The forces were recorded from 0.5 to 0.5 sec.

In figure 8 it is indicates the maximum breaking forces for all four tested specimens. The first specimen coded 4.3.1 has break at $F_{\text{max}} = 8.71$ [kN], the second one 4.3.2 at $F_{\text{max}} = 16.30$ [kN], the third one 4.3.3 at $F_{\text{max}}=19.05$ [kN] and the last one 4.3.4 at $F_{\text{max}} = 20.35$ [kN].

Based on data provided by the 3D GOM acquisition system, processed in Matlab, the following results were obtained: figure 9 and figure 10. These images show the deformation fields on the front and side of the specimen, in the direction of the stress, for the sample 434. The investigated area of the specimen was 40 mm in length (from -20 to 20). For the acquisition system we used the following features (ROI 15, Shift 3). The moving speed of the mobile part was 5 mm / min.

From the images presented, it is observed that, for the presentation, the points A, B and C, the decks before the break were selected (see figure 7).

Figure 8. The maximum breaking force of specimens 4.3.1, 4.3.2, 4.3.3, 4.3.4

Figure 9. The displacement field, in the direction of the load ($xx$), frontal view, in points A, B and C - sample 434

Figure 10. The displacement field, in the direction of the load ($xx$), lateral view, in points A, B and C - sample 434
4. Conclusions
Assembling via FSW is a non-dismountable assembly, so that the characterization by testing of the breaking of this weld, is primordial. In this study we achieve a decreasing of maximum breakage force in time with evolution of welding seams. In the same time with evolution of welding seams was identify a small increasing of the recorded temperature in process time, from 460 degrees to 470 degrees. Start with approximate 470 degrees for first sample (4.3.1), 460 degrees for second and third samples (4.3.2 and 4.3.3) and approximate 470 degrees for the last sample (4.3.4).

The maximum breaking forces are increasing (see figure 8). Sample 4.3.1 breaks at the lowest strength and sample 4.3.4 breaks at the highest strength. Thus, we can say that the welding process stabilizes. The maximum force to rupture the last samples 4.3.3 and 4.3.4 have similar values.

All samples were broken in the welding area.
The maximum displacement (deformation) values, figure 9 and figure 10, are 1.5 mm, before breaking (point C), highlighted on the color scale.

The data presented in the paper are only a few. In a series of future scientific articles [7], we will continue such characterizations. We will make observations about the influences of process parameters on an optimal FSW process.

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