

Preliminary Study of FSW Process of Dissimilar Aluminium Alloys in Battery Pack Assembly for Hybrid Vehicles Production

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Abstract. The requirement to join two dissimilar aluminium alloys produced with two different technological processes, extrusion and die casting, is fundamental in the automotive sector. In this research study was proposed the use of the Friction Stir Welding process to replace the traditional welding process. First of all was verified the weldability by using different process parameters and the results are reported in terms of microstructure and join aspect, which influence the Vickers microhardness. They show a suitable combination between the selected process parameters and the tool choice but also suggest to test different process conditions. Tool geometry and workpiece setup have to be redesigned. The final aim of this preliminary study is to find the best process conditions in order to proceed with components and machine tools design in the perspective of procedure industrialisation for hybrid vehicles battery pack assembly.

Introduction

In the automotive sector the major focus is now on the electrical cars development, in order to reduce the environmental impact and to search an alternative to fossil fuels. In the last few years, this transition is led by the hybrid vehicles, which gained an important market slice [1,2]. However, it's evident that the presence of both components, endothermic motor and electrical motor, make the whole car system very difficult to manage in terms of parts volume. This requirement increases if are considered the supercar, where the components volume and weight have to be reduced in order to increase the performances.

In this framework was developed this research activity moreover, considering the need to join in the same vehicle some different aluminium alloys, the Friction Stir Welding (FSW) process matches two principal requirements. First of all the advantage to use a solid-state welding which allows to deeply join materials of different composition and secondly the removal of any other welding bead that means weight and volume reduction, for these reasons this welding process is already largely employed in the automotive sector [3,4].

This research work has the objective to study the weldability of a 6xxx aluminium alloy workpiece extrusion manufactured and an AlSi10Mg die casting workpiece, in the perspective of FSW implementation in industrial battery pack production to replace the traditional welding processes [5]. Different authors investigated the effect of the FSW process when different materials were joined. In Wan and Hang are reported different joint configurations based on the significant differences in

thermal characteristics between the aluminium alloys and the steel [6]. In particular, for the lap joint is suggested to put the aluminium on the upper side and the steel on the lower side, but changing the position it obtains a localised fusion effect at the interface, which results in a semi-solid welding process. Concerning the die casting alloys, Kim et al. identified different windows, based on rotation speed and welding speed, to obtain the optimal welding conditions and to avoid the typical defects which are caused by excessive heat input, insufficient heat input or abnormal stirring [7]. The boundaries of each window result in cold or hot welding conditions and it influences the heat input quantity. Other useful indications on the welding parameters for die-casting aluminium alloy are reported in a research study that compares two different friction welding technologies, and in particular the friction stir welding of the AlSi10Mg [8]. The research works, which investigated the FSW process on dissimilar aluminium alloys, report a large window of process parameters depending on the thermal characteristics of the tested materials [9,10]. The combination of the two proposed materials is very challenging, and a similar situation was studied by Eskandari et al., which studied the joining of an aluminium wrought workpiece with an aluminium cast workpiece. They investigate the resulting joints by differentiating the position in the butt joint configuration. If the AA6061 alloy is positioned on the advancing side the maximum temperature and the heat generation is higher than the configuration with A390 on the advancing side, this is due to the lower flow stress of AA6061 with respect to A 390 [11].

Materials and Methods

Experimental setup The machine used to perform the FSW process is a traditional milling machine Adria Machine PBM-4EVS equipped with a tailored cylindrical tool, which was produced by FPT Industrie S.p.A. The materials to be welded, provided by Proma S.p.A., are two different aluminium alloys. An AA6xxx – T6 extrusion plate with four cavities in the middle section and an AlSi10Mg die casting workpiece. The chemical composition of both alloys is reported in Table 1. Fig. 1

Table 1. Chemical composition (wt%) of the selected aluminium alloys.

	Al	Cr	Cu	Fe	Mg	Mn	Si	Others
AA 6xxx	97.50	0.35	0.10	0.35	1.40	/	/	Balance
AlSi10Mg	87.90	/	0.05	0.55	0.60	0.45	10	Balance

It was decided to produce 4 samples for each test having dimensions 40 x 38 x 5 mm in order to place them in the four cavities as reported in Fig. 1. The FSW was then carried out on the upper surface of the extrusion component as shown by the setup reported in Fig. 2. The aim is to simulate the lap joint conditions having the AA6xxx extrusion component on the top and the AlSi10Mg die casting component on the bottom.



Fig. 1. Assembly of the Aluminium samples.

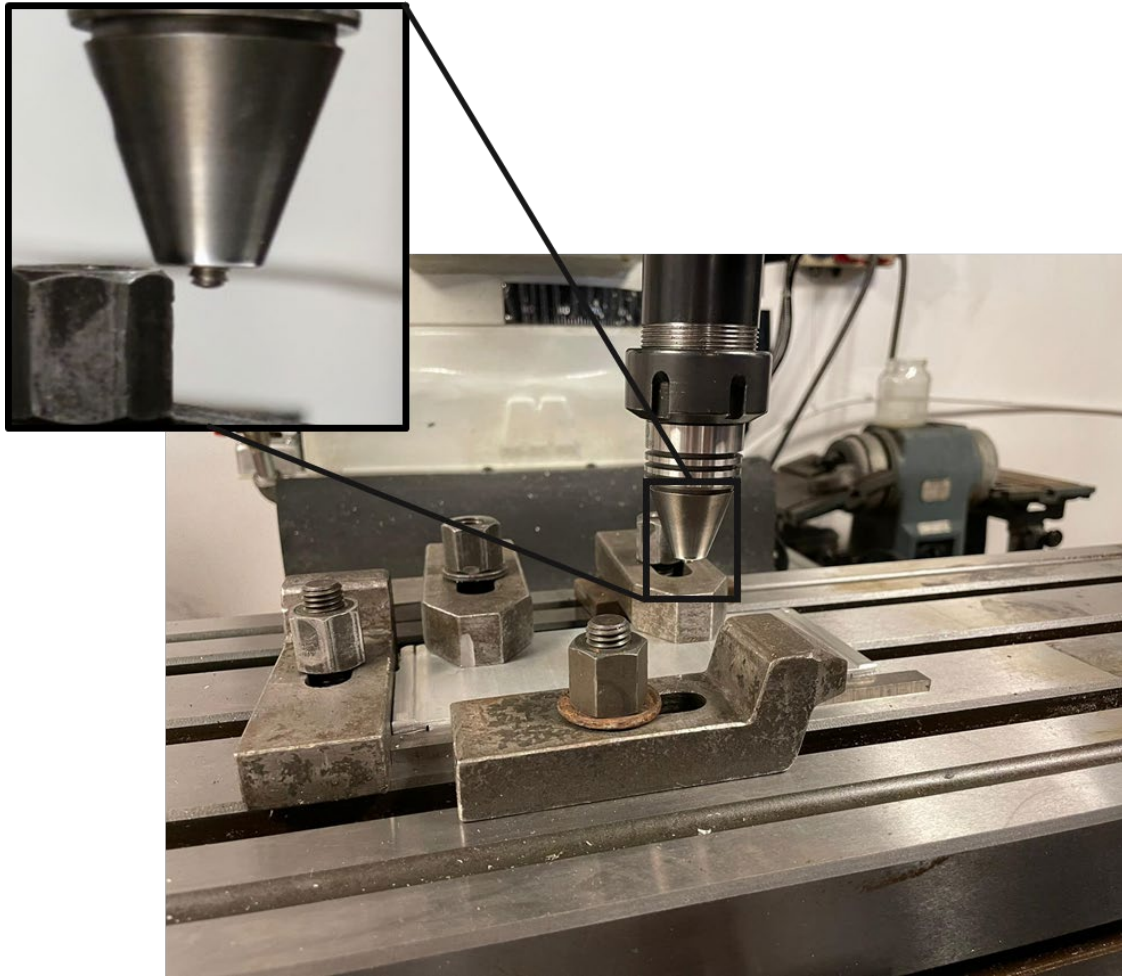


Fig. 2. Machine, tool and workpiece setup.

Process parameters. The particular setup proposed is very challenging for this type of welding process. As a matter of fact, the thinner component to join is also the one that has the greater thermal conductivity ($163 \text{ W/m}\cdot\text{k}$) and is directly in contact with the shoulder of the tool. The thicker component is slightly interested from the mechanical action of the tool because just the pin is in contact with it but is also the one that needs more time to reach the plasticity condition due to its low thermal conductivity ($100 \text{ W/m}\cdot\text{k}$). In this situation was decided to employ a dwell time of 10 seconds in order to allow the heat diffusion to the whole workpiece and to guarantee the plasticisation of the bottom component. Other studies performed on FSW of dissimilar aluminium alloys reported different ranges of process parameters [3,7,12–14], so it was decided to fix the rotational speed at 1350 rpm and the tilt angle at 2° . Preliminary tests were carried out by setting the welding speed at 100 mm/min and changing the tool in order to reach the best compromise between welding depth and quantity of the heat input. If the joint results properly done, another welding speed was tested, 140 mm/min, with the aim to reduce the heat quantity in input and preserve the integrity of the thinner plate and the mechanical characteristics of its thermal treatment. Three tools were employed having the geometrical dimensions reported in Table 2. Starting from the first tool, step by step the joints were verified, using the characterisation procedure described in the section below, and then was changed the tool with the following bigger.

Table 2. Geometrical dimensions of the FSW tools.

Tool	Shoulder diameter [mm]	Pin diameter [mm]	Pin length [mm]
1	13	5.20	2.5
2	13	5.40	3.0
3	13	5.90	4.0

Characterisation procedure. For each welding condition, four samples were cut at different parts of the welding bead that corresponds to the middle of each cavity. The characterisation procedure was aimed to evaluate the following characteristics:

- Microhardness
- Microstructure

Microhardness: CV cat 07-eseway b was employed to carry out Vickers microhardness tests. Twentyone indentations for each sample were performed using load of 100 g and a dwell time of 15 s. Seven indentations were performed in the middle of the upper plate, 0.7 mm above the interface, seven indentations below the nugget, 0.7 mm below the interface, and seven indentations in the bulk bottom material, 1.5 mm below the interface.

Microstructure: the specimens were prepared according to the standard metallographic preparation procedure [15]. Subsequently, the surface was chemically etched with a Keller's reagent made by 95 mL of water, 1 mL of hydrofluoric acid, 1.5 mL of hydrochloric acid and 2.5 mL of nitric acid. Two types of devices were employed to acquire the pictures for microstructure analysis, an optical microscope Zeiss Axioplan 2 working with ZEN Blue software for image analysis and a Leica DCM3D confocal microscope working with Leica Map software. In order to observe the zones, which are characteristics of the FSW, the microstructure of the samples was analysed along the welding direction by sectioning the sample in a plane perpendicular to the joint direction.

Results and Discussion

As mentioned before, the main difficulties are related to the heat input quantity, which could be excessive for the AA6xxx but insufficient for the die casting alloy, which has lower thermal conduction than the previous [7,11]. For this reason, the first test was carried out with the smallest tool n. 1, it was observed and insufficient penetration as shown in Fig. 3. The two component appears to be bonded but not welded because it doesn't show any mixing between the two materials. Then it was tested the tool n. 2 with base process parameters, the resulting joint appears to be well executed although the position of the nugget is very high in the welding zone and it fills up almost the entire extrusion plate as shown in Fig. 4. The third test was carried out with tool n. 2 and increasing the welding speed to 140 mm/min, also in this case the joint appears to be well executed and the observation on the position of the nugget are the same as mentioned in the previous case, it is shown in Fig. 5. The fourth test was carried out with tool n. 3, the biggest one, and it appears immediately the heat input quantity is very high, as a matter of fact, it was produced the rupture of the upper plate as shown in Fig. 6.

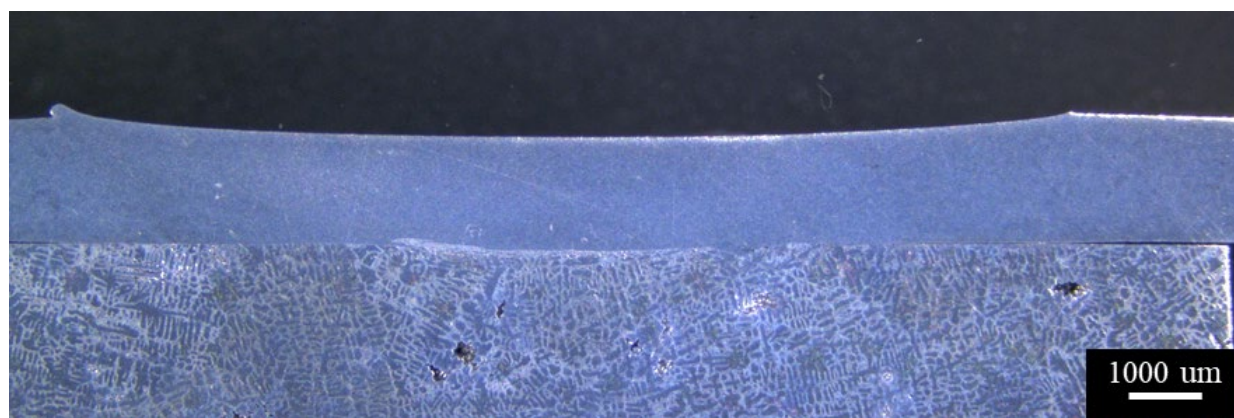


Fig. 3. Cross section of FSW joint made with Tool n. 1.

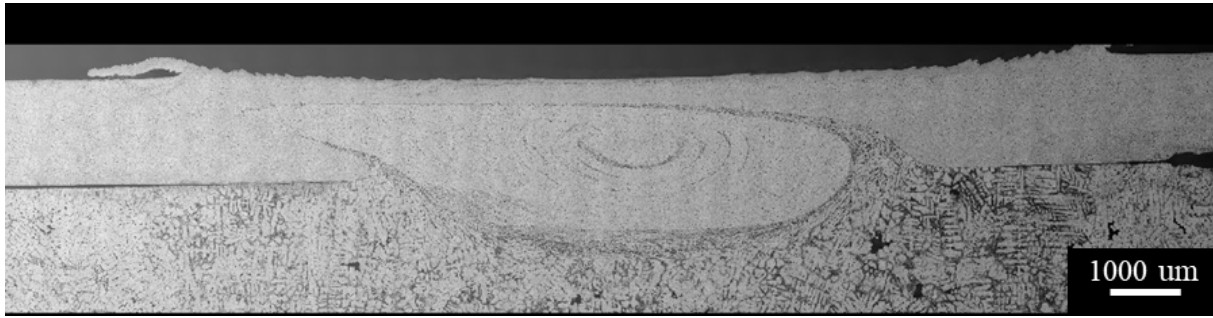


Fig. 4. Cross section of FSW joint made with Tool n. 2 – welding speed 100 mm/min.

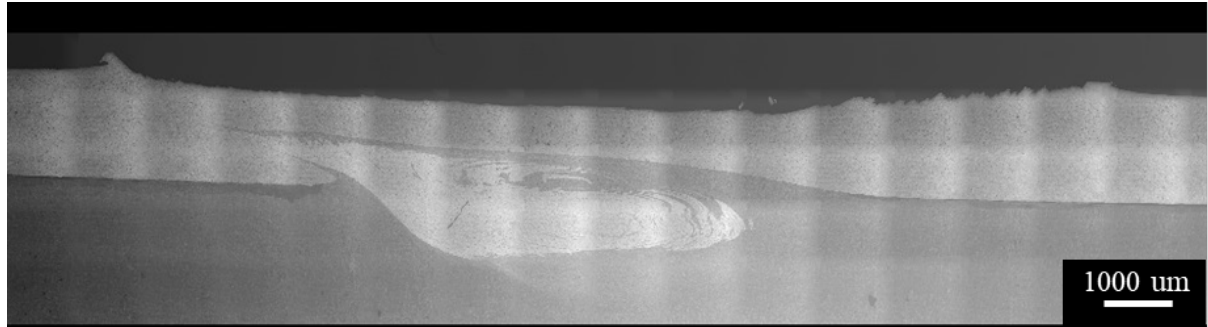


Fig. 5. Cross section of FSW joint made with Tool n. 2 – welding speed 140 mm/min.



Fig. 6. Particular of the FSW joint surface made with Tool n. 3.

Since it was observed that the only joints that show a proper aspect are the two, which were made with the tool n. 2, the cross-sectioned samples were used to evaluate the microhardness with the procedure reported in the section above. From the results reported in Fig. 7 it is possible to highlight that close to the welding zone the extrusion plate loses the heat treatment. As a matter of fact, the expected HV value for an AA6xxx with T6 treatment (90 HV) is so far from those that were measured, which tends to be more similar to the HV values of the same alloy without heat treatment. Moreover is possible to evidence that in the lower measurements line the HV values decrease close to the centre of the nugget, corresponding to distance 0 mm on the X axis, and increase moving away from that zone and they become more similar to the target value for AlSi10Mg (100 HV). In the middle layer the increase of the HV measured values close to the nugget points out the effect of the mixing, therefore this effect appears to be enhanced by the increase of the welding speed, for this reason the measured values are more dispersed on the graph.

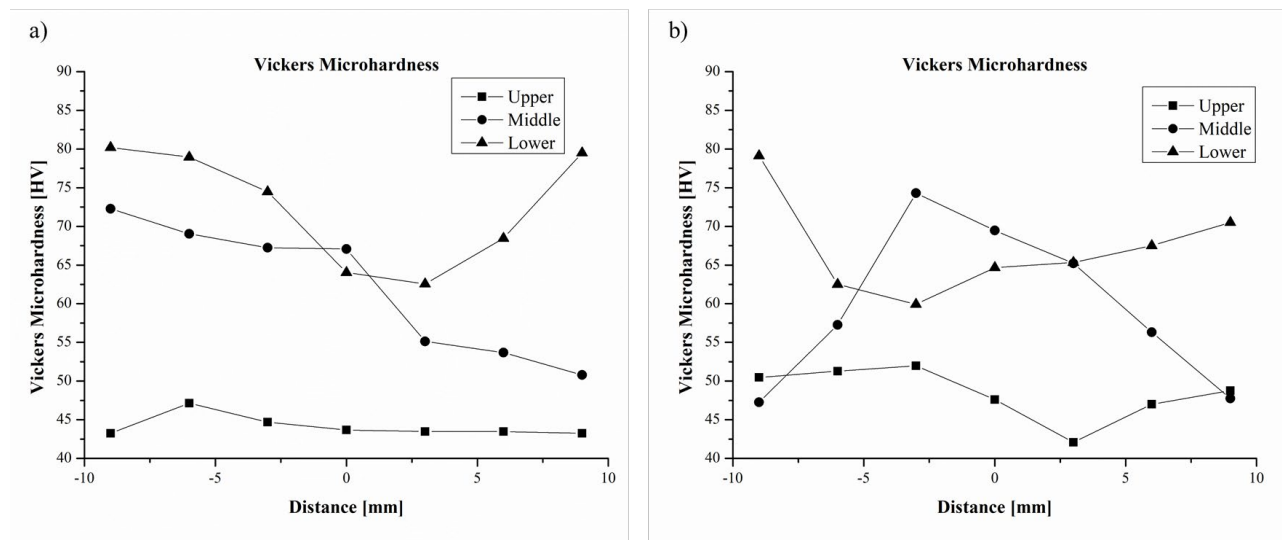


Fig. 7. Vickers microhardness measured on the FSW joint made with tool n. 2
Welding speed: a) 100 mm/min – b) 140 mm/min

Conclusions and Outlook

The following conclusions can be reported:

- Among the available tools, the most suitable is the one that has 3 mm pin length, the shortest one doesn't produce the welding and the longest one produces a rupture in the upper workpiece.
- With the chosen parameters, it is possible to perform an acceptable joint but the resulting heat input quantity is very high and it results in a mechanical properties decline and a loss of the previous heat treatment effect in the AA6xxx extrusion workpiece.
- The general increase in the HV values measured in the upper layer and in the middle layer, which was detected by increasing the welding speed, is the positive effect of the heat input quantity reduction.
- The trend reported by the HV measured values shows an efficient mixing effect between the two materials up to 1.5 mm below the interface of the two workpieces.

Considering the promising results obtained by performing the FSW with this setup and this characterisation procedure, and considering the conclusions, further tests have to be performed:

- Increasing the tool pin length from 3 mm to 3.5 mm, in order to obtain a deeper joint zone with better nugget placing and avoiding the rupture produced by using the tool n. 3.
- Testing different increases in welding speed in order to obtain a further heat input reduction and to verify an improvement in Vickers microhardness measured values and to better preserve the original characteristics of the base materials. Because, as mentioned above, the reduction in the heat input quantity affects positively the whole joint.
- Including an infrared optical device with the aim to evaluate the extension of the Heat Affected Zone, which should be useful to monitor the heat diffusion mechanism during welding process.
- Considering a modification of the workpiece geometry in order to avoid the challenging setup in which the thinner and more conductive component is overlapped to the thicker and less conductive item, another possibility regards the design of a butt joint with a backplate.
- Enhancing the characterisation procedure by performing EDS analysis on the SEM microscope for a deep evaluation of the microstructure and the effect of the materials mixing by highlighting the alloy elements.

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