FRICTION STIR WELDING OF FOAMABLE MATERIALS AND FOAM CORE SANDWICHES

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Abstract

Because of exceptionally high stiffness-to-weight ratio aluminium foams are very promising materials for lightweight construction, especially for use in large and complex lightweight panels or similar structures. One of the promising ways for they manufacturing is powder metallurgical process, where powders of aluminium alloy and foaming agent, e.g. TiH$_2$, are mixed and compacted via extrusion, thus creating so called foamable precursor, which expands on melting. However extrusion process does not allow manufacturing of precursor in the form of large or complex 3D-structures and this fact makes a foaming process significantly more difficult.

Main aim of this work is to show that joining of such foamable precursor profiles into large parts is feasible via friction stir welding (FSW). As this welding is performed in solid state no premature foaming of precursor was observed and foaming ability of both precursor and welds was preserved without any changes. Since FSW generates only low amounts of heat no thermal distortion or other geometry changes were observed on welded materials. It will be shown, that FSW is suitable technique also for welding of foam-cored sandwiches if appropriate distance profile between opposite coversheets is used. The coversheets are welded together without affecting foam core, which leads to excellent mechanical properties of welded joint. Even sandwiches made by gluing of coversheets onto foamed core can be welded by this method without destroying glued interface.

Keywords: sandwich plates, aluminium foam, friction stir welding
Introduction

FSW is relatively novel joining technique which has been invented by TWI (The Welding Institute, 1991). Material is joined during stirring and mixing of metal in solid state. Schematic display of FSW process is shown below /1/.

![Schematic display of FSW process /1/](image)

FSW technique is very simple. Pin of the rotating tool is inserted into interface between workpieces to be welded and moved along weld centerline. Heat is generated by friction between rotating tool and both material surfaces. Because of generated heat material is softened and easily stirred by rotating pin. Due to the shoulder attached directly to the upper surface of welded parts, stirred material cannot flow out of the weld and the original geometry of the welded cross section is thus retained. At first sight it is noticeable that tool design plays very important role and is decisive for the performance of whole FSW process. Other very important welding parameters are: tool rotating rate, tool traverse speed and upper force applied on a tool.

This technique is nowadays predominantly used for joining of metals with higher affinity to oxygen, such as aluminium, magnesium, zinc, lead and copper without need to apply any protecting atmosphere. The stirring efficiently disintegrate the surface oxides on both counterparts and provides thus optimum conditions for sound welds. Also joining of dissimilar alloys and even dissimilar materials is possible. Some of the other main advantages of FSW process are: low energy input into welds and thus lower thermal stresses and geometry distortion, harmless processing for the environment, fine grain microstructure in weld area, no need for additional weld material, low cost (no consumables, low energy), etc.

Within this work three types of experiments have been performed: FSW of foamable precursor material, FSW of aluminium foam which has inserts made of bulk aluminium and FSW of glued aluminium foam sandwich plates.

FSW of foamable precursor

Powder metallurgical route is one of the mostly used processing techniques for aluminium foam production. In this method the metal and foaming agent (TiH$_2$, ZrH$_2$, etc.) powders are mixed together and extruded creating so called foamable precursor. On heating the foaming agent evolves gas, thus creating foam with desired porosity. Due to extrusion the foamable precursor cannot be produced in the form of large or complex 3D-structures and thus joining of precursor is sometimes needed. In this case FSW is probably only welding technique which can be used without destroying the foamability of the precursor.

Main danger is decomposition of TiH$_2$ which starts at about 450°C and premature foaming of precursor due to the high amount of involved energy during welding. This can affect quality of the weld and significantly reduce the attainable porosity in subsequent foaming. The exact
temperature during FSW process is very hard to measure, even impossible, because of the nature of this technique. Some estimates (based on temperature measurements near to the weld line) give the temperature range between 400–480°C in case of aluminium alloys. It is clearly noticeable that this temperature is well below melting point of any commercial aluminium alloys, although the upper limit of this range can already lead to partial decomposition of foaming agent.

Welding experiments were performed on precursor material made of AlMg1Si0.6 alloy with addition of 0.4% ZrH2. Thickness of material was 5 mm and FSW parameters were: tool rotating rate - 1000 rpm and tool traverse speed - 112 mm/min.

The both surfaces of the weld and its microstructure are given in Figure 2 and 3 respectively.

![Figure 2: Weld surfaces after friction stir welding of foamable precursor (thickness 5 mm): a) upper part under shoulder; b) bottom part under pin](image)

![Figure 3: Microstructure of precursor material after welding: border area between base material and weld (detail A); microstructure of a weld zone (detail B) and of a base material (detail C).](image)
Fig. 3 confirms the assumption that FSW leads to smaller grain size in weld area compared to the base material [2]. Question is how this smaller grain size and overall FSW process affects the foamability of precursor.

Therefore several foaming experiments were performed with both original as well as welded precursor materials at linear heating rate of 1°C/s. Figure 4 shows expansion kinetics (bottom lines) with corresponding temperature profiles (upper lines). Blue line represents original material (outside the weld) and red one the welded part of the same precursor. Generally, it can be seen that the foaming ability of precursor material after friction stir welding remains almost unchanged. Slight shift of expansion towards shorter foaming times can be attributed to improved heat transfer within fine grained stirred zone. However these differences are negligible from practical point of view.

Figure 5 shows structure of welded precursor samples after foaming experiment. As it could be expected from results of foaming kinetics, there is no significant difference between foam structure obtained from the welded zone and from both original precursors.

**Figure 4.** Results of the foaming experiments.

**Figure 5:** Structure of foams made from original precursors (left and right) and from the welded zone (middle).
The experiments have shown that FSW is really very promising method for joining of foamable precursors. Premature foaming was not observed at all and the fine structure of stirred zone has not resulted in any significant difference concerning the foaming ability of both precursor and weld.

**FSW of aluminium foam**

The joining of foams is still very tricky task, especially when permanent metallurgical bonding has to be obtained [3]. In this case simple FSW is not possible, because foams are compressible and thus pressure necessary to create sufficient frictional forces between rotating tool and cell wall material does not arise after inserting a pin into the porous structure. One possibility is to insert a bulk aluminium profile made of alloy with higher melting point than the foamable precursor into the foaming mould before foaming and then to use this profile as a base material for final FSW. Fig. 6 shows an example, where such an insert was foamed-in AlSi10 foam and then used for welding with the similarly manufactured counterpart. The advantage against simple welding is significantly lower thermal loading of the part during welding and thus lower thermal stresses at the foam – insert interface. Moreover a part of foamable precursor, which was not allowed to foam (e.g. cooled edge) can be used instead of inserts which considerably simplify the manufacturing of foams for subsequent welding.

![Figure 6: FSW of two AlSi10-foam samples using bulk inserts made of plain Al.](image)

**FSW of foam-cored sandwiches**

If glued sandwiches are to be welded, the involving heat may not destroy the adhesive layer between core and coversheets also in the vicinity of the weld. This is very difficult (even almost impossible) to achieve with traditional welding techniques. Furthermore if hardened coversheets are used, their properties cannot be redressed via after treatment, because of low thermal stability of adhesive. As it was already mentioned, FSW produces significantly less heat than traditional welding, as the material is not melted at all, and provides therefore very promising method also in this case. The main problem to utilise FSW for this purpose is the low indentation resistance of the foam core. When the pin is inserted between two adjacent coversheets the material is partially pressurised into the pores below the pin and the frictional forces enabling good stirring and thus metallurgical bonding do not come up. Therefore some kind of support must be inserted between coversheets prior to FSW to provide stable base to rotating tool. Figure 7 shows several types of such inserts between sandwich plates.

![Figure 7: Various inserts between coversheets enabling FSW of sandwich plates.](image)
If the welding is performed properly the supporting profiles are also welded to both adjacent coversheets in one operation, which significantly improves the mechanical properties of the joint. The experiments have shown that satisfactory bonding can be attained for coversheets thicker than 1 mm. During welding no degradation of adhesive properties was observed. Heat generated in weld area is very quickly dissipated in the coversheet (without significant temperature rise), because of its very good thermal conductivity. For smaller pieces some kind of cooling can be optionally applied. The properties attained after thermal treatment of coversheets before joining can be preserved in this way as well.

Conclusions

It has been shown that FSW technique is very successful tool for joining of foamable materials. No degradation of foaming ability was observed in foaming of welded AlSi10 precursors. Next step should be the optimisation of the process (tool rotating rate, tool traverse speed, pin designs) for foamable precursors made of other alloys. The earlier start of foaming of stirred material if compared with original precursor needs also more profound explanation. Joining of aluminium foam core sandwich plates via FSW has also proven its feasibility. Heat generated during welding did not harm the properties of adhesive and interfacial bonding strength stayed preserved. Further research is needed to optimise the tool and joint design for FSW of thin coversheets and to investigate systematically the mechanical properties of obtained joints.

Reference