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Foaming around Fastening Elements

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Abstract. The aim of this work was to improve the joining between the fastening elements and the aluminium alloys foams. The research work was carried out on joining fastening elements into aluminium alloy foams during the foaming process, i.e., foaming around fastening elements. The foamable precursor material was produced by hot pressing the powder mixture of metal and a small fraction of the blowing agent. A steel mould containing a foamable precursor material and the fastening elements were heated to temperatures above the melting point of metallic matrix of foamable precursor material in order to obtain the final specimens. Each aluminium foam specimen (6061 and AlSi12) has 200x80x80mm and contains two fastening elements. The steel moulds design, the fastening elements geometry, the aluminium alloy composition, as well as the foaming parameters were studied in order to optimise the quality of the joints produced. The quality of the joints were determined by means of visual inspection and mechanical tests.

Introduction

In the continuing search to produce vehicle lighter and to reduce both fuel consumption and vehicle gas emission, the use of metal foams, in particular aluminium foams is being considered for a number of the applications [1,2]. Aluminium foams are specially suitable as energy absorbers and sound damping materials, for example when they are used as crash protectors in front and side panels of cars, bonnets, boot lids, sliding roofs, bumpers, and so on. Nowadays, there are some commercial companies of automobile components and car manufacturers that are testing these materials. A three-dimensional aluminium foam material can be used as core of aluminium sandwich panels, which can be stamped or formed into complex panels. The panels, which can be used for car parts can be up to 50% lighter and ten times stiffer than the conventional steel parts [3-5]. Nevertheless, industrial exploitation of a new material is not possible without having the techniques for its secondary processing like shaping, surface finishing or joining. The development of suitable joining techniques for aluminium foams is necessary in order to find the requirements from industry for various applications and design of foam components. Thus, it is important to improve materials, equipment and processes, that will make aluminium foams joining more effective and reliable. Tests have been carried out on aluminium foams to study the possibility of this materials bonding itself or with other materials by adhesives bonding, welding, brazing, soldering, screwing or joining using a combination of techniques. One alternative of joining techniques is to join metal foams with other materials during the foaming process. That also provides an opportunity that could simplify and improve the fabrication of vehicles components. The advantage of this process is to obtain the final components after foaming without consumables, which are usually used in conventional joining techniques. The most common type of fasteners parts used in vehicles are nuts, bolts, screws, pin rivets, and holes with or without threads.

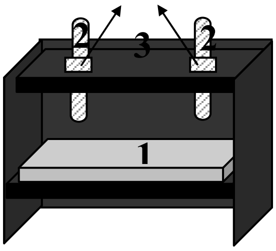
Experimental Work

Test Preparation

The specimens for foaming around fastening elements were produced by the application of Fraunhofer-Process [6], and comprises the following three steps: i) The foamable precursor materials were produced by hot extrusion of the powders mixture of aluminium alloy (AlSi12 or 6061) containing 0.6% wt. of titanium hydride. ii) The foamable precursor parts (195x79x20mm) were placed into the rectangular cavity (200x80x80mm) of steel mould. Two fastening elements were placed in one of the side of the steel mould (Fig. 1). The length of the insert inside the aluminium alloy foams is about 60 mm. iii) Finally, foamed parts containing the metallic inserts were obtained by heating the steel mould to temperatures above the melting point of metallic matrix of foamable precursor material.

The foaming process took place slowly inside the closed steel mould, which will become completely filled by the foam. The foaming process is stopped by simple cooling of the steel mould to a temperature below the melting point of the metal matrix of foamable precursor material.

A) Top side



B) Bottom side

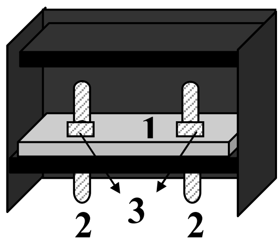


Figure 1: Position of the inserts into the rectangular steel mould. A) Top side; B) Bottom side. Legend: 1 - foamable precursor material; 2 - fastening element; 3 - nut-screw.

Mechanical Tests

The mechanical test was made to evaluate adhesion strength of the fastening element into aluminium foams. The final specimens were cutted in order to obtain two rectangular specimens containing each one only one fastening element. The typical specimen dimensions were 100x80x80mm. Tensile tests were performed at room temperature by using a mechanical testing machine with a constant displacement rate of 1 mm/min. During the tensile tests the force to pull out the fastening element from the aluminium foam versus the length of the fastening element extracted out from the foam was registered. The specimens were fixed by means of a special support made for these tests (Fig. 2)

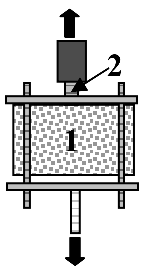


Figure 2: Uniaxial tensile tests. Legend: 1 – aluminium foam; 2 - fastening element

Results and Discussion

Preliminary tests

For preliminary studies some fastening elements with different geometry were chosen (Fig. 3). The rectangular foamed specimens of 6061-aluminium alloy were manufactured by filling an rectangular mould (200x80x80mm). Fastening elements were placed in the top of the mould (Fig.1A). As described, the final foaming metal specimens were cut into two pieces each one containing one fastening element. Thus, two samples of each configuration were tested.

The Fig. 4 shows the maximum force that it is necessary to pull out the fastening element from the 6061-aluminium foams for the different fastening elements. The Table 1 presents the density of the metal foams for different fastening elements configurations.

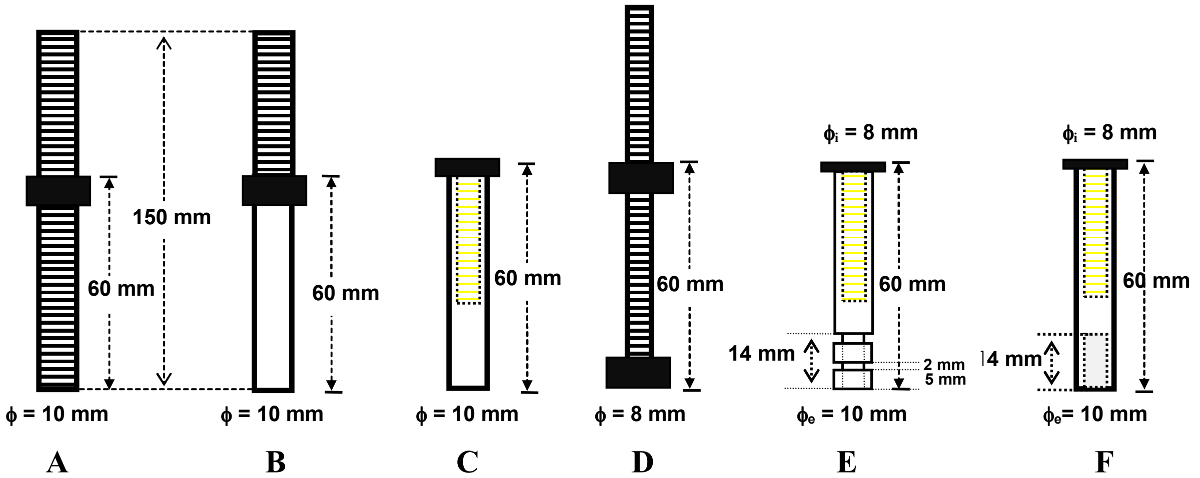


Figure 3: Fastening elements selected.

These preliminary results showed, for some of them, a great difference between the maximum force to pull out the inserts with same type of the geometry (Fig. 4). In general, the fastening elements with smooth surfaces present closer values, for example the configurations C, E and F. The highest value of the maximum force was obtained using the simple screw with one nut (6.9 kN, D-fastening type). However, with the other sample with the same configuration, a lower value was obtained (1.7 kN). This was due to big pore between the head of screw and the aluminium foam.

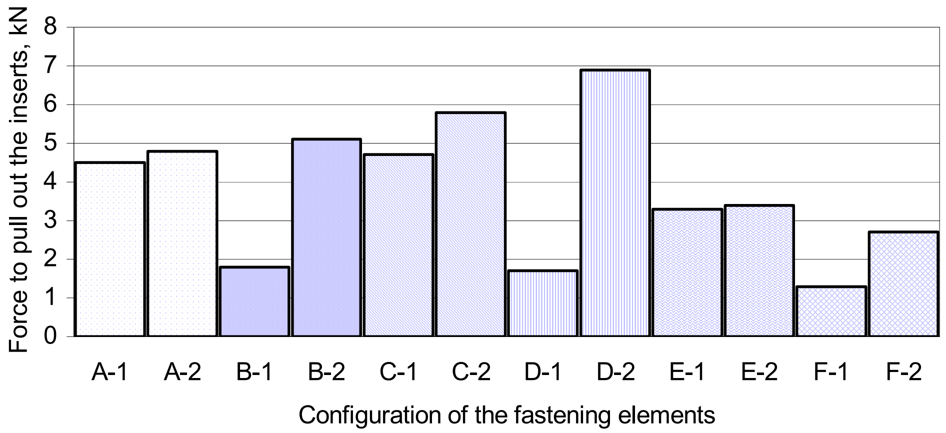
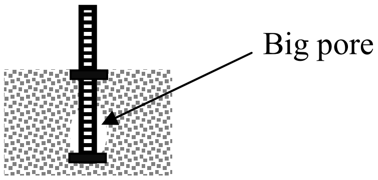


Table 1 – Density of 6061-aluminium foams for different fastening elements configurations.

Conf.	ρ, g/cm^3
A	0.51
B	0.52
C	0.57
D	0.49
E	0.54
F	0.59

Figure 4: Maximum force (in kN) of pull out the inserts from 6061-aluminium alloy.

After foaming, it was observed that all the specimens display cracks between the screw/nuts and the aluminium foam, in the region around the inserts (Fig. 5B). After the tensile tests, the specimens were cut using the WEDM machining in order to examine the joining amongst the fastening element and the aluminium foam. These visual inspection showed that the lowest values of maximum force to pull out the fastening element from the foam, correspond to specimens where were found big pores around the fastening element (Fig. 5A).

A)


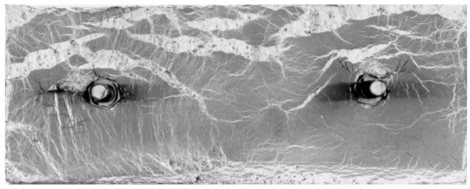
B)


Figure 5: Visualisation of A) Pores; B) Cracks around of nut-screw.

This preliminary study showed that is necessary to improve this type of join between the inserts and aluminium foams, in particular the parameters of foaming process must be optimised to avoid the big pores around the fastening elements in the aluminium foams and the cracks between the nut-screws and aluminium foams (Fig. 5B). In order to improve the joints quality, some experimental tests were conducted on foaming around fastening elements. For that the effects of some manufacturing process parameters on the joining between the fastening elements and the aluminium alloys, namely the position of the inserts in the steel mould, chemical composition of aluminium alloy and foaming temperature were studied.

Improvement of tests

Position of the fastening elements in the steel mould

Aluminium foams (6061 and AlSi12) containing two fastening elements were produced according to the manufacturing process previously described, with the change of the fastening elements position in the steel mould (Fig. 1). For the case where the fastening elements were placed in the bottom side of steel mould, it was necessary to make holes in the foamable precursor parts to insert the screws (Fig. 6). These tests were performed in order to facilitate the foaming process and decrease the cracks between the nut and the aluminium foams which appears during the foaming process.

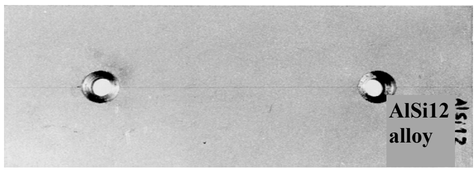


Figure 6: Foamable precursor materials with holes.

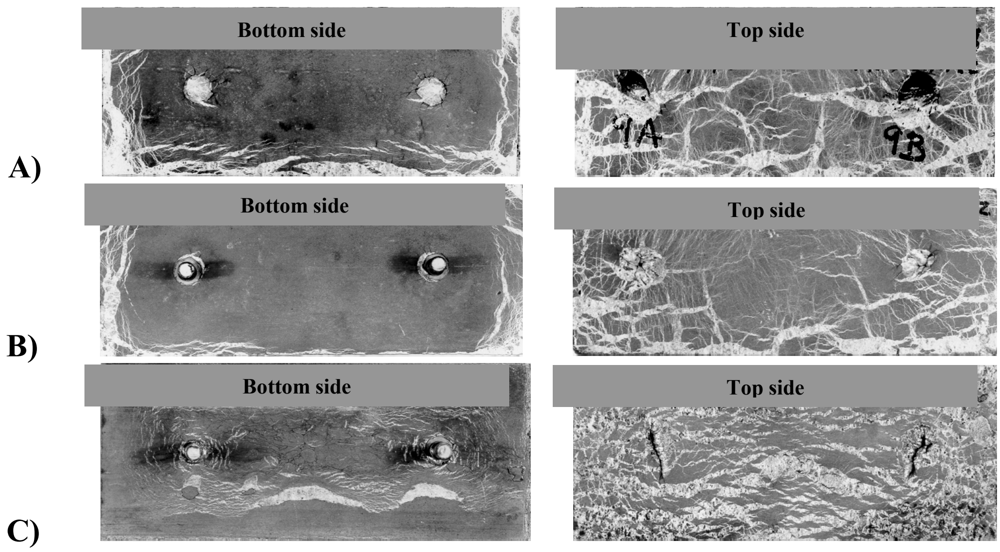


Figure 7: Visual aspect of the both sides of the aluminium foams with screws, placed in the bottom of steel mould. A) Al 6061 foams without screws. B) Al 6061 foams with two screws. C) AlSi12 foams with two screws.

The joining between the screws and the foams obtained when the screws were placed in both sides of the steel mould, can be observed in Figure 8. As it can be seen in Fig. 7, the cavity of steel mould was not totality filled with aluminium foam, in particular the corners and the opposite positions of the initial holes of the foamable precursor material. However, the joining between the nut-screws and the aluminium foams is apparently strong, without cracks, in contrast with the specimens obtained in preliminary studies. The joints along the screw into the aluminium foam were improved, but after the top-end side of screw, all the specimens show big pores (Fig. 8) in the foaming process direction.

The cavity of steel mould in the specimens obtained with the foamable precursor material with holes and without screws, was also not filled (Fig.7A). There is a difficulty of the foamable precursor material completely fill the moulds during its foaming, before the aluminium melts drawn out of steel mould. Apparently, there is not created enough pressure within of the mould in order to fill the mould cavity completely and we can to say that the position of the fastening elements of the mould has influence on the foaming process.

The joining between the screw-nut and the aluminium foams was improved, on the other hand there was difficulty to fill the mould cavity. The steel of the screws and the aluminium melts had a high contact angle, which means, that there is not molhability between the screws and the aluminium melts.

A)

B)

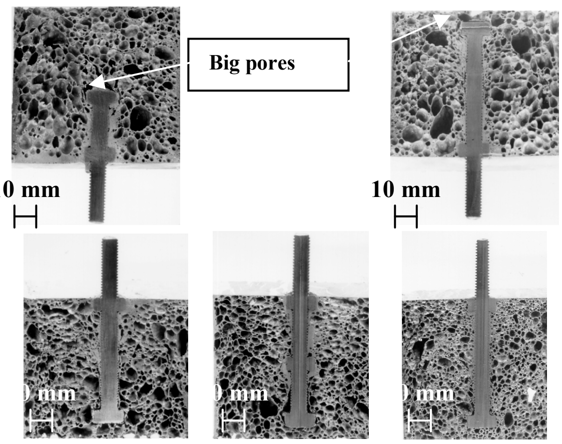


Figure 8: Visualisation of the joints quality. A) Screws were placed in bottom side of steel mould; B) Screws were placed in the top side of steel mould.

Foaming temperature

In order to improve the joining between the fastening elements and the 6061-aluminium alloy, avoiding the cracks between the screws-nut and the foam, the experimental tests were conducted increasing the temperature of foaming process. The simple increase of the temperature foaming process (10°C) shows that it improves the joining between the inserts and the aluminium foams, while the cracks decreased, as one can see in Fig. 9.

A) B)

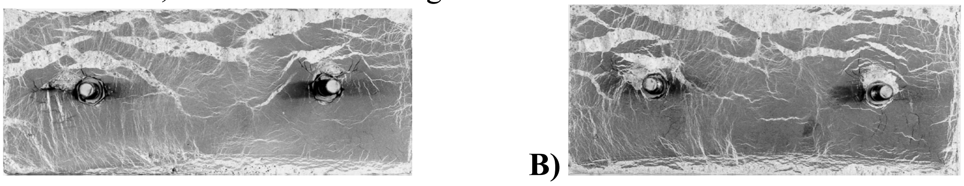


Figure 9: 6061-aluminium alloy foams containing screws, which were foaming with screws placed in the top side of mould with different furnace temperatures. A) 770°C; B) 780°C.

Aluminium alloy composition

A comparison between the foamability of used alloys was made. A good quality of AlSi12 aluminium alloy foams containing the screws in the top side of steel mould was obtained. As mentioned, the used furnace temperature was chosen according the IFAM background on foaming alloy [7,8]. In this case 750ºC was used and we can observe in Fig. 10 the visual aspect of the joining between the screw-nut and the aluminium foam. As it can be seen, the specimen does not present cracks around the nut-screw. This alloy has better foamability, than the 6061-aluminium alloy, which shows a poor surface quality.

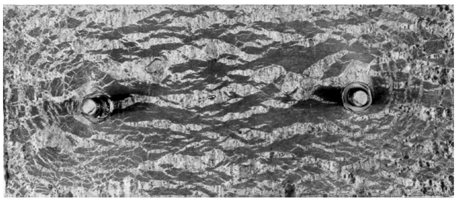


Figure 10: Visual aspect of the top side of the AlSi12 foams with fastening elements placed in the top of the mould.

Mechanical behaviour

The mechanical tests were conducted on good specimens of 6061 and AlSi12 aluminium foams containing one insert, which were obtaining placed the fastening elements in the top side of the mould, and using 750°C and 780°C respectively. The fastening elements starts to pull-out to the aluminium foams in twice values of the force of the conditions of the preliminary tests (13.8 kN). This means that in the contrast with the preliminary results it was possible to improve the joining between the fastening elements and the aluminium foams.

Conclusions

The main conclusion is the possibility to join aluminium alloy foams with fastening elements during the foaming process by the application of Fraunhofer-Process. The quality of the joint depending on:

1. Foaming parameters: the high foaming temperature of the mould improve the joints (avoid the cracks and pores) and conduct to a maximum expansion.
2. Fastening elements: the characteristics of the joint are strongly dependent of type, material, roughness, surface and geometry, as well as joining procedure and joints design. The geometry and the surface roughness are more important than its diameter and the fastening elements should be resistant to the temperature range during the foaming.
3. Aluminium alloy: the joints are strongly in the case of AlSi12 aluminium foams compared with 6061- aluminium foams.

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