

Joining of Aluminium Foams

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Abstract

Possible methods for the joining of aluminium foams have been discussed. The attention has been paid to the bolted, soldered, welded and glued joints with respect to the advantages and disadvantages of the recent techniques for their realisation. The effect of various structural and technological parameters on the strength of bolted and soldered joints has been evaluated. Potential utilisation of various integral foams for joining purposes is also briefly described.

1. Introduction

Industrial exploitation of a new material is not possible without having the techniques for its secondary processing like shaping, surface finishing or joining. Although a lot of work has been done in the preparation of aluminium foam and investigation of its mechanical and physical properties [1-6], only a little attention was paid to the secondary processing techniques [7].

Aim of this paper is to discuss the advantages and disadvantages of the possible methods which can be used for the joining of aluminium foam. The following types of joints are considered:

- bolted joints
- soldered joints
- glued joints
- welded joints
- joints using the built-in elements

2. Bolted joints

Aluminium foam possesses a cellular structure like a wood [8]. Therefore the similar joining methods as for wood can be presumed. Besides gluing, the joints in wood structures are usually created by the screws having the thread specially developed for the wood. If the wood screws are used for joining of aluminium foams, the strength of the joint depends on the following parameters:

- type of the screw (diameter ϕ)
- tightening torque
- diameter of the pre-drilled hole
- length L of the screw in the foam
- presence or absence of the surface skin on the foam
- density of the foam
- properties of the cell-wall material

Strength of the bolted joints can be derived from the force required for pulling out the screw from the foam. In this investigation the force was applied axially to the screw and measured

on INSTRON testing machine under the constant ram speed of $0.1 \text{ m}\cdot\text{min}^{-1}$. Following types of the foamed samples were used (typical density in the range $0.4\text{-}1 \text{ g}\cdot\text{cm}^{-3}$):

- cylindrical specimens with the diameter 25 mm and the length 50 mm made from AlSi12 or AlMg1Si0.6 aluminium alloys (with or without the surface skin)
- rectangular specimens $30 \times 30 \text{ mm}^2$ with the height of 10 mm made from AlSi12 or AlMg1Si0.6 aluminium alloys (with the surface skin)
- rectangular sandwich-type specimens $30 \times 30 \text{ mm}^2$ with a core made from AlSi12 foam (9 mm) covered by Al-99.7 sheet (thickness of 1 mm). The aluminium sheets were diffusion bonded to the foam during foaming.

The wood screws with the diameter 4, 5 or 6 mm and the length 50 mm were used. These were screwed into the aluminium foam up to the desired depth L through a steel washer using the tightening torque of 2 Nm. Maximum tightening torque (6-12 Nm) has been obtained in preliminary experiments and depends on the screw diameter and the density of the foam. The laboratory equipment used for axial loading of the joints is shown in Fig. 1.



Fig. 1: Laboratory equipment for axial loading of bolted joints.

The pull-out force is significantly affected by the density of the foam (Fig. 2). The dependence is non-linear with relatively large scatter in the experimental data. To compare the various types of samples independently on the density, the mean pull-out force F was introduced for simplification:

$$F = \frac{\sum_{i=1}^n r_i \cdot F_{mi}}{\sum_{i=1}^n r_i} .$$

Here F_{mi} is the pull-out force for the foam with the density r_i and n is the number of experimental values (at least 5 for each type of joint in this study). The influence of other parameters on the mean pull-out force obtained for various joints is presented in Figs. 3 - 6.

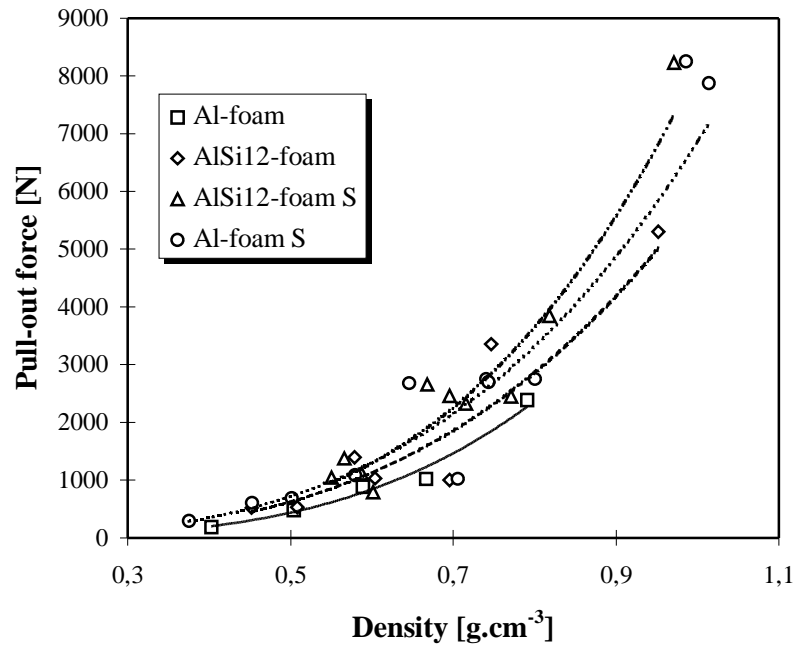


Fig. 2: Effect of the density on the strength of the bolted joints (wood screw: $f = 5$ mm, cylindrical specimens $L = 35$ mm, S- with surface skin).

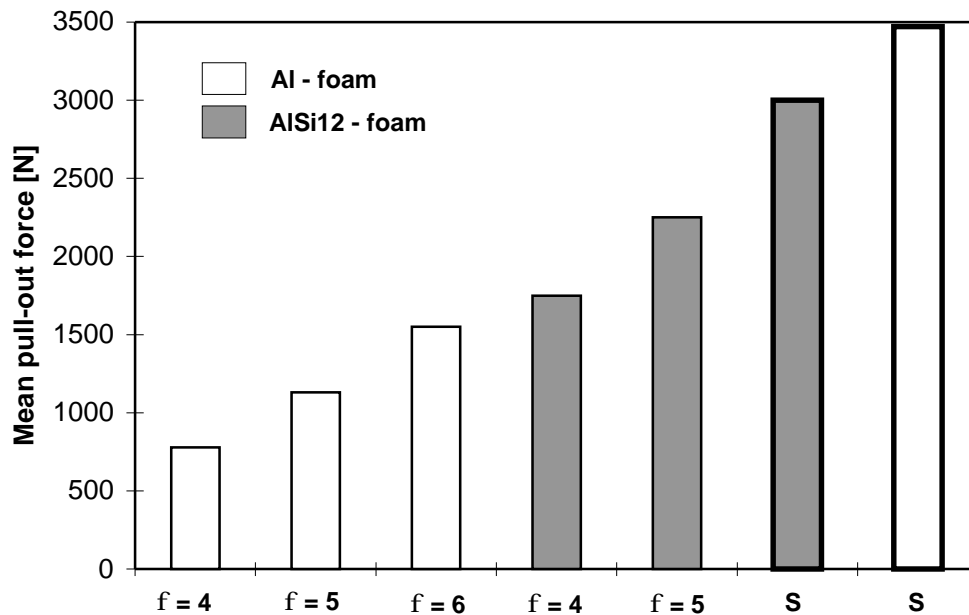


Fig. 3: Effect of the material composition, the screw diameter and the surface skin on the strength of the bolted joints (cylindrical specimens $L = 35$ mm, S- with surface skin).

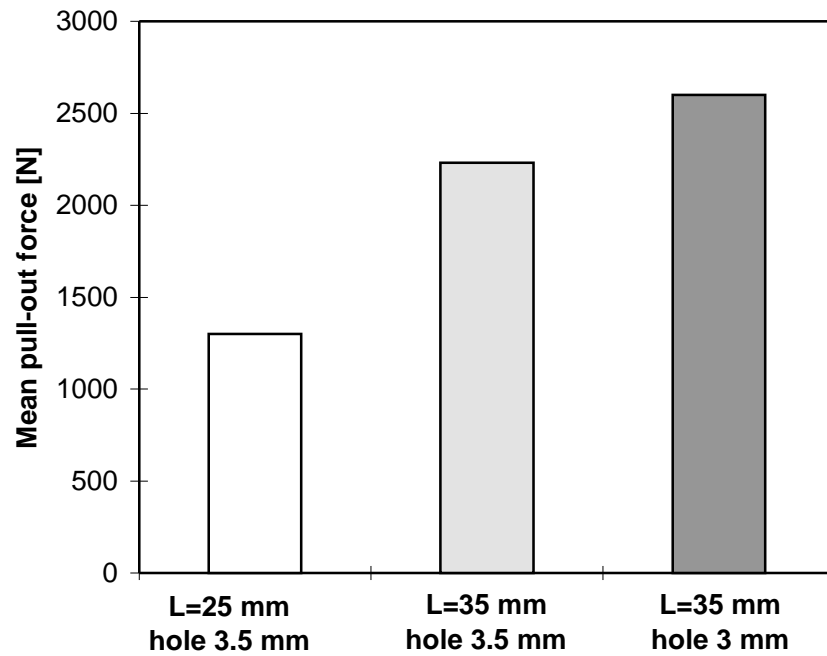


Fig.4: Effect of the length and the diameter of the pre-drilled hole in the foam on the strength of the bolted joints for AlSi12-foam without surface skin (screw $f = 5$ mm, cylindrical specimens).

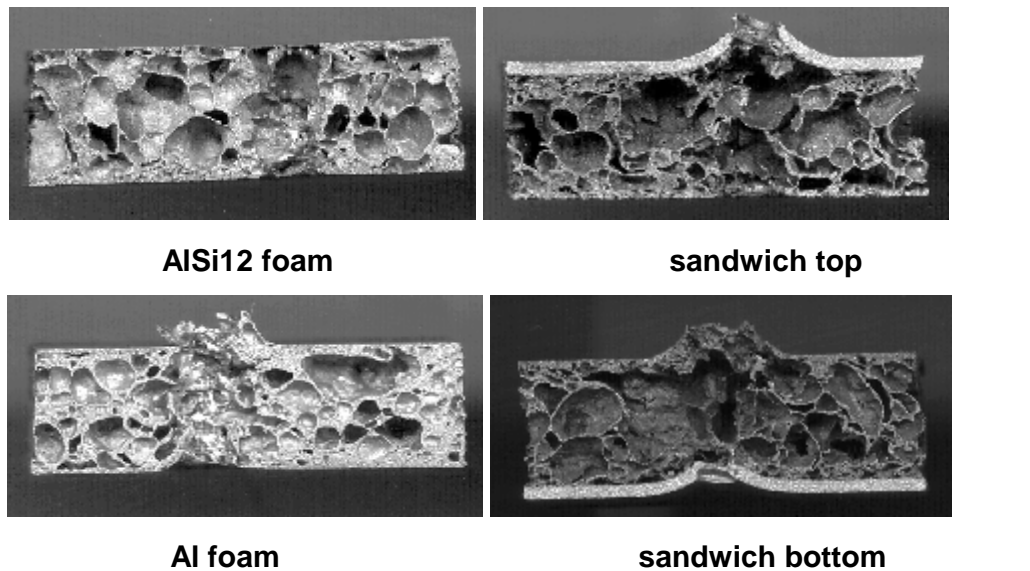


Fig.5: Cross sections of various joints after pull out. (screw: $f = 4$ mm, rectangular specimens $L = 10$ mm, right - direction of applied force)

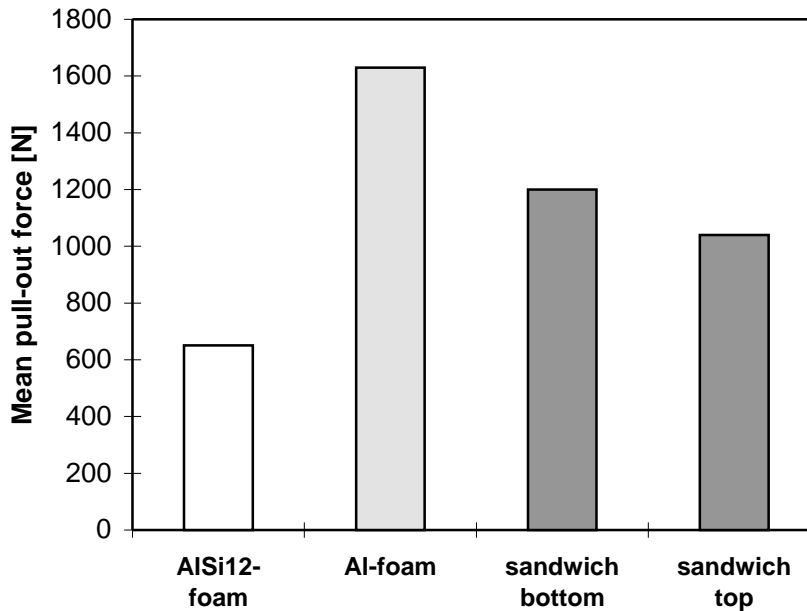


Fig.6: Effect of the cover sheet on the strength of the joints illustrated in Fig 5. (screw: $f = 4$ mm, rectangular specimens $L = 10$ mm)

As can be seen in Fig.3 the strength of the joints is significantly higher if the foam with the surface skin is used. In the case of the foams without surface skin the strength of the joint seems to be affected by the cell-wall material. However the higher strength of the joints made using AISi12-foams is probably due to the finer porous structure of these foams in comparison with Al-based foams (finer porosity provides larger contact area for the screw).

The influence of the diameter and the length of the screw on the strength of the joint is shown in Fig. 3 and 4. Generally the strength increases with the increasing diameter and length due to the larger contact area. This area depends significantly on the pre-drilled hole (see Fig. 4); the smaller is the diameter of the hole, the larger is the contact area. The lower hole diameter is limited by the maximum tightening torque, which depends on the apparent density of the foam. If the hole diameter is too small the cell-walls crushes before the desired depth is attained and the screw slips in the foam. The rupture of the screw has been also observed for higher densities.

The effect of the surface skin on the strength of bolted joint is demonstrated in Fig. 6. If an Al-coversheet with the thickness of 1 mm is diffusion bonded to the AISi12-foam the strength of the joints increases almost twice. The strength is slightly higher when the foam near the coversheet is loaded in compression (see Fig. 5 and 6-sandwich bottom). This is due to the rapid crack growing in AISi12-foam under the tensile stress [9]. In the distinction from AISi12-foams the Al-based foams possess considerably thicker surface skin (see Fig.5). This skin acts similarly as a coversheet in sandwiches. The presence of the surface skin on both sides of the tested foamed specimens was probably (although surprisingly) a reason, why the strength of the joint for the one-side-sandwiches was lower than for the Al-based foams with the surface skin.

3. Soldered Joints

The aluminium foam is always covered by a layer based on alumina or other oxides. This layer must be removed before or during soldering, in order to create a sound metallic joint. The oxide layer can be removed either mechanically by scraping of oxides, or chemically

using soldering flux. The scraping must be performed under the molten solder to prevent the further oxidation. Use of soldering flux is possible only if the surface of the foam is dense. If not, the soldering flux penetrates into the porous structure and can cause the serious corrosion problems. Since the surface of aluminium foam usually contains a lot of cracks, the soldering with the flux can be successfully applied only for sandwiches (see Fig. 7d).

The foams without surface skin can be soldered without flux (see Fig.7), nevertheless the strength of the joint is significantly lower than if the surface skin is utilised (oxides cannot be fully removed mechanically from the opened foam surface).

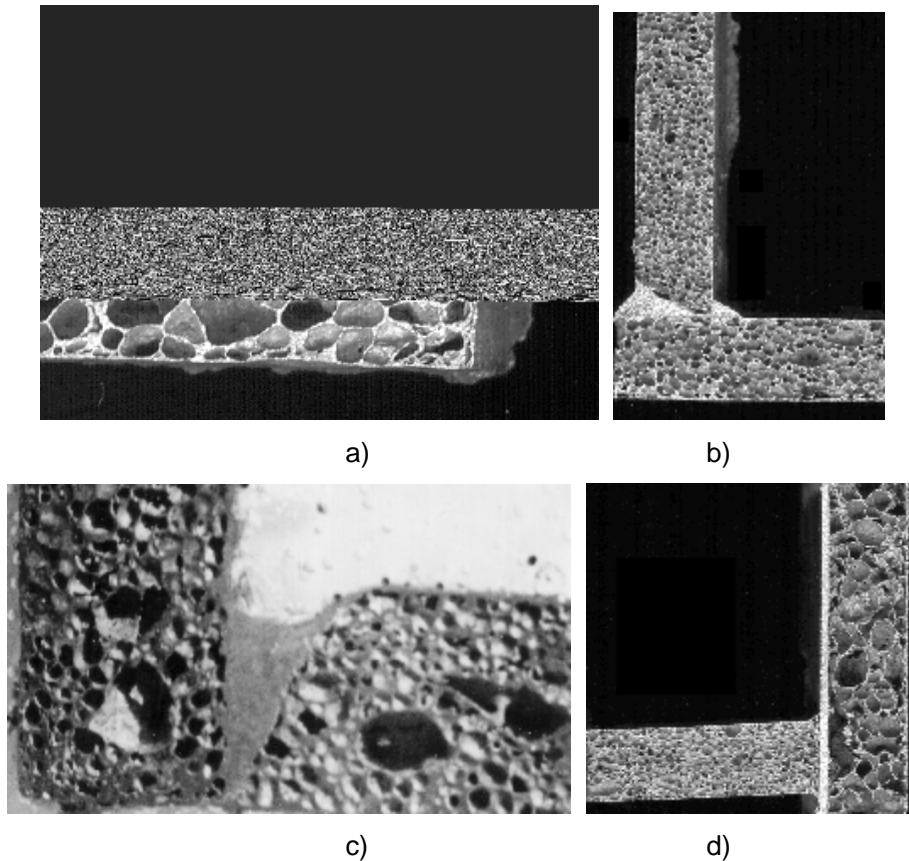


Fig.7: Various types of the soldered joints: a) - c) aluminium foams with and without surface skin, d) AISi12 foam and sandwich soldered using soldering flux.

Various types of solders can be used for soldering of aluminium foams, e.g.:

- Sn90Zn - melting temperature 250°C
- Cd82Zn - melting temperature 300°C
- Sn70Zn - melting temperature 350°C
- Zn90Sn - melting temperature 420°C

The aluminium foam must be preheated to the melting temperature of the used solder before soldering. This can be done either by a heating of the whole foamed sample on the plate heater, or by a local heating using e.g. acetylene torch. If the plate heater is used, the temperature can be controlled more precisely, however the consumption of the time and energy is considerably higher than if the local heating is applied; especially for the large parts. On the other hand the local heating can cause the overheating of the foam and requires relatively quick removing of oxides before the solder solidify.

The strength of the soldered joint was measured on the INSTRON tensile testing machine with the ram speed of $0.1 \text{ m}\cdot\text{min}^{-1}$. Cylindrical AlSi12-foam samples with the diameter 10 mm and the length 200 mm were used. The results are illustrated in Fig. 8. For the comparison also UTS values of the AlSi12 foam are plotted for various densities. As can be seen the strength of the joints is significantly lower than the tensile strength of aluminium foam at the same density, although the fracture always occurred in the foam near the joint (see Fig. 9). It indicates that the zone near the soldered joint is affected by the solder.

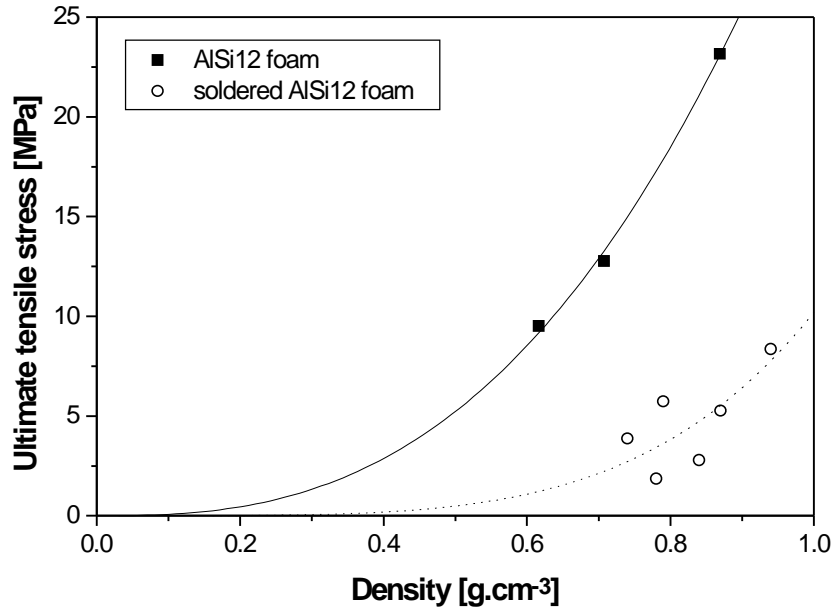


Fig.8: Effect of the density on the strength of the soldered joints. (AlSi12 foam with the surface skin, Sn90Zn solder)

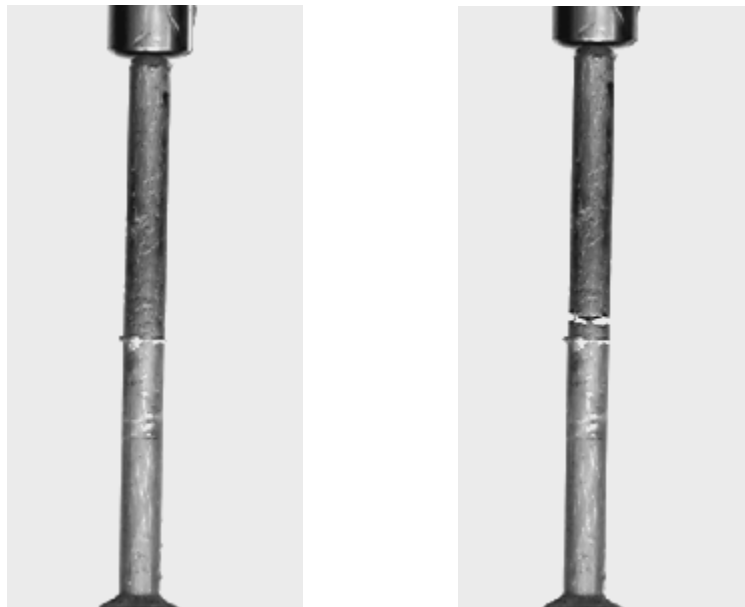


Fig.9: Soldered joint before and after tensile test (AlSi12 foam with the surface skin, Sn90Zn solder)

4. Glued Joints

Aluminium foams can be glued with all types of adhesives used for gluing of aluminium. The joints can be made very simply and in a flexible way. The strength of this type of joints is usually higher than the strength of the foam [7]. However, this joining technique possesses also some disadvantages:

- low thermal stability of the joint
- lower endurance limit due to the ageing of the glue
- mismatch in CTE
- creating of the thermal and electrical isolation barrier

5. Welded Joints

Aluminium foam consists only of the aluminium alloy and of the air pores. Weldability of some aluminium alloys is very good. In the case of aluminium foam, the welding problems occur due to the very low and variable thickness of the surface layer. This obstacle can be partially overcome using controlled heat input into the joint, e.g., by laser-welding (see the work of Bergmann and Burzer in this proceedings [10]), however some limitations, namely the higher costs, should be expected using this technique.

6. Joints Made Using Integral foams

Another possibility for joining of aluminium foam is the use of the integral foams; i.e. the foams containing the parts made from bulk material, which are built into the foamed structure and if possible diffusion bonded to the foam during foaming (Fig. 10). These parts provide the contact counterparts of the foam for a joint. The bulk material can be either locally placed inside the foam (Fig. 11a), or it can create a large portion of the foam's surface (Fig. 11b). Material of built-in element should be compatible with the cell-wall alloy with respect to the corrosion resistance and thermal expansion. Locally distributed elements need precise positioning and suitable fastening to avoid the displacement due to the foam motion during foaming. This difficulty can be overcome using various bulk covers with a thickness which is sufficient to create a contact area for the joint (see Fig. 11b). In this case, of course, the overall weight of the foamed part is higher than if locally distributed elements are used.

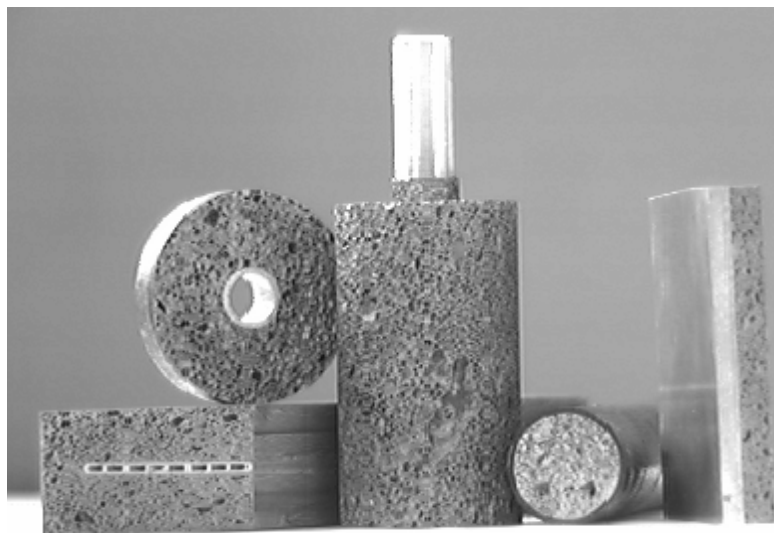


Fig.10: Various integral foams.

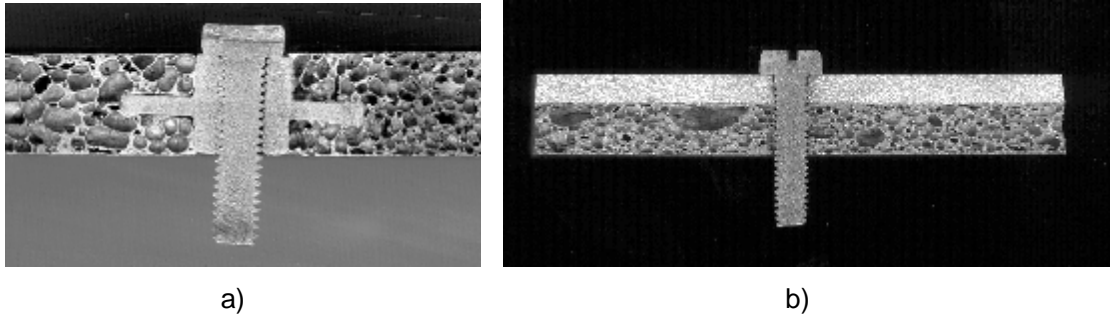


Fig.11: Joints made using bulk aluminium parts diffusion bonded to the AISi12 foam as: a) locally placed element, b) 3 mm thick Al - coversheet

7. Conclusions

Aluminium foam can be jointed using the wood screws with acceptable strength of the joint. This method is simple, quick, flexible and cost effective. Additionally, the joint is detachable. The strength of the joint depends primarily on the density and pore size of the foam and can be significantly increased if the foam with the surface skin is utilised.

Soldering offers the flexible method for joining of aluminium foams with surface skin. However it often requires a qualified manual work and is cost intensive. Moreover, the solders can cause future corrosion problems. Therefore the soldering of aluminium foams can be recommended only for joints designed for special purposes, e.g. for higher temperature applications.

Glued joints are practically limited only by the temperature resistance of the used adhesive. Because of the simplicity and flexibility, they can be recommended for preparation of permanent joints.

Welded joints are very promising, however the techniques need further development and the costs are still relatively high for practical application.

The bulk material elements locally built-in the foamed structure can be used for joining purposes if the position of joint is known before foaming. They need precise positioning and fastening which makes the foaming procedure more expensive. The use of various coversheets which are diffusion bonded to the foam during foaming can eliminate the higher costs and lower flexibility of the built-in elements, on the other hand the higher overall weight of foamed part must be taken into account.

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