

Production technology for aluminium foam/steel sandwiches

J. Baumeister,

Fraunhofer-Institute for Manufacturing and Applied Materials Research, Bremen

Abstract

3-dimensional shaped sandwich panels with a very high stiffness can be produced in an elegant way by combining steel face sheets with an aluminium foam core.

For this, a mixture of aluminium powder and a foaming agent is compressed to a semi-finished product of nearly vanishing porosity by extrusion, powder rolling or hot isostatic pressing. The resulting foamable semi-finished aluminium material is roll-clad with sheets of conventional steel. As a result a precursor material is obtained consisting of two face sheets which are metallurgically bonded to the foamable core layer. This sandwich precursor material can be shaped into a 3-dimensional part by conventional techniques, e.g. by stamping or deep drawing. In a final step the foamable precursor material is heated up to the melting point of the core layer thus initiating its expansion into the desired 3-dimensional shaped sandwich structure. The porosity of the foamed core layer is in the range from 80 to 90% so that the integral density of the sandwich structure can be as low as $0,7 \text{ g/cm}^3$.

The sandwich materials combine the low weight and high bending stiffness with the advantages of the face sheets, i.e. the high strength and weldability.

The manufacturing process will be described in detail and the determination of properties will be discussed.

1. Introduction

A symmetric, double-sided sandwich construction usually consists of two components, the thin face sheets with a high density and the extremely lightweight thick core layer. While the facings have to resist most of the edgewise load and the bending moments, the core component is used to separate and stabilise the face sheets as well as to transmit the shear forces. The new sandwich material described here consists of a lightweight aluminium foam core and steel face sheets as facings.

2. Production of steel sandwich with aluminium foam core

There are several possible ways to obtain sandwich materials of this kind. Investigations have been carried out regarding mostly two fabrication processes: roll plating and adhesive bonding.

The first way is based on a powder metallurgy process developed by the Fraunhofer Institute for Manufacturing and Applied Materials Research, Bremen [1], and shown in Fig. 1. Aluminium alloy powders are mixed with a foaming agent using conventional mixers. This powder blend is compacted to form a dense non-porous, but foamable solid aluminium product.

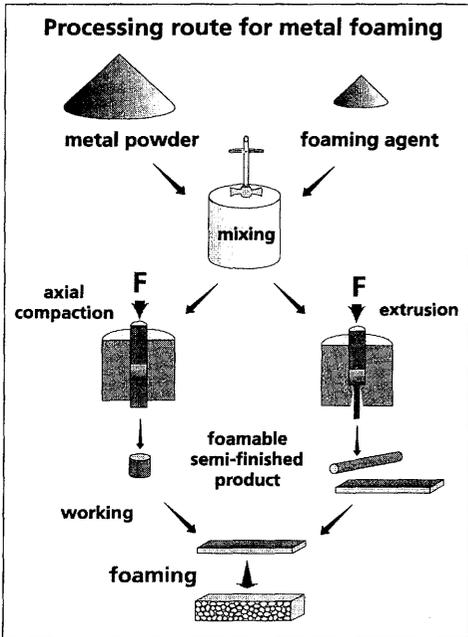


Fig. 1: Production of metal foams (powder metallurgical IFAM-Process) [1]

After this, the foamable aluminium is joined with aluminium-plated steel face sheets by rolling as presented in the schematic process diagram in Fig. 2. This rolling can be done as cold or warm rolling, requiring different necessary equipment, deformations and surface treatments [2]. Optionally, the composite obtained can be shaped into a 3-dimensional part by conventional techniques, e.g. by stamping or deep drawing. In a final step the foamable precursor material is heated up to the melting point of the core layer thus initiating its expansion into the desired 3-dimensional shaped sandwich structure. The porosity of the foamed core layer is in the range from 80 to 90% so that the integral density of the sandwich structure can be as low as 0,7 g/cm³.

It could be shown that the foaming of sandwich materials can be done in a continuous belt furnace, which allows for the production of larger quantities of material.

The basic principle of the continuous belt furnace used shown in Fig. 3. The three heating zones of this furnace can be operated and controlled individually so that the necessary temperature profiles for the foaming step can be obtained.

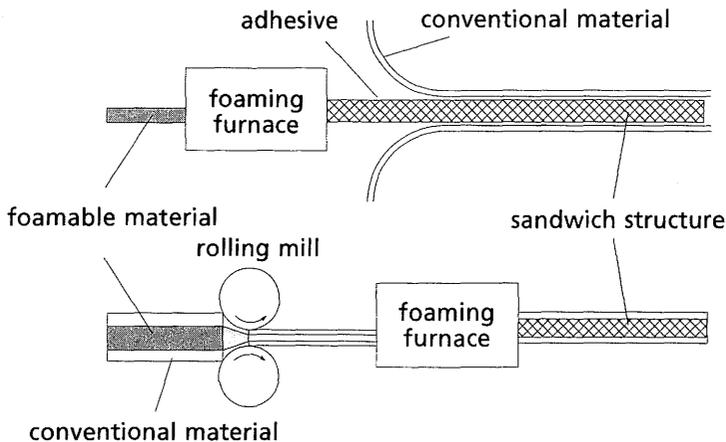


Fig. 2: Schematic processes for of the production of steel sandwich with aluminium foam core

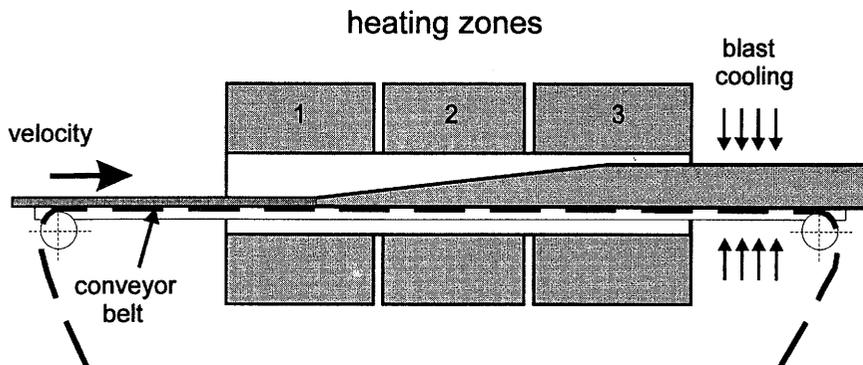


Fig. 3: Schematic principle of the continuous belt furnace for foaming of the core layer

The other production route shown in the upper part of Fig. 2 is based on the use of high viscosity epoxy resins to get an adhesion between the foam core and the steel face sheets. Using this method the foam core can consist of an aluminium foam produced by melt foaming (mf) processes [3] or also of powder metallurgical (pm) foam. To improve the strength of the adhesion between face sheets and core, a surface treatment by grinding and a warm-hardening treatment for the epoxy resin should be carried out.

3. Testing of steel sandwich with aluminium foam core

The behaviour of sandwich test pieces under compressive, bending and shear loads is examined using special materials testing methods that are described in German standards (DIN) or the similar ASTM-standards. Fig. 4 shows schematically the test set-ups and the typical resulting load-deformation diagrams obtained from the respective test procedures [4].

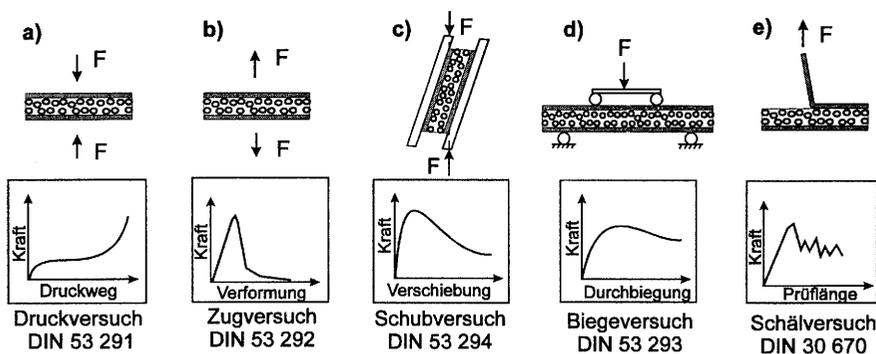


Fig. 4: Schematic test set-ups and load-deformation curves for sandwich testing.
 a) compression test, b) tensile test, c) shear test, d) bending test, e) peeling test

3.1 Compression test

The compression test (DIN 53291/ASTM C365) is carried out with a compressive load applied vertical to the face sheets (Fig. 4a). The load-deformation or stress-strain curves show the typical course for cellular solids with three stages of deformation. Following an almost linear-elastic behaviour at low strains the curve shows a long plateau with almost constant load and increasing plastic deformation due crushing of cell walls. The third stage is marked by densification of the foam with sharply rising loads. The compressive strength can be determined and information can be obtained about the energy absorption capacity of the foam by measuring the area below the curve at the end of the second stage.

Fig. 5 shows four stress-strain curves of aluminium foam cores with different densities. It is obvious that higher densities of the core material result in a higher compressive strength. It can also be seen that a good shape of the plateau regime only is obtained with the lower density foams.

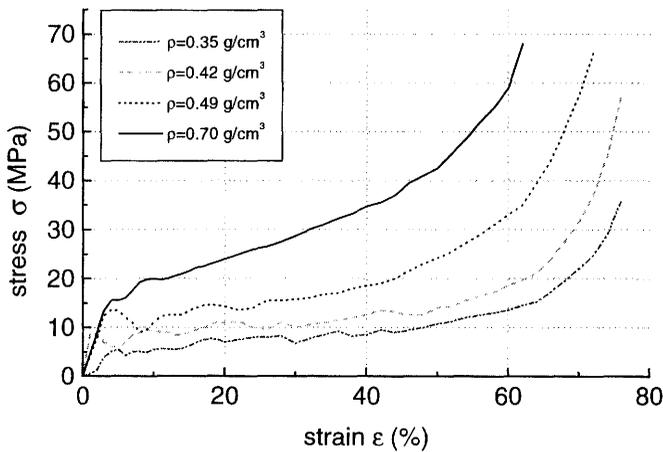


Fig. 5: Compressive behaviour of the aluminium foam used as a core material for steel sandwiches, different foam core densities (powder metallurgy route) [5]

3.2 Tensile test

With this method (DIN 53292/ASTM C297) small specimens of the sandwich material are tested under a tensile load at a constant rate of motion as schematically shown in Fig. 4b. In a first stage the load-deformation curve indicates a linear-elastic deformation behaviour. After plastic deformation a crack starts at the maximal load, propagating through the foam core. After this, the load decreases very quickly. This allows for the determination of tensile strength and demonstrates that deformations are quite small and energy absorptions very low in tension even for ductile alloys.

3.3 Shear test

The determination of the shear properties of a sandwich core is of special interest because the lightweight core has to transmit the shear loads. The shear test (DIN 53294/ASTM C273) is

demonstrated in Fig. 4c. A compressive load is introduced so that the specimen is subjected to a shear load. The specimen is glued to two load-introducing steel plates. The deformation in the specimen is measured as the postponement of these plates against each other. The resulting load-postponement curve demonstrates an almost linear-elastic start that passes into plastic deformation. The maximum defines the failure of the test specimen visible as a crack cutting the whole foam core. After this maximum the load decreases fast. The maximum determines the shear strength of the foam core.

Fig. 6 shows the fields of shear strength found testing four different aluminium foam alloys with a homogeneous pore structure. As expected regarding the mechanical properties of the dense materials the shear strength of the AlSi12 (pm) is lower than that of AlMgSi (pm) over the tested density range. The hardenable AlCu4-foam (pm) shows a high shear strength up to 10 MPa in accordance to the high strength of the base alloy. The melt foamed aluminium has a shear strength between that of the AlSi12 and AlMgSi alloys (both pm).

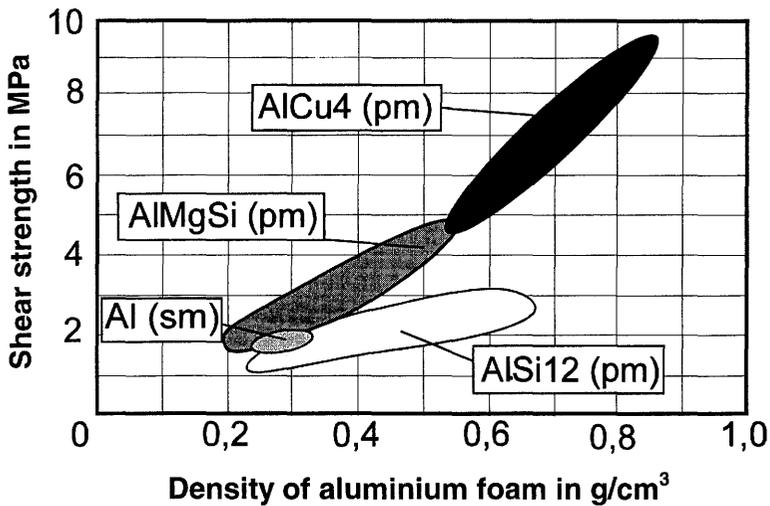


Fig. 6: Shear strength of various Al-foam core alloys (pm: powder metallurgical (Foaminal[®]), sm: melt foaming (Alporas[®]))

3.4 Four-point-bending test

The bending test (DIN 53293/ASTM C393) characterises the sandwich material with a symmetrical load near to reality including compression, bending and shear forces. The load-deformation curve in Fig. 4d shows the typical response to this load. After a linear-elastic start the deformation becomes plastic with increasing load until a maximum is reached. This point marks the failure of the sandwich specimen, visible in symmetric cracks diagonally arranged in the foam core between the load points. The slowly decreasing load emphasises the high tolerance against total failure of this sandwich construction. The bending test gives information about the bending moments, the loads in the face sheets as well as the shear strength in the foam core during failure. This test indicates a very small tendency towards a failure by buckling of the face sheets or by cracks between the sandwich partners stressing the sufficient adhesion.

3.5 Peeling test

The peeling test (DIN 30670) shown in Fig. 4e is not a special one for sandwich testing. But as it is an easy way to get information about the delamination behaviour in general, it is used on this new type of sandwich. A part of one facing is torn away applying a load perpendicular to the specimen. The delamination process is shown in the load-length of specimen curve in Fig 4e. The necessary load to start the delamination process is usually much higher than during the rest of the process. The applied load related to the width of the specimen is interpreted as the resistance of the adhesion against delamination.

4. Conclusions

Using the test procedures presented, the characteristics relevant for structural applications of the new sandwich material can be described. Regarding applications under the usual loads as compression, bending and shear, the sandwich material combines structural characteristics like a high stiffness, satisfying mechanical properties and a low density with functional properties of the foam core.

References:

- [1] Baumeister, J.: *Verfahren zur Herstellung poröser Metallkörper*, German Patent DE 4018360 C1 (1991).
- [2] Baumeister, J., v. Hagen, H., Hatzfeld D., Paschen, M., Weber, M.: *Werkstoffprüfung an neuartigen Sandwich-Verbundwerkstoffen aus Stahldeckblechen mit Aluminiumschaumkern*, Proceedings 11. Aachener Stahlkolloquium, 20.-21.6.1996, Aachen, p. 169/176.
- [3] Akiyama, S. et al., *Foamed metals and method of producing same*, European Patent EP 0210803 B1 (1989).
- [4] H. von Hagen, D. Nicklas, W. Bleck: *Production and testing of steel sandwich with aluminium foam core*, Euromat '97, 21.-23.4.1997, Maastricht, The Netherlands, Proceedings Vol. 1 (Metals and Composites), p. 415/418.
- [5] J. Banhart, J. Baumeister: *Deformation characteristics of Metal Foams*, J. Mat. Sci. **33**, 1431 (1998)