Aluminium Foam Sandwich Panels: Manufacture, Metallurgy and Applications

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Sandwich panels consisting of a highly porous aluminium foam core and aluminium alloy face sheets are manufactured by roll-bonding aluminium alloy sheets to a densified mixture of metal powders – usually Al-Si or Al-Si-Cu alloys with 6-8% Si and 3-10% Cu – and titanium hydride, and foaming the resulting three-layer structure by a thermal treatment. We review the various processing steps of aluminium foam sandwich (AFS) and the metallurgical processes during foaming, compare the process to alternative ways to manufacture AFS, e.g. by adhesive bonding, and give an overview of the available literature. Two ways to treat AFS after foaming are presented, namely forging and age-hardening. Some current and potential applications are described and the market potential of AFS is assessed.

INTRODUCTION

Metal foam can be produced in a variety of shapes ranging from simple flat products to almost arbitrarily shaped components. Currently available processing technologies either generate metal foam from a liquid alloy containing special additives or involve baking an originally solid precursor containing a blowing agent which triggers foaming when the precursor starts melting [1][2]. Depending on the manufacturing process used, metal foam parts may exhibit closed outer skins when they have been expanded inside a mould or – in cases the foams have to been cut to size – show partially open pores. The natural skins delimiting the foamed components play an important role. They can increase compression strengths significantly [3] and also protect the highly porous foam. In many cases, however, they may still be too thin to effectively seal the foam or to provide enough mechanical stability. A proper sandwich design based on dense face sheets can optimise compressional, tensional, torsional or flexural properties much more efficiently [4],[5]. In this paper, we shall discuss '**A**luminium **F**oam **S**andwich (AFS)', a composite comprising an aluminium (alloy) foam core and two dense metallic face sheets firmly attached to the core.

The benefit of using foams instead of dense materials becomes clear from Figure 1. We consider stiffness, which is a measure for elastic deformation caused by an applied load in a given geometrical situation. An ordinary dense aluminium sheet has a stiffness S, that is given by its thickness d and its Young's modulus E, and $S \propto E \times d^3$. During foaming, such a dense sheet is expanded in height by a factor η to a height ηd. Foaming will hardly change its mass but (effective) Young's modulus will go down to $1/\eta^2$, since approximately $E \propto d^{-2}$, according to experience [4]. Therefore, S is approximately proportional to the expansion factor η and, as a consequence, the stiffness-to-mass ratio of a foam is also η times higher than that of the

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corresponding dense material. This is one of the reasons why foams are good materials for lightweight construction. This oversimplified comparison, however, is misleading since using simple sheets is the worst thing one can do to optimise stiffness. An optimisation of the mass distribution of a plane sheet of constant mass will rather lead to structures such as honeycomb structures, stringer-stiffened plates or the waffle plate shown in Figure 1 that has a much higher stiffness than the sheet. On the other hand, the bare foam can also be improved by combining it with face sheets and a more meaningful comparison is between optimised structures such as the waffle plate on the one hand and the foam core sandwich panel on the other. This time the regular engineered structure on the left is stiffer than the irregular foam on the right [4]. This does not come as a surprise: regular structures contain material aligned exactly in the directions in which the applied loads occur, whereas foams are statistical structures containing "dead material" not contributing to mechanical performance. Although foams obviously not have a peak performance in a single selected load situation they may perform better in an average sense. A honeycomb structure, e.g., will perform very well in bending but fail quickly in certain shear situations, whereas the foam will show acceptable performance in all situations.

In practice, materials selection is not exclusively guided by stiffness arguments. Other aspects are also important such as,

1. ability to produce **3D shapes**: AFS can be manufactured in complex geometries,
2. **costs**: AFS costs are moderate,
3. **damage tolerance**: AFS can be damaged without immediate loss of performance,
4. **failure behaviour**: usually benign, not catastrophic failure,
5. available **joining** technologies: e.g. welding technologies are available,
6. **damping** behaviour: very good especially when adhesives are involved,
7. … other properties: AFS can be non-inflammable when produced without adhesives

Considering all these aspects real applications for AFS have been found. Automotive industry first picked up the technology when the German car maker Karmann presented a concept car based on AFS in 1996 [6]. At present more applications are emerging, see section on applications.

TECHNOLOGIES

Various technologies have been proposed for making sandwich panels combining aluminium foam and metallic sheets, see Figure 2. The most obvious approach is to start from a sheet of metal foam and to bond face sheets to it, e.g. by adhesive bonding, brazing or diffusion bonding, Figure 2a. We shall call this *ex-situ bonding*. A foam panel – either sliced off a larger block or foamed as a flat product in a mould – is bonded to two dense sheets. The properties of the resulting sandwich panel are then given by the interplay of foam, sheet and adhesive and, depending on the parameters chosen, a variety of properties and failure modes are observed [4]. Table 1 provides an overview of the literature in which the manufacture or the properties of such ex-situ bonded sandwich panels are described. The table also includes alternative approaches such as using a multitude of small 'APM' aluminium foam spheres instead of a foam sheet to assemble a sandwich panel.

While the adhesive can add valuable properties – e.g. a high damping capacity – usually the problems associated with the glue – reduced stiffness, high costs, difficult recycling, additional mass – provide a motivation for alternative types of bonding. One way is to combine metal foam manufacture with bonding, i.e. to create the bonding in-situ. As metal foams are liquid when they are made, this involves high-temperature processing steps.

One way, Figure 2c, to manufacture AFS was developed at the Fraunhofer-Institute in 1992 [34]. A three-layer composite comprising a foamable(containing TiH_2 as a blowing agent) aluminium alloy sheet as a core layer and two face sheets on both sides (usually aluminium alloy, but steel and titanium have also been used) is made by extrusion or powder rolling and various subsequent rolling operations, after which the core layer of the panel is expanded by heating to the foaming temperature. The core expands, while the face sheets remain both solid and firmly bonded to the foam during this step. The advantages of this process are obvious: a pure metallic bonding is maintained that is less heat sensitive than an adhesive and can be used to manufacture heat resistant non-inflammable structures. In addition, recycling of such AFS should be easier than recycling of polymer-bonded sandwich panels. By shaping the three-layer precursor prior to foaming, a 3D shape can be produced, see Figure 3, which is hardly possible by ex-situ bonding techniques. Disadvantages include that the number alloy combinations is restricted as will be explained in the next section and that high-temperature tooling is required.

Since preparing a three-layer composite is an additional process step one is temped to try making AFS by merely expanding a piece of foamable precursor between two face sheets kept at distance Figure 2b. This procedure, however, leads to difficulties since the oxide layers on both the face sheets and the foam make a true metallic bonding difficult. Moreover, temperature control is more difficult in this case since heat has to be introduced into the foam through the face sheets and the danger of melting these is high in case of aluminium face sheets. Therefore, this technology is still in an experimental stage.

Yet another strategy to manufacture AFS is to manipulate the foaming process in a way that a dense skin is created during foaming without using any dense sheets, Figure 2d. By expanding the precursors used for the processes described above under special conditions can lead to the metal equivalent of a structural foam in polymer foam technology, i.e. a foamed core with a thick, nearly dense skin which originates from the material used for foaming (see Fig. 1 of Ref. [35]). Recently a new technology has been developed which allows for making structural aluminium or magnesium alloy foam parts in a die casting machine by injecting liquid alloy and blowing agent into the die and applying an appropriate pressure profile [36]. In this way flat panels can be produced with a near-dense outer skin.

Table 2 provides an overview of some of the literature describing AFS sandwich panels manufactured by in-situ bonding.

Finally, there have been approaches to get around the use of face sheets by replacing them by wire meshes [62]. The idea is that such meshes perform well in tensile loading situations and the use of sheets is not mandatory in these cases. At present the performance of AFS and such reinforced foams has not been compared systematically.

PROCESS FOR MAKING AFS BY IN-SITU BONDING

Face sheet and foam core have to be made of alloys with different melting points since foaming takes place in the semi-solid or even liquid state. At these temperatures the face sheet must not melt. In early foaming practice furnaces were heated to temperatures well above the melting point of the foamable material (e.g. 750°C) to ensure a rapid temperature increase in the AFS precursor material after it had been placed inside the furnace. The corresponding temperature course is shown in Figure 4a. As face sheets and foamable core are in close contact and the heat conductivity of the two alloys is high, temperature is approximately the same throughout the material. The material with the lower melting temperature (the foam) therefore limits the increase in temperature during melting and therefore effectively cools the face sheets as long as it is still semi-solid. After complete melting of the foam, temperature rises rapidly and the face sheets will also melt unless the sample is taken out of the furnace for cooling [46].

The solidification temperature T_S of the face sheets therefore has to be above the liquidification temperature T_L of the foam. This restricts the number of usable aluminium alloy combinations. Early choices of materials were pure aluminium or 3003 alloy (AlMn1) for the face sheets and near-eutectic Al-Si alloys for the foam, see Table 3, first two entries. No problems with melting are encountered when using steel or titanium face sheets, but in theses cases intermetallic compounds can be formed with the possible danger of embrittlement [57].

The situation is more favourable when the heating process is actively controlled as it is in modern industrial practice. Here, the foamable material is heated up to an end temperature as quick as possible, after which the temperature is kept approximately constant. This offers the possibility to create the foam just above the solidification temperature of the foam and chose face sheets from alloys which melt just above this temperature, see Figure 4b.

In this way a wider range of alloy combinations can be processed. Three groups of aluminium alloy face sheets are currently being used:
- Non heat treatable 3000 alloys, mainly 3103 (AlMn1)
- Non heat treatable 5000 alloys: 5005 (AlMg1), 5754 (AlMg3) or 5083 (AlMg4.5),
- Heat treatable 6000 alloys: 6016, 6060 or 6082 (Al-Mg-Si system)

For the foam core, two groups of alloys based on the Al-Si system have been developed and tested. Currently, the alloy AlSi6Cux (x $\approx$ 3…7) is preferred for its low solidification temperature and very good foaming behaviour [3].

In all cases the foamable core contains TiH_2 in the usual contents, see e.g. Ref. [43], acting as a blowing agent. Blowing agents are pre-treated to tailor the temperature of gas release according to the principles outlined in Ref. [63]. Foaming larger panels is a real challenge since a uniform temperature profile has to be maintained over an area of up to 3 m^2. Spatial temperature heterogeneities can lead to cleavage, foam collapse or cell damage during foaming.

PRODUCTION

A small-scale production plant for AFS has been set up by the company '*alm*' [64] in Saarbrücken (Germany) in co-operation with the Austrian company '*Alulight International*' [65]. The starting powders are supplied by powder manufacturers and are processed at '*alm*'. Processing includes drying of the metals powders and pre-treatment of the hydrides in order to improve both pressing behaviour and decomposition characteristics. The powders are then densified to a three-layer composite and are first hot-rolled, then cold-rolled to the appropriate dimensions by companies specialised on rolling such complex products. It is worth noting that establishing a processing route for making large three-layer composites with good and reproducible foaming characteristics took from 2003-2005. Figure 5a shows foamable three-layer precursor sheets (2×1 m^2), Figure 5b corresponding foamed AFS plates ready for shipping.

Various alloy combinations of face sheet and foamable core layer have been developed in the past.

Table 3 lists these alloys together with designations used by 'alm'. 'IFAM' designations refer to historical combinations first used at the Fraunhofer-Institute.

In terms of product sizes the following restrictions apply. The total area is limited by the size of the discontinuous foaming furnace, currently 2500×1200 mm^2. This is more a practical than a physical limit, since heating up large panels with good temperature control gets increasingly difficult with increasing panel dimensions. AFS thicknesses range up to 130 mm, but usually are below 80 mm. Face sheet thicknesses vary between 0.6 to 10 mm, thinner sheets representing the more serious technological problem. This implies that the foam core is 8 to 80 mm thick at a density between 0.22 and 0.4 g/cm^3. Figure 5c illustrates the range of achievable thicknesses.

The maximum throughput of the existing foaming furnace is 10 panels per hour. The total output of the small-scale factory is 50 tonnes of AFS per year. Upscaling is possible, most obviously by using various batch foaming furnaces in parallel, but possibly also by making use of continuous foaming furnaces instead of batch foaming furnaces. Corresponding investigations are being carried out.

Naturally, the costs of a new product are difficult to determine and largely depend on the conditions under which a batch of parts is produced. Universities are offered to buy standard flat AFS material for test purposes for 30€/kg in small quantities. Probably the price of AFS produced in large quantities will lie around ½ this value or even lower. This means, that AFS is not a cheap product but rather a material which is worth being applied in performance-dominated and not in cost-driven markets as we will see from the application examples.

POST-PROCESSING OF FOAMED AFS PANELS

Foaming of the three-layer composites leads to flat AFS panels unless the panels have been shaped prior to foaming. Due to differences in temperature and heterogeneities of the starting material, panel thickness is usually not uniform and the AFS panels have to be calibrated. Two further processing steps are worth mentioning here since they provide unique opportunities: forging and age-hardening of AFS. In addition, joining techniques play a central role in the processing chain of AFS.

Forging of AFS

Although AFS technology allows one to manufacture 3D-shaped sandwich panels, these have nearly constant cross sections and open edges. Forging provides a unique opportunity to manufacture more complex shaped parts which are closed on the outer side while maintaining a porous core. For this, AFS panels are cut to a suitable size and are forged in a die that closes the edges while only moderately deforming the remaining parts. Figure 6 displays schematically the individual process steps. A possible result of such a forging process is presented in Figure 7a.

Although one might expect that forging largely destroys the foam structure, the image obtained by X-ray tomography proves that this is not the case, see Figure 7b. Although the cells have been visibly deformed – discernible by many buckled cell walls – the porous core still exhibits large and separated cells. Figure 7c demonstrates the benefit of the method, the very good densification at the margins of the part which seals off the foam core and facilitates fixture of the component in engineering systems. The properties of such forged components are under evaluation.

Age hardening of AFS

Whenever AFS contains heat treatable alloys, age hardening can be considered. Age hardening of aluminium alloy foam has been studied [66] but is difficult to carry out in the AFS process chain. Firstly, the alloys used for the foam core are selected for good foaming characteristics and might not be susceptible for age hardening. Secondly, quenching the foam core with rates high enough to create the supersaturated solid solution required is difficult due to the low thermal conductivity of the foam and the presence of rather thick face sheets with a high thermal inertia.

Age hardening of the face sheets is simpler as some of the alloys employed are age hardenable. Still, it is a challenge to carry out such a treatment for various reasons: (i) the quench rates are restricted by the limitation to single side quenching and the presence of a heat reservoir – the hot foam – on one of the sides, (ii) water quenching leads to water intrusion into the foam and warping of the AFS. For this reason, air quenching must be chosen. Figure 8a shows the temperature history of a combined foaming/ageing process. As a consequence of the problems mentioned, ageing of the face sheets to T6 is in general not possible as it requires fast forced cooling.

In order to exploit at least partially the advantages of age hardening, a facilitated treatment – called 'T5' – of the 6XXX face sheets of an AFS has been studied which comprises natural or slightly accelerated cooling after foaming at moderate rates, followed by an artificial ageing step [55]. 'T5' was shown to yield a hardness value between the value of the 'as foamed' states and the full T6 hardness obtained in reference experiments in which the face sheets were water quenched and age hardened, see Figure 8b.

Joining of AFS

A variety of different welding techniques for joining AFS has been studied [40] but there is no sufficient space her for a review. Laser welding, TIG/MIG welding, pin/bolt welding were shown to be suitable techniques to joint two AFS panels with each other or an AFS panel with a piece of dense material or a fastening element. This is important since light-weight construction based on AFS largely depends on efficient joining techniques as will be seen in the next section.

APPLICATIONS

Telescope lifting system

Teupen (Gronau, Germany) has developed a novel concept for the support structure of a telescope arm lifting a working platform [67]. The goal was to increase the current working height of 20 m to 25 m, the horizontal outreach to 11 m, while keeping the total vehicle weight below 3500 kg, a vehicle category for which European drivers merely need the 'Euro B' driver's licence instead of a higher class, which is an advantage for the company operating the vehicle. The support structure consists of six flat C-type AFS panels (see Table 3) cut into shape and a number of aluminium alloy 6060 and 6082 sheets that are joined to the AFS by MIG and TIG welding. The rim of the AFS is efficiently sealed by these sheets and the foam core therefore invisible. An insert for the rotation axis is glued into a drilled hole. The structure, see Figure 9, is almost 2.5 m high and has been tested under multi-axial cyclic loads (100 kN vertical, 14 kN horizontal). The test item survived 100,000 cycles and therefore surpassed the requirement of 40,000 cycles without failure. The structure weighs 110 kg, 50% less than the conventional steel counterpart. 60 to 100 pieces are manufactured per year by 'alm' and Teupen.

Alimex plates

The German company Alimex (Willich, Germany) [68] has added an AFS sandwich panel to its product line of high-precision and high-stiffness aluminium plates (both cast and rolled). A typical panel is 2000×1000 mm^2 large, has 6 mm thick 5754 face sheets and a 30 to 60 mm thick, 0.4 g/cm^3-density aluminium alloy foam core. The AFS plates are more than 50% lighter than their corresponding dense counterparts and merely 8% less stiff. Costs are higher but the spectrum of properties, including good weldability of the 6 mm thick face sheets, inflammability, insulation properties etc., make these plates good candidates for a range of applications, e.g. in metrology and machine engineering (platforms for milling machines, tooling).

Ariane 5 rocket adaptor prototype

The European 'Ariane 5' rocket uses two cone-shaped adaptors which support the payload. At present they are made of aluminium honeycomb and have to be processed under high costs. The objective of replacing these cones by a cheaper and easier to handle AFS-based version was met by welding together 12 curved AFS (1.3 mm alloy 6060 face sheets, AlSi6Cu6 foam core, i.e. C-type) segments by manual TIG welding [56]. The resulting cone, see Figure 10, is almost 4 m wide at the base and weighs 180 kg. In tests with up to 100 kN load both in the normal and the shear plane the prototype showed sufficient strength but a stiffness which was still 10% too low. The next prototype will be built with higher stiffness to meet the final requirements. Interestingly, this development was motivated by the cost reduction potential by using AFS.

Bicycle crank arm prototype

AFS forging has found a first prototypical application with a crank arm for racing bicycles. Conventional parts are made of forged 6082 alloys. The lightest parts on the market weigh slightly more than 300 g. The forged AFS replacement of the crank arm – see Figure 7 – weighs 222 g, i.e. 30% less. This is a big achievement since the lightest products on the market currently differ by some tens of grams only. As AFS forging technology is cost effective and the design can still be further improved, a potential high volume market can be anticipated.

Cookware

Cookware is an attractive potential mass market for advanced materials. Consequently, application of aluminium foams and AFS has often been discussed in the past. One such potential application [69] is described in Figure 11. In a saucepan or a frying pan heat is added from the bottom in a very localised way, e.g. by a flame. Successful cooking often requires an extended area over which the temperature is constant. The incoming heat therefore has to distributed and the corresponding temperature field equalised. If the base plate is made of AFS, the lower face sheet will transport heat in the transverse direction very quickly due to the high thermal conductivity of the dense aluminium alloy. Transport through the foam layer will be much slower since the thermal conductivity of foam is of the order 20 times lower than that of the dense material. The upper face sheet will again equalise the heat distribution. Practical tests indeed show that the boiling of water is much more uniform in an AFS than in a steel pan.

MARKET SITUATION

In the early days of the search for metal foam applications, i.e. from year 1991 to 1996, the main market for aluminium foam products was seen in the automotive sector. This industry

was very active and initiated many research projects in these years. In the meantime, however, only few applications of aluminium foam – non of them AFS – have materialised in this mass market, see Ref. [70], and cost issues are still very dominant, making production of aluminium foam a difficult business. In view of more recent developments, other industrial sectors promise to be more profitable especially as far as AFS is concerned. Currently, three applications fields derived from the application examples presented above appear promising:

- **Light sandwich structures**: These aim at weight-optimisation, are more cost tolerant and thought to be found mainly in trucks and trains,

- **Replacement for high precision plates**: here, the number of parts is small but the mass of the individual part is large. One thousand tonnes/yr. in 2010 could be a realistic production volume,

- **Small forged components**: this would be a high volume market and 100,000s of parts seem possible, each weighing less than ½ kg. The market for sport articles and tooling appears most promising, while the automotive market is still seen sceptically. The parts would replace classical small (i.e. < 400 mm) forged parts.

SUMMARY AND OUTLOOK

AFS technology allows one to manufacture both flat and curved aluminium foam core sandwich panels and to shape them to more complex closed components by forging. Improved foaming technology has widened the range of accessible alloys for both the skins and the core. Heat treatment to T5 improves the strength of 6XXX alloy face sheets without the need for quenching after foaming. The number of serial applications is still small but promising prototypes have been developed recently.

The availability of AFS through various companies [64][65][71] will facilitate the development of further applications as a commercial product called 'AFS' is now available. Upscaling of technology is on the way and currently manufacturing technology is being developed with the prime objective to reduce costs by making processing routes shorter and to ensure a more constant product quality.

Despite this success, there is still need for more fundamental research. Research on the foaming process is necessary to understand the interrelationship between alloy composition and foamability. Improvement of the blowing agent by heat treatment, coating or other means is important to fine-tune gas decomposition in the expanding melt. Development of improved alloys for the foam core can contribute to success, as demonstrated by recent efforts to replace copper in the core alloys by the less expensive, less corrosive and cheaper magnesium [72]. Finally, the product 'AFS' has to be characterised more thoroughly since important mechanical properties are still not sufficiently known.

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FIGURES
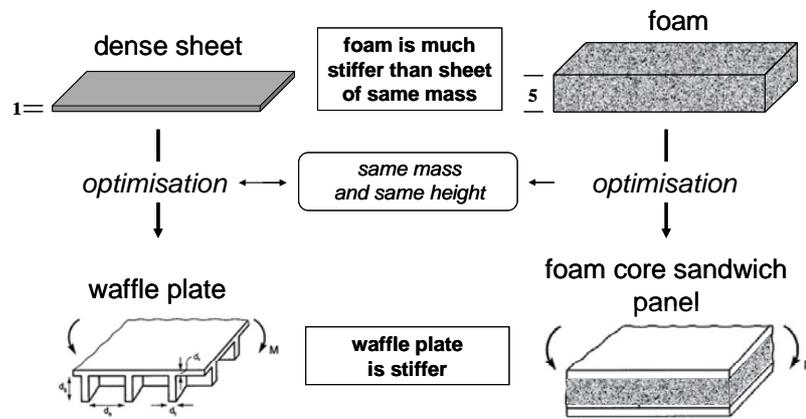
Figure 1. Optimisation of dense sheets and foams.
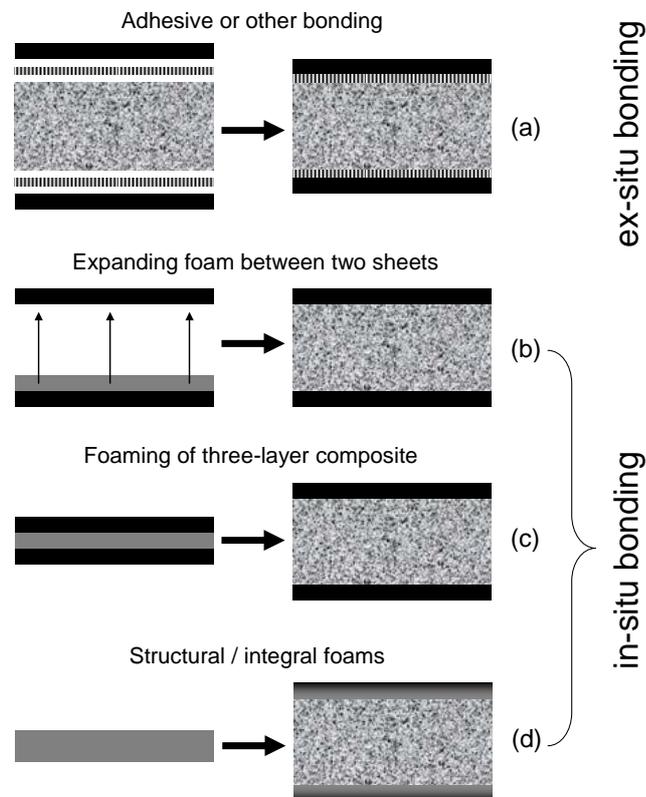
Figure 2. Various technologies for manufacture of AFS.

Figure 3. 3D-shaped AFS made by torsional deformation of a strip of AFS precursor, followed by foaming.
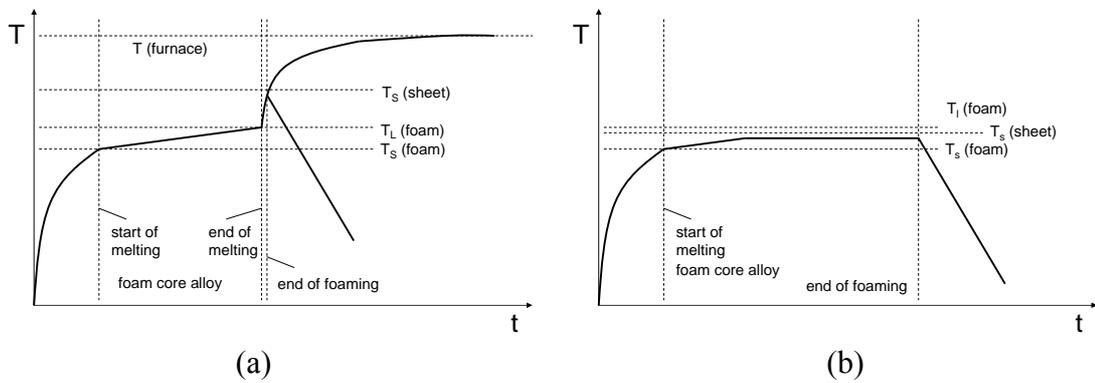
Figure 4. Temperature course of AFS foaming in, (a) a furnace kept at a constant temperature $T>T_L$, (b) furnace with a dynamic heating profile ensuring that $T<T_s$.

Figure 5. (a) Three-layer composites used for AFS making, (b) foamed AFS panels ready for shipping, (c) comparison of very thin and very thick AFS panel.
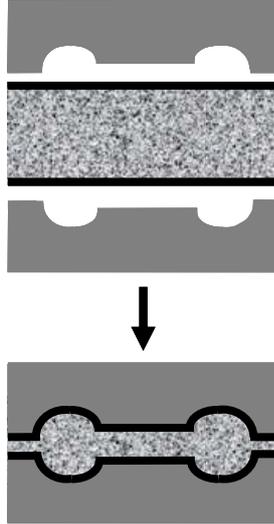
Figure 6. Forging of AFS: schemical process diagram.
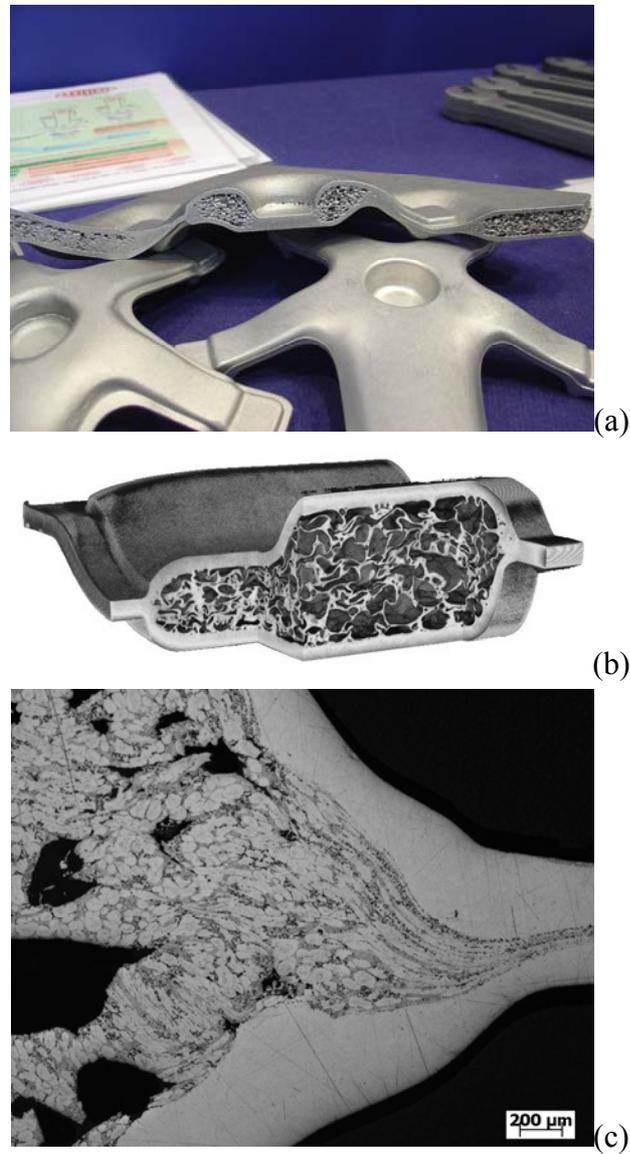
Figure 7. Forged AFS, (a) part and section, (b) tomogram of interior (courtesy of F. García-Moreno), (c) microstructure of densified rim.
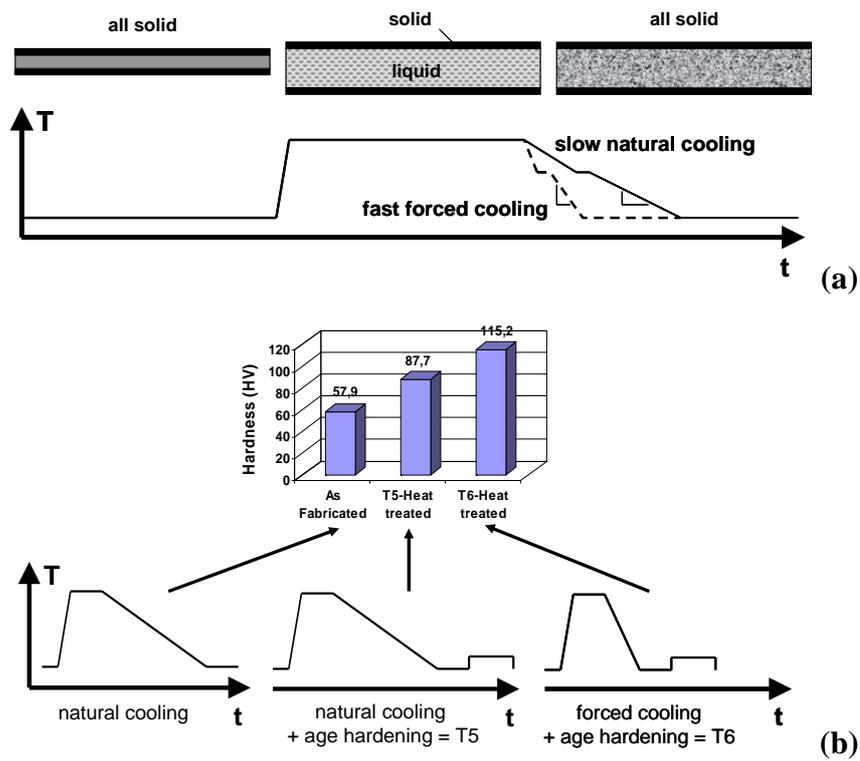
Figure 8. Age hardening of AFS. (a) temperature course, (b) microhardness of 6082 face sheets on a AlSi6Cu4 foam core after different heat treatments [55].

Figure 9. Vehicle with a Teupen 'EURO B25T' lifting arm support. Arrow points at AFS part [67].

Figure 10. Ariane 5 rocket cone prototype made of AFS [56]. Left image shows location of part in the rocket.

(a)   (b)   (c)

Figure 11. Boiling water in, (a) steel and (b) AFS pan (courtesy of Lisa Smith), (c) thermal flow in AFS pan under cooking conditions.

TABLES

Table 1. Selection of experimental work done on AFS material manufactured by ex-situ bonding. Column 'technology' refers to one of the four possibilities given in Figure 2, 'foam' gives commercial or generic name (PM stands for foams made by expanding a powder compact). In 'references' the letter specifies what type of information a reference contains.

technology	foam*	face sheet	reference**
(a)	Alporas©	Al alloy	P: [7],[8],[9],[10],[11],[12],[13],[14],[15],[16]
		steel	P: [17],[14][15]
		GFRP or	P: [18],[19]
		CFRP	M: [20]
			P: [21],[14],[22]
		alumina	P: [23],[14][24]
	Cymat©	Al alloy	P: [25],[26]
		GFRP	P: [27]
	PM foam	Al alloy	2: [28]
			P: [29]
		alumina	P: [30][31]
	APM© spheres	Not specified	[32]
	Open cell foam	Al alloy	P: [33]
		steel	P: [17]

* PM: Powder Metallurgy; LM: Liquid metallurgy, ARB: Accumulative Roll Bonding, APM: Advanced Pore Morphology
** M: Manufacture (metallic foam), P: properties, A: Applications, S: Structure, 2: Secondary operations, E: Economy

Table 2. Same as Table 1 for AFS manufactured in-situ.

technology	foam*	face sheet	reference**
(c)	Al alloy (PM, TiH_2)	various	A: [34],[37],[38],[41],[43]
			2E: [39]
			MA2: [40]
			MP: [42] [45]
			PA: [44]
(c)	AlSi7 (PM, TiH_2)	Al 3XXX	M: [46]
			P: [47],[52],[53]
			2: [48],[49],[50],[51]
(c)	AlSi6Cux (PM, TiH_2)	Al 6XXX	S: [54]
			P: [55],[53]
			A: [56]
(c)	AlSi12 (PM, TiH_2)	steel	MP: [57]
(b)	AlSi12 (PM, TiH_2)	Al	P: [58]
(d)	AlSi9Cu3 (LM, MgH_2)	=foam	MSP: [36]
(c)	5XXX (ARB, TiH_2)	=foam	M: [59]
(c)	6XXX (PM, TiH_2)	steel	MP: [57]
			M: [60]
(d)	open cell foam	1XXX	MSP : [61]

Table 3. In-situ bonded AFS: Alloy combinations currently in use.

AFS designation	foam alloy*	sheet alloy EN numerical	sheet alloy ISO chemical
IFAM 1	AlSi12	1050A	Al99.5
IFAM 2 = alm-A	AlSi7	3103	AlMn1
alm-F	AlSi7	5005	AlMg1(B)
alm-D	AlSi6Cux	3103	AlMn1
alm-B	AlSi6Cux	6016	-
alm-C	AlSi6Cux	6060	AlMgSi
alm-E	AlSi6Cux	6082	AlMgSi1MgMn
experimental	AlSi6Cux	5754	AlMg3
experimental		5083	AlMg4.5Mn0.7

* x= 3 to 7 wt.%