Aluminium foam – Production, Properties and Recycling Possibilities

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Since some years aluminium foams become popular because of their properties high stiffness combined with a very low density. Several applications such as have already been found (e.g. for energy absorption in door panels or as bumpers) and many more are currently investigated. – Parallel to the growing demand for aluminium foams the development of suitable recycling processes is required due to economical and ecological reasons. In a cooperation project, funded by BMBF, a recycling concept has been developed by IME Process Metallurgy and Metal Recycling, RWTH Aachen and Hydro Aluminium Deutschland GmbH, R&D Bonn. Commercially available foams are characterized regarding to their composition, structure and the presence of foaming agents. The foam scrap is molten under conventional salt using various amounts and compositions, as well as different agitation conditions. The results show that the high specific surface area, related to increased aluminium oxide contents in foam scraps does not have negative impact in respect to the aluminium yield. But the regained material can be added to common recycling processes only in small amounts, as special attention has to be paid to the hydrogen and titanium content in the melt.

Keywords:

Aluminium foam – Production – Recycling – Purification – Salt treatment

Aluminiumschaum – Produktion, Eigenschaften und Recyclingmöglichkeiten

Aufgrund der Eigenschaften von Aluminiumschaum, wie z.B. eine hohe Festigkeit, verbunden mit einer sehr geringen Dichte, wächst seit einigen Jahren seine Verbreitung. Verschiedene Anwendungen, z.B. als Füllmaterial in Stoßdämpfern oder Schalldämpfern, wurden bereits gefunden und weitere werden in den nächsten Jahren folgen. – Parallel zur steigenden Nachfrage ist die Entwicklung geeigneter Recyclingkonzepte für Aluminiumschäume aus ökologischen und ökonomischen Gründen notwendig. In einem Forschungsprojekt, das vom Bundesministerium für Bildung und Forschung gefördert wird, wurde vom IME Metallurgische Prozesstechnik und Metallrecycling, RWTH Aachen und der Hydro Aluminium Deutschland GmbH, R&D Bonn, ein solches Recyclingkonzept entwickelt. Kommerziell erhältliche Schäume werden bezüglich ihrer Zusammensetzung, ihrer Struktur und der Gehalte an Aufschäummitteln charakterisiert. Der Schaumschrott wird in einem Salzschmelzprozeß behandelt. Parameter sind hierbei die Salzzusammensetzung und -menge sowie die Rührbedingungen. Die Ergebnisse zeigen, daß der erhöhte Aluminiumoxidgehalt in den Schäumen, der auf die große spezifische Oberfläche zurückzuführen ist, keine negativen Auswirkungen auf die Metallausbeute hat. Dennoch kann das gewonnene Material nur in geringen Mengen in den konventionellen Aluminiumrecyclingprozeß eingebracht werden. Besondere Aufmerksamkeit muß hier dem erhöhten Titangehalt im Aluminium gezollt werden.

Schlüsselwörter:

Aluminiumschaum – Produktion – Recycling – Metallreinigung – Salzbehandlung

Mousse d'aluminium – production, qualités et possibilités de recyclage

Espuma de aluminio – producción, características y posibilidades de reciclaje

The basis of this publication forms a lecture that was held at the OEA Congress, 18th March 2003 in Munich.

In aerospace as well as in the automotive industry light materials are used in order to reduce weight and thereby fuel consumption. These materials are often utilized in form of light metals. But even as alloys they often have insufficient mechanical properties like strength. This resulted in the development of new materials combining the required properties with low density. A recent outcome of materials research is aluminium foam that is stiff and ultra light because of its porous structure. The use of foamed aluminium has big advantage in large sandwich constructions and in the stiffening of hollow aluminium profiles or sometimes even steel profiles. Other application possibilities are present in the automobile and construction industry and in aerospace industry.

It can be expected that the demand for such materials will grow also in other sectors as soon as the production and processing costs can be reduced. Parallel to the growing demand the development of suitable recycling concepts is

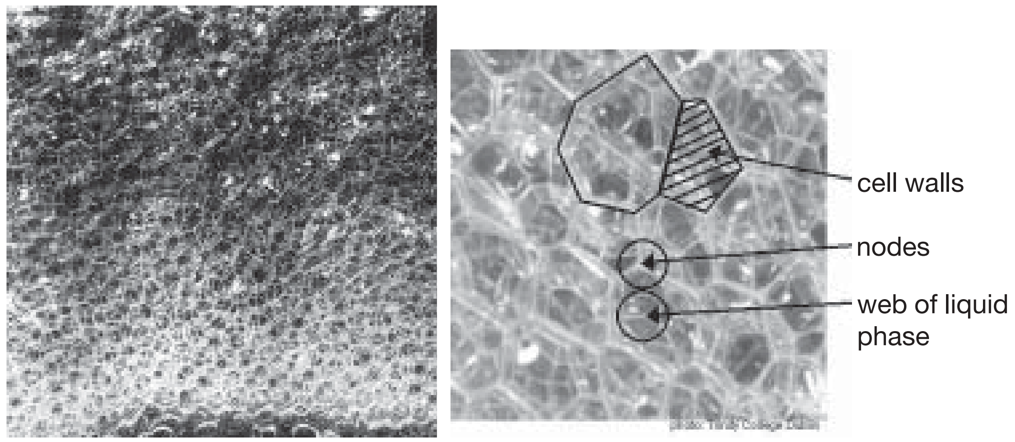

Fig. 1:
Principle of a foam [2]

necessary to save raw material resources due to increasing requirements concerning environmental protection.

Due to this in a government supported project IME Process Metallurgy and Metal Recycling together with Hydro Aluminium Deutschland GmbH are searching for recycling concepts for advanced materials like composite materials, special alloys with lithium or scandium contents, iron containing cast parts and as well aluminium foams and AMC. Test runs in laboratory scale and investigations on metallurgical basics are done at IME, scale up test runs in pilot scale and material characterisation are done at Hydro Aluminium Deutschland GmbH.

Within this project at IME aluminium foams are treated in a salt based process to regain the aluminium that possibly can be added to conventional aluminium recycling processes. Special attention has to be paid on the titanium content in foams that had been produced with TiH_2 because the titanium enrichment in the aluminium matrix can reach values of about 0.7 %. This material has to be diluted with pure aluminium or scrap to decrease the titanium content to less than 0.1 %.

1 Definition of foam

Foams are systems of two phases that are thermodynamically not stable. Mostly they consist of a big gas volume that is dispersed in a small liquid or solid volume (Figure 1). Aluminium foams are disperse systems of a gaseous phase and a solid aluminium phase with a porosity of up to 80 %. They can consist of an open or a closed cell structure depending on the production process. Pure liquids do not form foams. There has to be a substance that inhibits the coalescence of the gas bubbles. In case of aluminium foams these stabilizing agents are oxides, ceramic particles, carbides or intermetallic compounds, depending on the production method.

The gas bubbles in the foam can be spherical or polyhedral depending on the porosity of the foam. With a porosity of more than 74 % they are polyhedral, otherwise they are spherical. The reason for this is the surface tension. In a smaller porosity the surface tension is higher than in bigger porosity so the bubbles are spherical to possess a surface energy as small as possible [1].

The cells of a closed cell structure are bordered by very thin films of the liquid or solid phase. The edges of the cell walls that are connected by nodes form the web of the cell structure. If the cell walls are damaged or if they flow into the edges at the end of the foam formation, an open cell structure is formed [1].

2 Foam production methods

For the production of aluminium foams several processes exist. The pores can either be formed by gas expansion or by place holders. Three possible production methods will shortly be described.

Metal foams can be produced by lost wax casting or casting into moulds filled with place holders as for example polystyrene balls. In these procedures the aluminium is cast into the moulds and afterwards the place holders, wax or polystyrene balls, are burned so that pores supersede the former place holders and open cell structures are formed (Figure 2).

In another production method inert gas or air is blown into an aluminium melt that is stabilized by ceramic or oxide particles. The gas forms bubbles in the melt and the stabilizing agents build a layer around them and this way prevent them from collapsing. The stabilized bubbles float to the surface of the melt and form a closed cell structured foam there that is removed by conveyor belts continuously. The surplus aluminium melt runs out of the foam and down to the melt again. In this process only foam blocks or

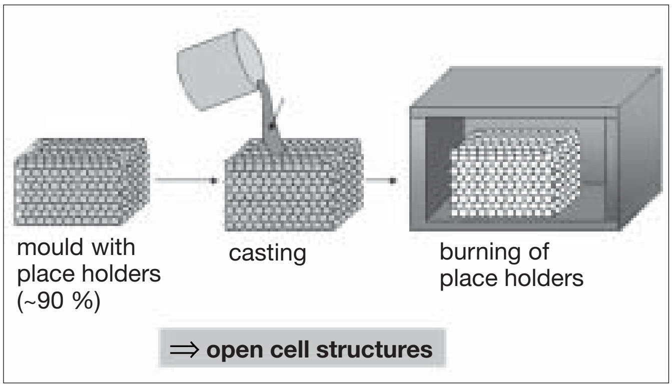

Fig. 2: Diagram of foam production by casting processes

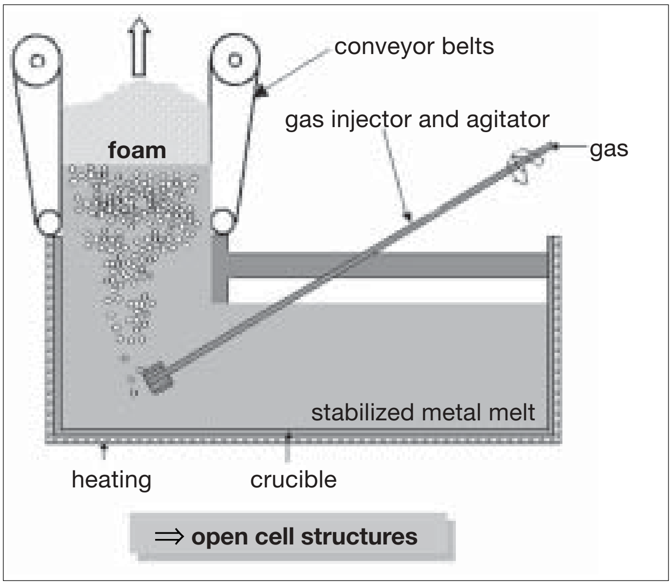

Fig. 3: Diagram of the gas injection technique for foam production, according to [3]

plates can be produced. It is not possible to receive any shaped parts (Figure 3) [3].

A third possibility to produce aluminium foams should be the powder metallurgical way (Figure 4). In this process aluminium powder and a powder of blowing agent are mixed and afterwards pressed into an optional form. Blowing agents can be metal hydrides like TiH_2 or MgH_2, carbonates, hydrates or other volatilizing substances. After compaction the shaped parts can be processed if necessary. Processing steps can be for example roll-bonding to create sandwich structures, extruding or cutting. In a last step the pressed parts are foamed at temperatures slightly above the melting point of aluminium. At these temperatures the blowing agents are expected to volatilize and the arising gas forms pores in the metal phase. In this process as well as in the lost wax casting process finished shaped parts of aluminium foam of more or less complicated geometries can be produced [4, 5].

3 Properties and possible applications

In comparison to bulk aluminium material aluminium foams have some special properties. These properties however depend very much on their cell structure. Open cell structures possess a good liquid and gas permeability, a large inner surface and due to this a good heat conductivity. In contrast to this, closed cell structures possess heat insulating properties because neither liquids nor gas can pass through them. Both kinds of foam have a high stiffness, a high capability of shock absorbing and vibration damping and what is most important in combination to the previously mentioned properties low densities.

The application of aluminium foam has advantages when parts are redesigned to optimize the multi functionality. According to different studies up to 70 kg of foam can be used in an average car. It could provide structural reinforcement and energy absorption in door panels, front hoods, bumpers, roof panels, crash boxes and body frame elements [6, 7]. Or it can be used as a combination of firewall, acoustic dampener, energy absorber and semi-structural component between the passenger department and trunk [6].

The two main competitors of aluminium foam concerning energy absorption are honeycomb structures and polymer foams. But in contrast to honeycomb structures aluminium foams have isotropic properties and they are much stronger and stiffer than polymer foams. They also can operate at much higher temperatures and have constant properties over time, humidity ranges and crash speeds [6].

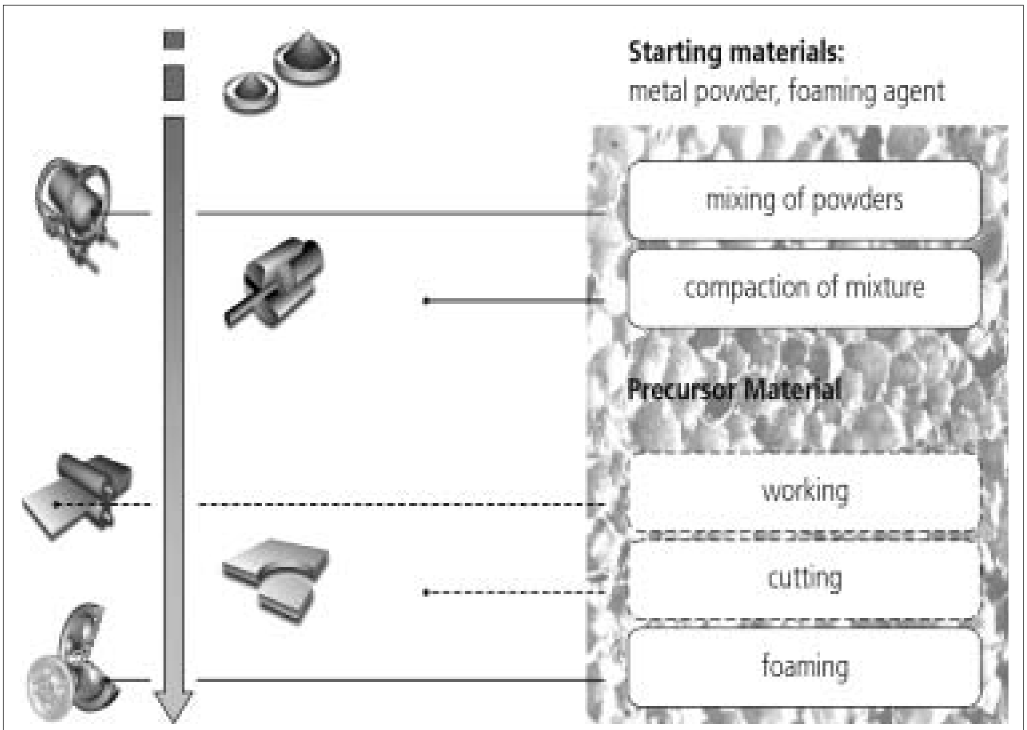

Fig. 4: Diagram of the powder metallurgical foam production method, IFAM

4 Aluminium foam recycling

4.1 State of the art of recycling possibilities

Up to now only a few examinations concerning the possibility to recycle aluminium foams have been published. Mainly these tests are limited up to the addition of particle stabilized foams produced by gas injection technique into the MMC production or to recycle them to new foams [8]. Aluminium foams produced with metal hydrides are recommended to be recycled in the conventional aluminium recycling processes concerning to laboratory tests [8].

4.2 Test runs at IME

Within the scope of this project it was examined under which circumstances aluminium foams produced with TiH_2 can be added to conventional aluminium recycling processes. With this intention several test runs were done with two kinds of foams (see Table 1) to evaluate the influences of foam analysis, salt quantity (0 to 50 % of the charged foam mass) and composition (0 to 15 % CaF_2 in the salt) on metal yield, alloying element concentrations and porosity of the recycled metal. The test parameters are given in Table 2.

The foam material was charged into a graphite crucible with salt consisting of NaCl and KCl (70/30) and up to 15 % CaF_2. Afterwards it was molten in a resistance heated furnace.

After melting the material it was stirred with different agitator frequencies for about 20 min to evaluate the influence of the stirring conditions on the porosity of the recycled aluminium ingot.

In the test runs without salt addition the metal yields were very low because a lot of dross appeared. The results were very much better when salt was added. In test runs where the quantity of added salt was big in comparison to the metal quantity and no CaF_2 was added the metal yield was quite low because most of the metal remained dispersed in the salt slag (Figure 5). That is why the metal yields are better in test runs with only 20 % salt. The quantity of metal that can be dispersed in the salt slag is smaller and due to this the metal yields are bigger. An addition of CaF_2 improved the metal yields once more (Figure 6).

The presented results proof the possibility to reach metal yields of more than 95 % when CaF_2 is added to the salt and the melt is well stirred (Figure 6). CaF_2 in the salt melt lowers the surface tension and enables metal drops dispersed in the salt slag to coagulate and to settle down to the rest of the metal phase again. Also a stronger agitation of the melt in addition to a CaF_2 addition in the salt leads to a better coagulation of the dispersed aluminium drops and so to a better metal yield.

Table 1: Chemical analyses of two industrial foams (Hydro Aluminium Deutschland GmbH)

	A	B
Al [%]	93.3	89.5
Ti [%]	0.50	0.72
Oxides [%]	6.5	10.4

Table 2: List of test series executed with aluminium foam

Test series	1	2	3	4	5
Salt [$\%_{foam}$]	0	20	50	50	50
CaF_2 [$\%_{salt}$]	–	–	–	15	15
Agitation [rpm]	100	100	100	150	250

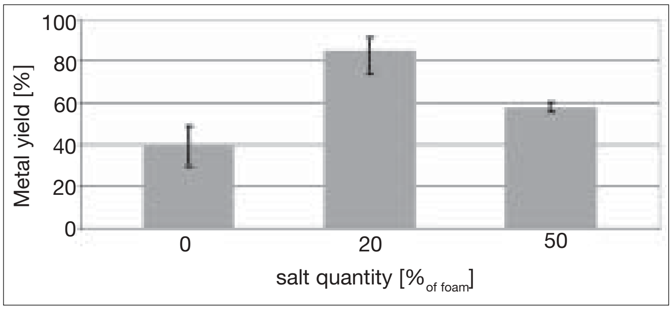

Fig. 5: Metal yield in dependence from salt quantity without CaF_2 addition

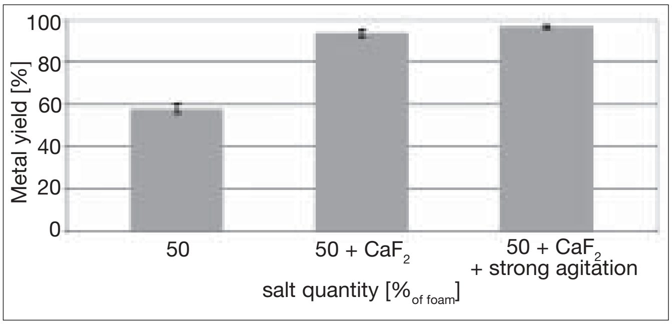

Fig. 6: Metal yield in dependence from CaF_2 addition and agitating conditions

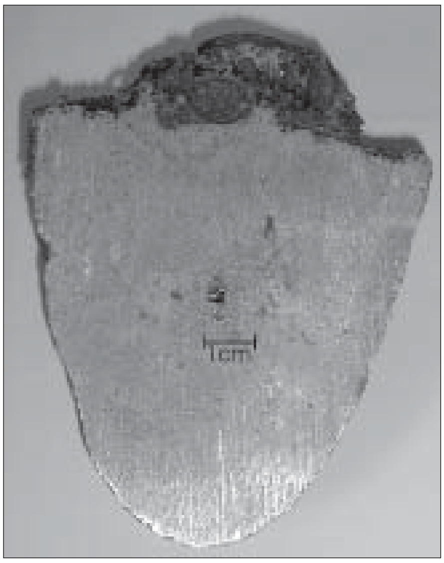

Fig. 7: Aluminium ingot with pores

All ingots of recycled aluminium show macro-porosity in the middle independent from agitating conditions or salt quantity and composition. Figure 7 shows an ingot and these pores.

During foam production with TiH_2 the titanium enriches in the aluminium phase but also a big part of the titanium remains as precipitations at the surfaces of the pores in the foam [9]. This titanium that is not already solved in the aluminium however cannot be eliminated completely from the aluminium matrix during recycling of the foam but can only partly be transferred to the salt slag. Micro-

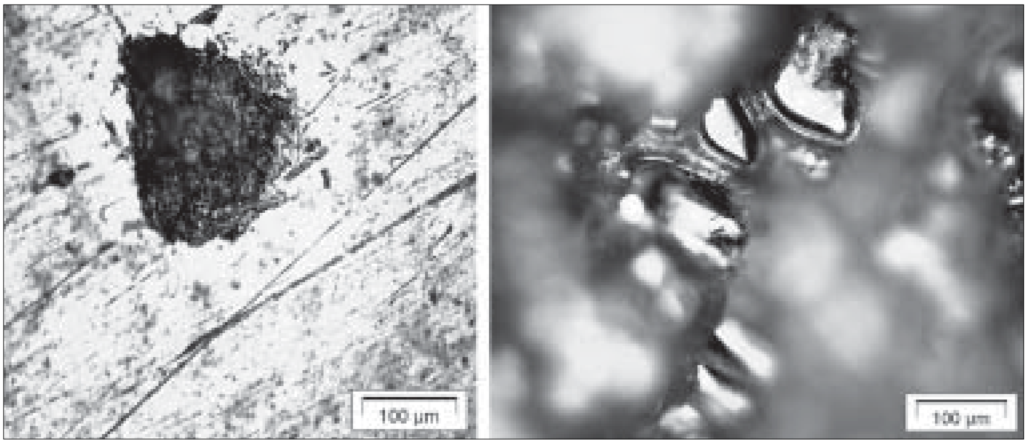

Fig. 8:
Precipitated Ti-Al phases in the aluminium matrix (left) and in the pores (right)

graphs of the pores proof that it precipitates in the pores that are visible in the castings and in the metal matrix as high-tensile Al-Ti phases (Figure 8). The rest of the titanium is supposed to be dissolved in the aluminium matrix concerning to the chemical analyses in Table 3.

Table 3: Chemical analyses of the recycled aluminium ingots (average values)

Test series	1	2	3	4	5
Al_{Oxide}[%]	0.64	0.66	0.43	0.54	0.1
Ti [%]	0.5	0.46	0.56	0.22	0.49
Si [%]	9.96	8.32	9.38	9.8	10.1

A problem for the recycling of aluminium foams that were produced with TiH_2 is the elevated content of titanium in the aluminium matrix. The titanium concentrations in aluminium foam amount about 0.5 to 0.7 %. Nevertheless the titanium content can be lowered to about half of the initial content in aluminium. As a result of these test runs care shall be taken to add aluminium foams foamed with TiH_2 into conventional aluminium recycling processes. The titanium concentration is very high and due to this the produced recycling aluminium would have to be diluted with pure aluminium or scrap to diminish the titanium concentration under an acceptable value for other alloys. As another solution the recycled aluminium from foams can be used as master alloy for titanium alloys.

5 Conclusion

The test runs that have been done until now for the recycling of aluminium foams show that high metal yields can be reached by the recycling with salt melts. Problems are given in consequence of the high titanium concentrations in the aluminium phase. For industrial application there is only the possibility to dilute the recycled aluminium from foams with pure aluminium or conventional recycling aluminium or to use foam scrap to form titanium containing master alloys. But for the dilution with other recycling materials there has to be taken care of the entire concentration of alloying elements in the aluminium that must not reach too high values.

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