Al-Foam Production Scrap – Source for Recycling?

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Due to growing demands in industry and engineering sectors investigations on Al-foams have been pushed during the last years. Processes for recycling foam scraps are necessary to save natural resources and to comply with legal requirements concerning to our environment. This becomes critical as the quantity of foams used in automotive or construction industry will rise and with it the scrap volume. This article presents the results of test runs in laboratory scale.

1 Introduction

In aerospace as well as in the automotive industry light metals are used in order to reduce weight and thereby fuel consumption. But even optimised 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 which 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. Also a high potential is present in the automobile and construction industry. It can be expected that the demand for aluminium foams will grow also in other sectors as soon as the production and processing costs can be reduced. Parallel to the growing demand an early development of suitable recycling concepts is necessary to save resources due to increasing requirements concerning environmental protection.

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

The Al-foam scrap is treated in a salt based process. It is to be investigated if the aluminium 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.

2 Experimental Program

2.1 State of the Art of Foam-Recycling

Up to now only a few examinations concerning the recycling of Al-foams have been published. Mainly the information is limited to the addition of particle stabilised foams produced with gas injection into the MMC production or into new foam production [1]. Aluminium foams produced with metal hydrides are recommended to be recycled in the conventional aluminium recycling processes concerning to laboratory tests. The recy-

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clability of metals, enabling environmentally friendly product management, is described as one of the advantages compared to polymers [1].

2.2 Test Runs at IME

Within the scope of this government funded project the process conditions are investigated to treat aluminium foams produced with TiH_2 together with a conventional aluminium recycling scrap mix. In addition to published concepts there may be some additional problems in recycling compared to bulk material. Metal foams possess a much larger surface and so a bigger content of oxides. Also impurities like nitrides, carbides or further elements like titanium from the foaming process may cause problems that are less present in the recycling of a conventional scrap mix.

For particle stabilised foams produced by air or gas injection existing test results for the recyclability of metal matrix composites (MMC) can be used. MMCs as well as such aluminium foams consist of a metal matrix that contains reinforcing, respectively stabilizing, particles of SiC or Al_2O_3. In the molten state physical and chemical phenomena that appear during the recycling process, such as too high surface tensions or reactions between the components, are supposed to be the same in both cases. The pores of the aluminium foam will disappear from the melt as soon as it is well stirred and the foam material can be treated like bulk MMC material. At IME SiC-particle reinforced MMCs were treated using a laboratory scale immersed centrifugal collector. It was demonstrated that the elimination of SiC-particles from the aluminium matrix is possible. Also the treatment of MMCs with salt melts have given very satisfying results. The particles can be removed from the metal melt from an initial concentration of 30 vol-% SiC to concentrations of 0.1 % [5]. It should be possible to eliminate the particles completely from the metal melt with the help of injected gases like argon or chlorine. It is a cost-effective method that can be executed in conventional furnaces and easily transferred to particle stabilized foams. Their initial particle concentration varies between 10 and 20 vol-% SiC [2] which is less than in MMCs. So it can be expected that the SiC-particles in case of foam are fully absorbed by the salt due to the reduced surface tension carbide-chloride (see Fig. 2). The feasibility for particle stabilized foams is subject to a separate work programme.

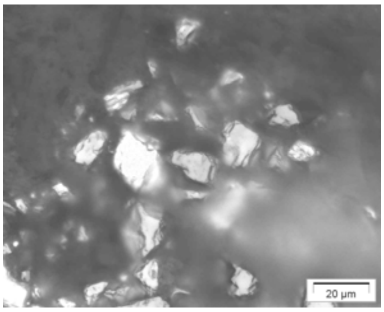

Fig. 1. SiC-particles in salt slag after treatment of MMC-scrap

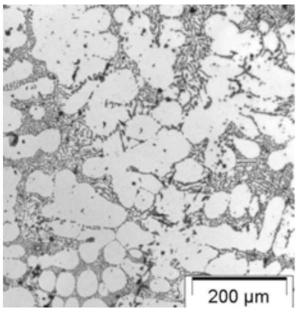

Fig. 2. Metal after treatment (from AMC)

The main focus of this paper is on the TiH_2-foamed material. It was chosen as model substance because it seems to be the more complicated material in comparison to foam produced with magnesium hydride. If the foaming agent reacts with the aluminium matrix during remelting, it would be no problem in case of magnesium; not so with titanium. Titanium forms different intermetallic compounds with aluminium and has only a solubility of ~ 1 at-% in aluminium whereas magnesium is soluble in aluminium to ~ 19 at-% and forms intermetallic compounds only at magnesium concentrations of more than 40 at-%. In addition, magnesium won't disturb the recycling process because it is used in many aluminium alloys. In contrast to this the acceptable maximum titanium content in most aluminium alloys amounts 0.1 % and brittle intermetallic compounds will influence the mechanical properties of a workpiece negatively.

With scrapped TiH_2-foam several test runs were conducted to evaluate the influence of salt quantity (0 - 50 % of the charged foam mass), the salt composition (0 - 15 % CaF_2 in a 70:30 NaCl-KCl salt) on metal yield, on impurity level on and porosity of the recycled metal. To prevent the porous metal from oxidising, the foam material was charged cold into a 5 l-volume graphite crucible together with salt covering the metal completely (Fig. 3). Table 1 shows the initial analyses of two different foams used for the test series. Every test run was carried out with both types of foam to see if the results depend on the initial composition of the material.

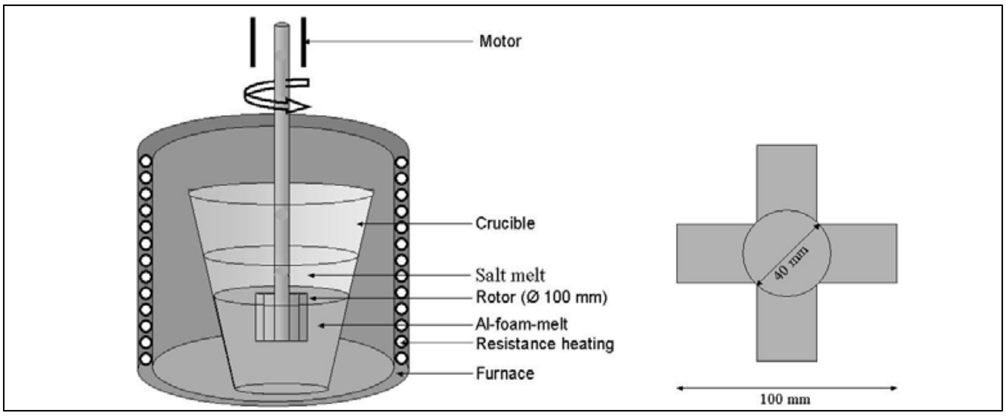

Fig. 3. Experimental set-up and scheme of the carbon stirrer

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

Table 1. Chemical analyses of two industrial foams used in the test runs

After melting in a resistance heated furnace the metal-salt mix was stirred by a carbon stirrer (Fig. 3) for 20 min. Each test started with 2000 g of foam material. The temperature was kept constant at 750 °C. The parameters of the test series are given in Table 2.

Test series	1	2	3	4	5
Salt / $\%_{foam}$	0	20	50	50	50
CaF_2 / $\%_{salt}$	-	-	-	15	15
stirring / rpm	100	100	100	150	250

Table 2. List of test series executed with aluminium foam

The results show that the metal yield ($\eta = m_{Metal}^{output} / m_{Metal}^{input}$) is very low in test runs without any salt addition. They improve with a salt addition of 20 % of the foam mass but degrade again if more salt is charged (Fig. 4). With a salt addition of 20 % of the foam input the salt slag becomes crumbly, so for the process an addition of 50 % salt is more easy to handle. If CaF_2 is added to the salt the metal yields increase even with bigger salt quantities charged to the metal. A stronger agitation of the melt improves the metal yield once more (Fig. 5)

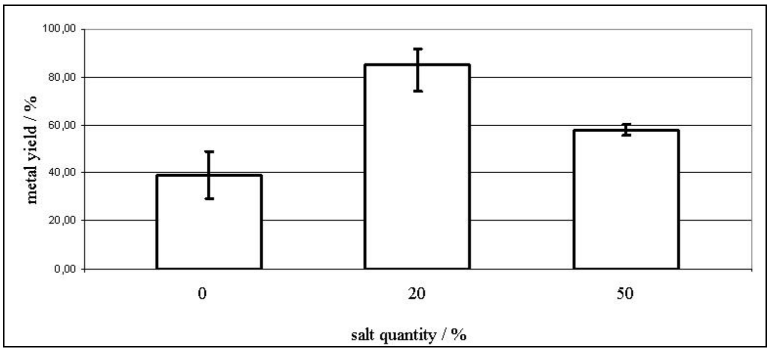

Fig. 4. Mean metal yield and variance in dependence on salt quantity related to Al-foam input (no fluorine ion present) [4]

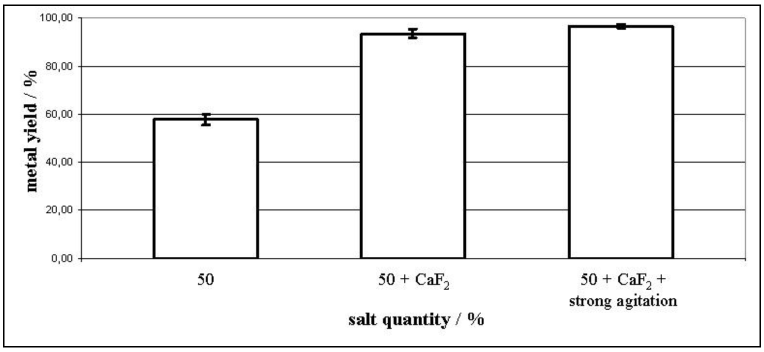

Fig. 5. Metal yield in dependence on salt fluorine content and agitating conditions [4]

The results presented show that metal yields of more than 95 % are possible under laboratory scale conditions if CaF_2 is added to the salt and the melt is well stirred. CaF_2 in the melt lowers the surface tension of the salt melt and enables metal drops dispersed in the salt slag to coalesce, settle down and combine with the bulk of the metal phase again. In test runs with high salt additions and without CaF_2 the metal yield was reduced because most of the metal remained dispersed in the salt slag. High surface tensions and a big salt volume inhibited the metal drops from coalescing into bigger drops. The stronger agitation of the melt in combination with a CaF_2 addition in the salt leads to a better coalescence of the dispersed aluminium drops because of a more turbulent flow, which increases the probability that the drops meet each other.

All ingots show macroporosity in the middle independent on agitating conditions or salt quantity and composition (Fig. 6).

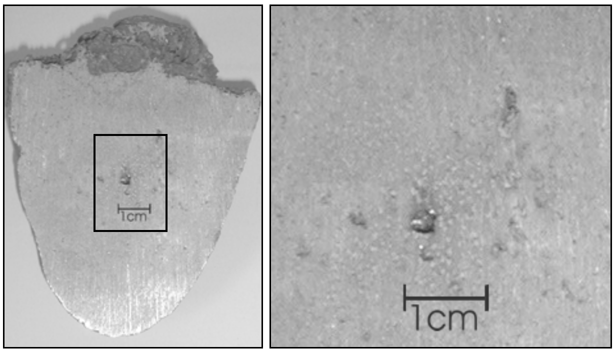

Fig. 6. Aluminium ingot with pores from foam recycling (total view and detail)

During foam production with TiH_2 a part of the titanium dissolves in the aluminium phase but a second part precipitates as intermetallic Ti_xAl_y-compounds at the surfaces of the pores in the foam [3]. Also this titanium cannot be transferred completely during recycling to the salt slag. The main part of the titanium is supposed to be dissolved in the aluminium matrix concerning to the chemical analyses in Table 3. Micrographs show that the precipitates in the casting pores and in the metal matrix are very hard Al-Ti-phases (Fig. 7).

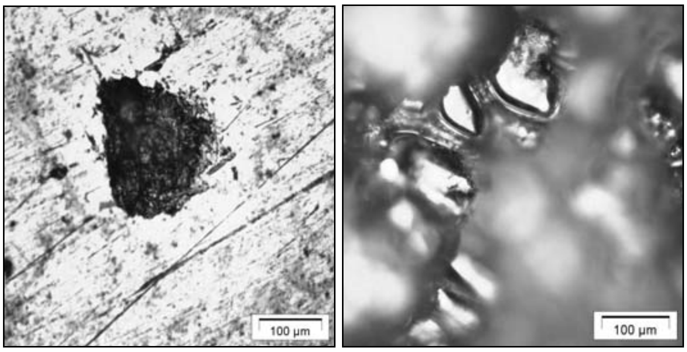

Fig. 7. Precipitated Ti-Al-phases in the Al-matrix (left) and in the pores (right) [4]

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

Table 3. Analyses of the recycled aluminium ingots (average values of test series) (test parameters see Table 2)

The test runs show that there were no differences in metal yield and quality of the recycled aluminium with the foam material that was used. The analyses also show that not only is the metal yield best but also the oxide content is lowest if 50 % salt with 15 % CaF_2 are used and the metal melt is stirred well. A major issue for the recycling of aluminium foams produced with TiH_2 is the resulting content of titanium in the aluminium. The titanium concentrations in the aluminium foam amount about 0.5 to 0.7 %. Nevertheless the titanium content can be lowered to about half of the initial content in the aluminium foam. As a result of these test runs, care must be taken to add aluminium foamed with TiH_2 into conventional aluminium recycling processes. The titanium concentration in the aluminium must be diluted with pure aluminium or Ti-free Al-scrap to reduce the titanium concentration under an acceptable value for the desired alloys. As another solution the recycled aluminium from foams may be used as master alloy for titanium alloys, but this has to be proven by foam producers.

3 Conclusion and Perspectives – Further Work

The test runs for recycling of aluminium foams show so far that high metal yields can be reached by using salt melts. Problems are created by the high titanium concentrations in the aluminium phase. For industrial application there is 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.

Next steps at IME will be the examination of particle stabilized foams and Mg-hydride foamed aluminium to verify if a transformation of the results gained in these test runs and in MMC recycling is possible. Also the elimination of intermetallic Ti-Al-compounds of the recycled aluminium from foams may be a subject to examine.

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