Large scale production and applications of alloy metal foam

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1 Introduction

Open porous structures offer an outstanding potential to combine material properties with a functionality resulting from their specific morphology. In the last two decades numerous cellular materials were developed based on different technologies and tested in R&D labs around the world. Most well–known is the replication method using polyurethane sponge as a template, which is coated with a powder slurry and enclosed heat treated [1, 2]. The variety of alloys and structural properties is interesting for manifold applications. On the other hand an important base for the customer acceptance of a new material is the availability on an industrial level.
A large scale production technology for nickel and iron based metallic foams with open cell structure is described in chapter 3. The powder metallurgical process was developed at Fraunhofer IFAM Dresden in cooperation with ALANTUM. The industrial production line is now established. The alloy metal foam is available as a semi-finished part and the base for the product development together with users for a wide range of applications.

2 Alloy foam production

2.1 Production process

A powder metallurgical process was developed that allows the conversion of a nickel or iron foams into high-temperature-stable and corrosion resistant alloy. The most important material parameters, namely the final composition, the specific surface area and the pore size of the foam can be varied in order to achieve optimum flexibility for the respective applications.

In the patented manufacturing process [3, 4, 5] the nickel or iron foam, which is used as a precursor material, is continuously unwound, coated first with a binder solution using a spraying technique and then with a high alloyed powder. Afterwards the foam is cut into sheets of the desired size. The following heat treatment includes a debindering and sintering step in which the elements from the powder diffuse into the foam struts and ensure a homogeneous alloy foam composition.

Figure 1: new production plant in Onsan, built in 2010

Figure 2: inside view of production plant

Based on the developed technology a pilot plant production was established in 2006 in Germany. Because of a continuous process optimization and the high success of application development a new production line was established in Onsan (Korea) with an annual production capacity of 500.000 m² alloy foam (Figure 1 & Figure 2). All production processes are controlled by image analysis, operators and weighing processes to document the production steps. The sintering furnace ensures an exact control of the atmosphere, the debindering step of the organics and the highly homogeneous temperature distribution for the sintering process. Before packing each foam is marked with a consecutive production number for the documentation in a quality management system.

2.2 Iron based alloy foam

2.2.1 Iron foam substrate production

For producing an open cell metal foam an open cell PU foam is used as a precursor substrate. For an electroplating production process the PU foam needs to be conductive. For this purpose a thin Ni layer is deposited on the PU foam in a continuous sputtering process. After that the foam can be electroplated with nickel or iron (Figure 3).

The electroplating bath of pure Fe is a specialty and needs different conditions to that of the Ni plating process. Iron is plated from acidic solutions like Fe(II) salts. The presence of Fe(III) in these baths is not acceptable, because it lowers the cathode efficiency and makes the final product brittle. So the bath is containing Fe(II) sulfate or Fe(II) chloride or a mixture of both. The advantages of a chloride bath are:

- permits higher current density
- faster deposition rates
- yield ductile deposits

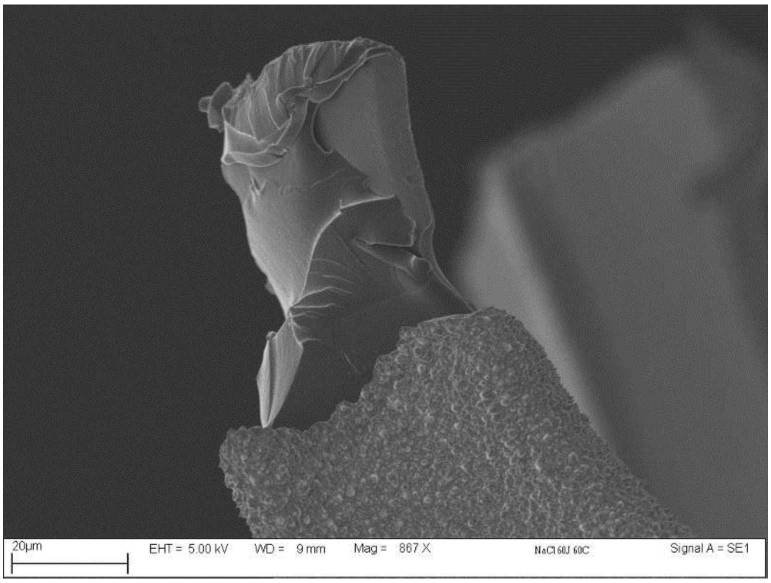


Figure 3: PU precursor with electroplated metal surrounded

The most common bath for iron electroplating is a Fe(II) and calcium chloride which is named as Fischer-Langbein solution. This bath yields dark-colored, hard, highly stressed deposits at 25°C. The biggest problem in the electroplating process is the low pH value (0.8-1.5 pH). The current density is a around 2-9 Adm^{-2}. The production speed through the bath is depending to the target thickness of electroplating, which is in the range of 10 to 15 µm.
The next step in production order is a to two step heat treatment. First the precursor (PU foam) is pyrolized at around 560°C. In the second step at around 950°C the foam material is annealed. The obtained material is a iron foam with hollow struts (Figure 4 & Figure 5). This metal foam precur-

sor is used for the further powder metallurgical process for the high temperature foam production (see chapter 3.1)

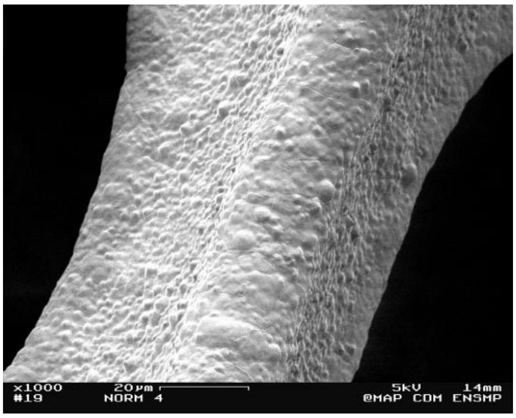


Figure 4: surface of strut

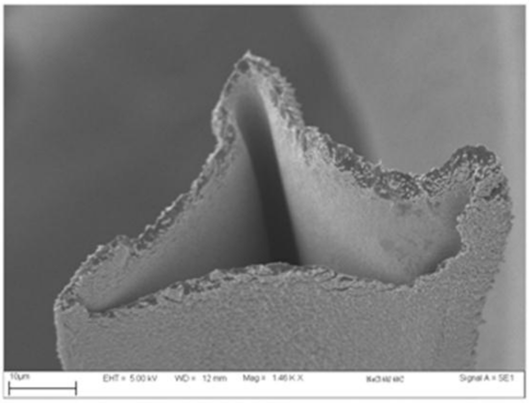


Figure 5: hollow strut, precursor burned

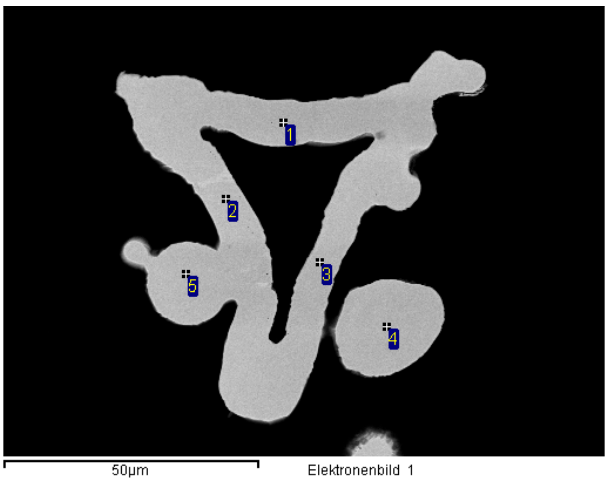
2.2.2 Stainless steel and FeCrAl foam

2.2.2.1 Stainless steel foam

One group of alloys that can be manufactured based on a Fe-based substrate, are stainless steel alloy foams. The first alloy foam is based on stainless steel 316L (1.4404). The target composition is summarized in Table 1. Foam production was done by the established processing route (see chapter 3.1). An image of the foam microstructure together with EDX analysis is shown in Figure 6. A single-phase microstructure is observed. The average values of the main elements are apart from a slightly too high Cr content close to the target composition. The measured carbon content is in the range of 0,006 – 0,012% and therefore within the specification.

Table 1: composition of alloy 316L (1.4404), all values in wt%

Fe	Cr	Ni	Mo	other
bal.	16,5 – 18,5	10 - 13	2 – 2,5	C (≤ 0,03), Si (≤ 1), Mn (≤ 2), P (≤ 0,045), S (≤ 0,015), N (≤ 0,11)



	Cr	Fe	Ni	Mo
1	20.32	66.67	10.57	2.44
2	20.19	67.35	10.34	2.11
3	20.25	67.77	9.71	2.28
4	19.01	63.87	14.17	2.95
5	19.89	68.07	9.94	2.10
average	***19.93***	***66.75***	***10.95***	***2.37***

Figure 6: foam structure and composition of alloy foam based on stainless steel 316L

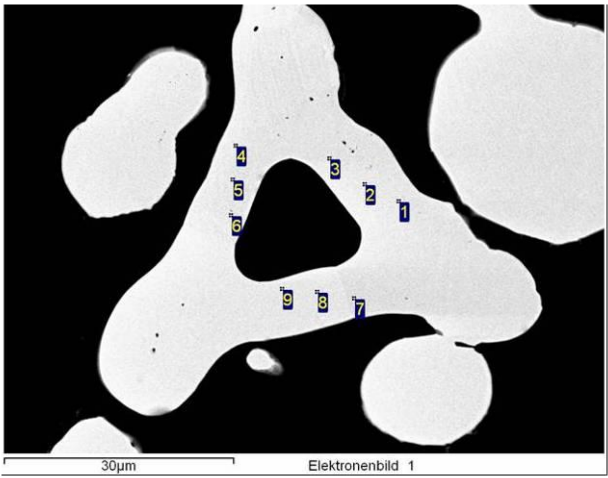
2.2.2.2 FeCrAl foam

general foam appearance

Another established class of high-temperature materials are those from the system Fe-Cr-Al. For the foam development program a composition, which is based on the recently developed FeNiCrAl alloy [6], was chosen (target composition see Table 2).

Table 2: target composition of FeCrAl alloy foam

element	Fe	Cr	Al
content [wt%]	bal.	22	6



	Al	**Cr**	**Fe**	**Ni**
1	6.29	23.54	69.27	0.90
2	6.44	23.88	68.87	0.80
3	6.25	23.33	69.66	0.77
4	6.35	24.15	68.31	1.19
5	6.16	24.06	68.92	0.86
6	6.22	24.22	68.72	0.84
7	6.20	23.79	68.94	1.07
8	6.42	24.25	68.43	0.90
9	6.32	24.06	68.58	1.04
average	**6.29**	**23.92**	**68.86**	**0.93**

Figure 7: foam structure and element distribution of FeCrAl alloy foam

The typical microstructure and element distribution is shown in Figure 7. The measured Cr content is slightly higher than the target. The measured Ni originates from the Fe foam substrate. Overall, the measured element distribution is close to the target composition.

3 Applications

3.1 Retrofit diesel particulate filter

Because of sheet type material, Alantum introduced a new generation DPF concept material. In the case of DPF application, almost 5,000 sets of the Alantum foam filter were installed on Korean retrofit program Light Duty Diesel truck below 3L engine. Schematic designs of the Alantum foam filter and images of the installed Alantum foam filter are shown in Figure 8 and Figure 9.

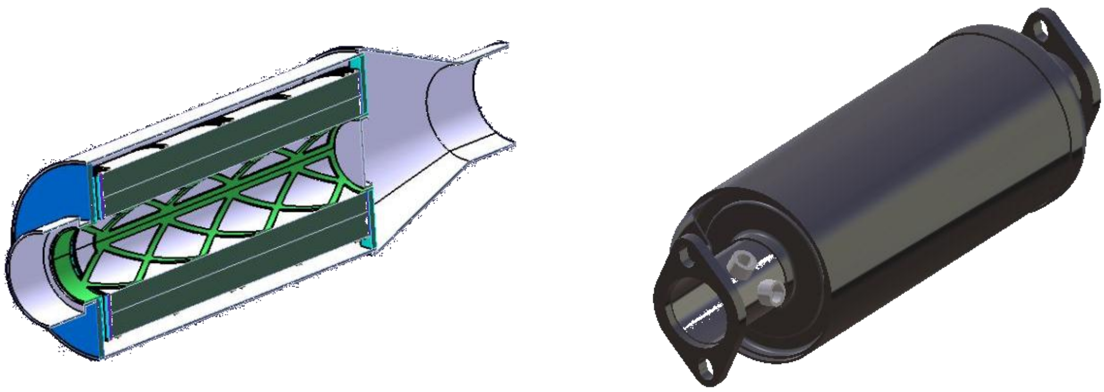


Figure 8: Schematic design of ALANTUM foam filter for Korean Retrofit program

Figure 9: Light duty diesel truck and installed ALANTUM foam filter

The ALANTUM foam filter has been certified by South Korean Government and over 5,000 systems are currently in operation. It has over 70% of PM reduction rate in average. It has showed good durability also under “worst case” city-driving conditions.

In Table 3 the test result of government certification program is shown in terms of emission values of the different exhaust gas components. Alantum foam filter keep the good performance after over 20,000km on world driving test. The durability test is currently ongoing over 150,000km.

Vehicle	Pregio (g/km)					
Item	fresh			after 20,000 km		
	Base	Sample	Reduction	Base	Sample	Reduction
CO	0.485	0.064	87%	0.479	0.067	86%
THC	0.071	0.003	96%	0.068	0.007	90%
NOx	1.633	1.677	-3%	1.655	1.676	-1%
PM	0.079	0.022	72%	0.073	0.025	66%
Vehicle	**Bongo Frontier (g/km)**					
Item	fresh			after 20,000 km		
	Base	Sample	Reduction	Base	Sample	Reduction
CO	1.103	0.087	91%	0.951	0.085	91%
THC	0.222	0.008	96%	0.184	0.009	95%
NOx	1.034	1.066	-3%	1.060	1.068	-1%
PM	0.099	0.032	68%	0.084	0.034	60%

Table 3: Alantum foam filter performance before and after real world 20,000km driving.

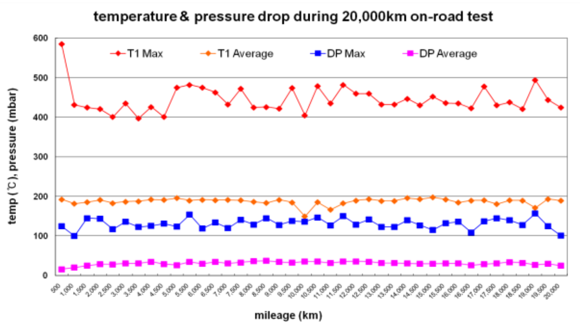


Figure 10: Fleet test data of ALANTUM foam filter (operating temperature and pressure drop)

In Figure 10 the differential pressure between front side Alantum foam filter and rear side (DP) and the operating temperature (T1) are summarized over the driving test mileage. It can be seen that the DP value is kept stably during 20,000km low speed driving test, which indicates that soot is not accumulated to critical values during the test.

4 Conclusions

A cost efficient technology which was successfully up-scaled to a large scale production was introduced. A couple of iron and nickel based alloy foams offer a wide range of applications for exhaust after treatment systems, chemical engineering and electrical power units. The production process allows to adjust the alloy composition of the semi-finished foam product for the respective operation conditions like corrosive environment and high temperatures. Combined with the structural properties of the foam a wide range of different applications in exhaust after treatment, catalyses, noise absorption and burner units was demonstrated.

5 Acknowledgement

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6 References

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