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Aluminum Foams as Permanent Cores in Casting

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Abstract: Low density, high specific stiffness and impact energy/vibration absorption ability make Al-based metal foams as promising materials in applications for which lightweight, and energy/vibration absorption are crucial. In view of these properties, Al-based foams can be extremely interesting as cores in cast components in order to improve their performances and simplify their whole technological process. However, both in the scientific literature and in technological application, this topic is still poorly explored. In the present work, Al-based metal foams, (Cymat foams and Havel Metal Foams in the form of bars of rectangular section), are inserted in gravity casting experiment of the Al-Si-Cu-Mg alloy (EN AB-46400). The foams have been fully characterized before and after insertion in casting: porosity, cell wall and external skin thickness, microstructure, infiltration degree and the quality of the interface between the foam core and the dense cast shell have been investigated by means of optical microscopy and Scanning Electron Microscopy equipped with Energy Dispersive Spectroscopy (SEM-EDS).

The analyses evidenced that a continuous and thick external skin protect the foam from infiltration by molten metal preserving the initial porosity and insert shape. A detailed analysis of the foam external skin highlights that the composition of this external skin is crucial for the obtainment of a good joining between the molten metal and the Al-foam core. In fact, the presence of Mg-oxides on the foam surface prevents the bonding and maintains a gap between the core and the shell. This point opens the opportunity to design innovative surface modifications of this external skin as promising strategies for the optimization of cast components with a foam core.

Keywords: Al-based foams; casting; foam cores

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1. Introduction

Al-based foams are gaining increasing interest due to their low density, high specific stiffness and impact energy/vibration absorption ability, fire resistance, and recyclability [1,2]. The scientific literature documents this situation through publication of papers on this topic which rises from 100/year to 600/year in the last 20 years [3]. Moreover, industrial applications are emerging in this field. In many cases, however, the performances of metal foams can be enhanced only by the realization of sandwich structures or hollow structures with a foam core, which are widely studied in the literature [2, 4]. On the other hand, the use of Al-based foams as cores in casting component production is still poorly explored (few papers/year, less than 10 patents published on this topic), even if it can have numerous advantages such as weight reduction vs dense components, obtainment of «cavities» in cast objects, strength increase vs hollow or T-shaped sections, impact energy and vibration absorption, acoustic insulation, together with the simplification of the technological processes (no removal/recycling of traditional sand cores) and recyclability [3].

The few published works related to Al-based foams as cores in casting include some details and characterizations and almost no solutions are proposed and discussed for the overcoming of criticism. The present research, for the first time, considers and compares different foams, analyzes both foams and cast objects, individuates main issues and proposes new strategies for their overcoming.

2. Materials and Methods

Al-based metal foams with a dense and thick outer skin AF1 (Al alloy with a limited amount of TiH_2 as foaming agent, Havel Metal Foams GmBH) or with a thin and not completely homogeneous outer skin AF2 (Al alloy with SiC particles as stabilizing agent, Cymat Technologies Ltd) were considered.

Samples density was measured by means of weight and volume measurements. The dimension and distribution of pores, as well as the thickness of cell walls and outer skin were estimated by optical microscopy (Reichert-Jung MeF3, Leica Microsystems Srl) on metallographic sections of the foams.

Morphology and semi-quantitative composition of the foams surface was investigated by means of Scanning Electron microscopy equipped with Energy Dispersive Spectroscopy (SEM-EDS JEOL, JCM 6000 plus and JED 2300).

Foam samples in the form of rectangular bars were used as cores in gravity casting experiments with an Al-Si-Cu-Mg alloy (EN AB-46400).

Cast objects were sectioned, visually inspected to estimate the degree of infiltration and the stability of the foam core in the cast component. Small samples of the cast metal and of the cast metal with foam inserts were cut, resin mounted and mirror polished for optical microscopy observations.

3. Results and discussion

The visual appearance of the foams used as inserts is shown in Figure 1.

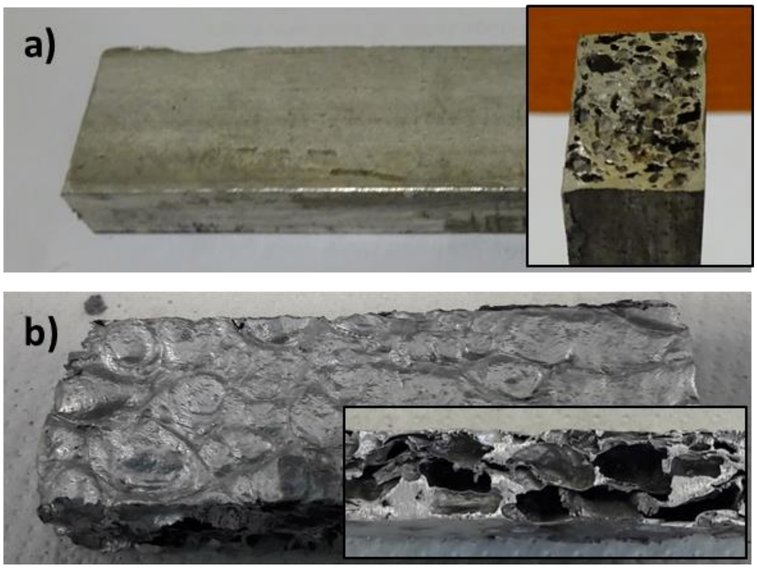

Figure 1. a) Foam AF1, **b**) Foam AF2.

It can be observed that AF1 foam presents a thick outer skin which uniformly covers almost the whole lateral surface of the bar (it has been produced by powder metallurgy as shaped part). On the other hand, AF2 foam presents a thin outer skin which is not completely homogeneous and covers only the top and bottom surfaces of the bars (they have been cut from large panels).

The relative density ρ_s (considering the density of compact Al, 2.7 g/cm^3 as reference) is between 0.4 and 0.6 for the AF1 foams used and between 0.1 and 0.2 for the AF2 ones.

The pore dimension is highly variable for both foam types, according with the self generation route used in both production process (powder metallurgy with TiH_2 as foaming agent for AF1 and gas injection in the molten metal for AF2) [3, 4]. Pore dimension values in the range 95-3900 μm can be reported for AF1 foams and in the range 1000-20000 μm for the AF2 ones.

The wall thickness is in the 15-400 μm range for AF1 and in the 50-1000 μm one for AF2. Finally, the outer skin thickness is up to 1200 μm for AF1 and up to 300 μm for AF2 ones, confirming the higher thickness for the first type of foams.

EDS analyses on the foam surfaces evidenced the presence of C, O, Mg and Al on AF1 samples and of C, O, Al and Si on AF2 samples. Moreover, AF1 samples showed numerous particles rich in O and Mg, attributable to Mg-rich oxides and carbonates frequently observed on Al-Mg alloys [5-7]. These particles are hardly removed; only mechanical grinding can detach them from the surface. On the other hand, few particles (rich in Al and O) can be found on AF2 surface samples and are easily removed with sample ultrasonic washing. These observations suggest a higher oxidation degree for AF1 samples compared to AF2 ones. This feature can influence the possibility for foam to react with molten metal in casting experiments, as discussed in the following.

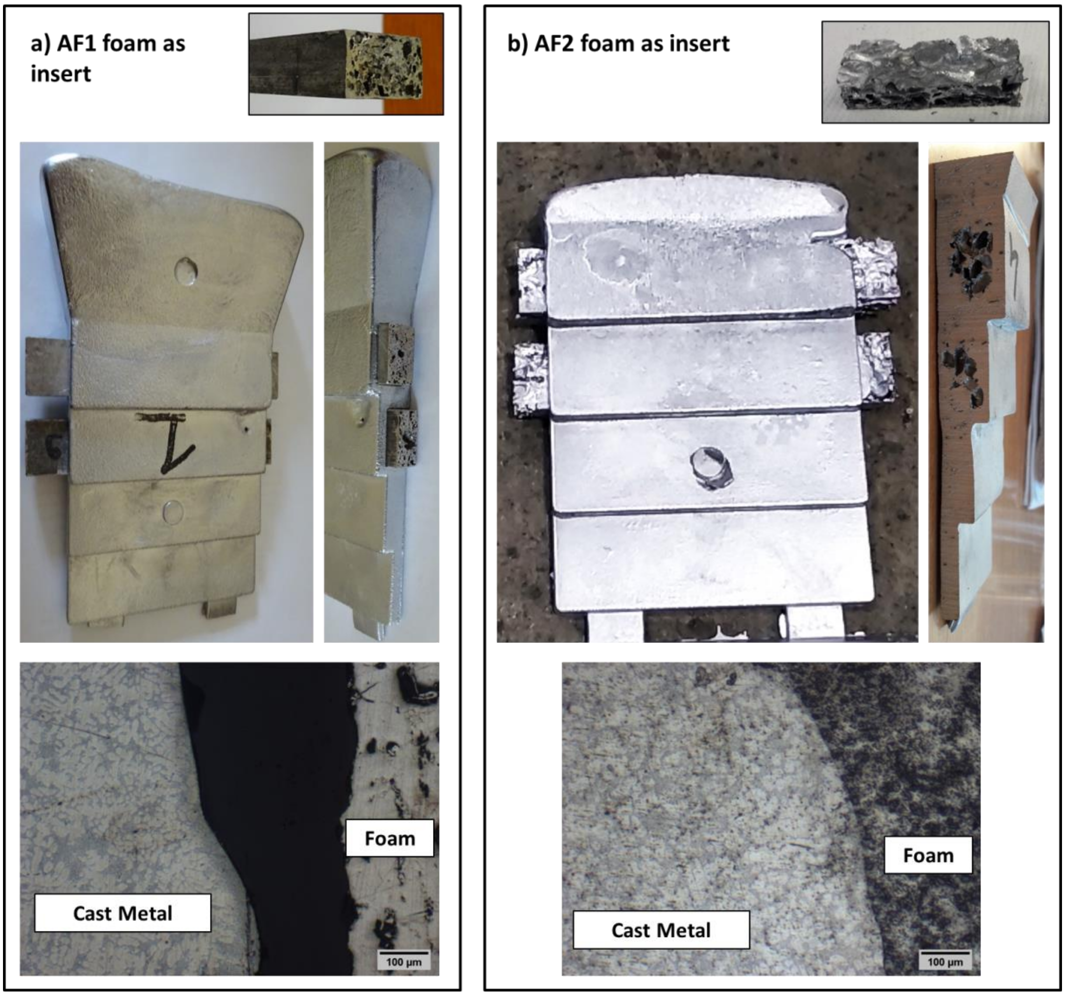

Figure 2. Casting experiments, **a**) AF1 foams as inserts, **b**) AF2 foams as inserts.

The visual appearance of cast samples and the optical images of the foam core- cast metal interface are reported in Figure 2 (-a) for AF1 foam inserts and b) for AF2 ones).

It can be observed that the foam core is completely unaltered after the casting experiment for AF1 (the foam bar maintains its shape and porosity) while a certain degree of infiltration can be documented for AF2, even if part of the porosity is maintained.

These observations suggest that the thicker outer skin of AF1 foams, which covers all the surface exposed to the molten metal effectively protect them from infiltration during casting experiments, while the thin outer skin of AF2 cores, which does not cover all the sample surface exposed to the molten metal, allows a certain infiltration.

Looking at the interface between the foam core and the cast metal, it can be observed that a thick gap (hundreds of microns) is clearly observable for AF1 cores while a metallurgical continuity is documented for AF2 cores in many zones of the interface. In this case it can be supposed that the well adhered oxide layer, rich in Mg, evidenced by SEM-EDS analyses on the outer skin of AF1 cores, can obstacle the reaction with the molten metal, as frequently reported in the literature for Al-Mg alloys. On the other hand, the surface of AF2 foams present a lower amount of oxides poorly adhered to the surface and consequently is more prone to reaction.

4. Conclusion

Al-based foams in the form of bars have been used as cores in gravity casting experiments. Foams with thick and continuous outer skin on the whole external surface are effectively protected by infiltration of molten metal and maintain their shape and porosity. However, the high surface oxidation of the outer skin inhibits its reaction with molten metal hampering metallurgical bonding between the foam core and cast metal. On the other hand, metallurgical continuity can be obtained when the outer skin is less oxidized. But in this case the lower thickness and the absence of skin in some areas of the external surface allow the infiltration of molten metal. This research suggests that Al-based foam with a thick and continuous outer skin can be suitable as cores in casting if their surface does not present a significant oxide layer, or if it can be properly removed.

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References

1. Bauer, B.; Kralj, S.; Busic, M.; Production and application of metal foams in casting technology. Tehnicki vjesnik 2013, 20, 1095–1102.
2. Banhart, J. Aluminum Foams: On the Road to Real Applications. MRS Bull. 2003, 28, 290–295, doi:10.1557/mrs2003.83.
3. G. Ubertalli, S. Ferraris, Al-Based Metal Foams (AMF) as Permanent Cores in Casting: State-of-the-Art and Future Perspectives, Metals 2020, 10, 1592; doi:10.3390/met10121592
4. Korner, C.; Singer, R.F. Processing of Metal Foams—Challenges and Opportunities. Adv. Eng. Mat. 2006, 2, 159–165, doi:10.1002/3527606165.ch1.
5. Hu, S.P.; Niu, C.N.; Bian, H.; Song, X.G.; Cao, J.; Tang, D.Y. Surface activation assisted brazing of Al-Zn-Mg-Cu alloy: Improvement in microstructure and mechanical properties. Mater. Lett. 2018, 218, 86–89.
6. Schällibaum, J.; Burbach, T.; Münch, C.;Weiler,W.;Wahlen, A. Transient liquid phase bonding of AA 6082 aluminium alloy. Materialwiss. Werkst. 2015, 46, 704–712.
7. S. Ferraris, S. Perero, G. Ubertalli, Surface Activation and Characterization of Aluminum Alloys for Brazing Optimization, Coatings 2019, 9, 459; doi:10.3390/coatings9070459