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Replication casting of open-cell AlSi7Mg0.3 foams

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ABSTRACT

A typical aluminum alloy for casting (AlSi7Mg0.3) was used to produce open-cell foams by replication of a salt precursor. The process was set to minimize complexity and costs of the casting operations: the preform sintering was avoided and mold temperature lower than the eutectic temperature of the alloy was used. Open-cell foams with a relative density about 35% and high compressive strength resulted. Material analyses showed that, in replication casting, the material response to the process is optimal and a homogeneous and fine grain size distribution is visible in the foams.

1. Introduction

Metal foams can be produced by means of a casting procedure in the case of the replication method. Molten metal is infiltrated into a porous salt precursor which is subsequently evacuated by dissolution in water. In 1961, a pioneering study of Polonsky et al. showed the feasibility of the replication casting for aluminum alloys: the authors sintered coarse rock salt (NaCl) in air for a few hours to fuse the grains together [1]. Molten metal was then poured in to infiltrate the pores of the sintered preform, and the salt dissolved to produce an open-cell foam with cell size about 3–4 mm. In 2001, San Marchi and Mortensen revive the production of high-purity foams by replication [2]. The salt pattern was prepared by sintering a packed bed of coarse chemical grade sodium chloride powder with an average particle diameter about 500 μm. In 2004, San Marchi et al. extended the study to the eutectic Al–Si alloy [3]. In 2005, Brothers et al. showed that the same technology could be used to cast amorphous metallic foams with an open-cell structure [4]. Zr-based metallic glass foams were produced by using SrF_2 and BaF_2 packed powders as precursors. After infiltration, the preforms were eliminated in 2 M nitric acid solutions and samples with relative densities in the 20–25% range were obtained. Therefore an appropriate combination of liquid metal and preform material is able to produce open-cell metal foams with medium relative densities but the mechanical properties of the final foams strongly depend on the cell structure (i.e. on the size properties of the precursor powder). In the same year (2005), Pollien et al. also showed that the replication process can be extended towards the production of functionally graded porous structures [5]. Individual layers of NaCl powder were pressed and stacked between two skins of dense aluminum. The stacked preforms were subsequently infiltrated with pure aluminum and solidified before dissolution of the salt in water.

In 2006, the uniaxial deformation of microcellular metals was further studied by Despois et al. which used tensile and compression tests on pure aluminum (99.99%) open-cell sponges (relative density from 13% to 33%) [6]. In 2008, Kadar et al. studied the compression behavior of salt-replicated foams, made of a eutectic Al–Si alloy, by means of acoustic emission [7]. In the same year, Boonyongmaneerat and Dunand extended the casting replication process to Ni–Mo–Cr foams thanks to the use of sodium aluminate as space-holder [8]. More recently, Yu et al. have discussed the case of a Zn–Al alloy (ZA22) with the typical NaCl space-holder [9].

Scientific studies show that the replication process is able to produce open-cell aluminum foams with good properties but a gap has to be filled to open this new manufacturing technology to the industrial world. Typical alloys for casting have to be used with casting procedures which could be integrated in the existing manufacturing systems. Moreover, a comparison is necessary between traditional processes and this new process in terms of material properties so as to understand if replication casting is able to achieve the maximum allowable performances of the material.

2. Materials and processing

Material used for this study was an aluminum alloy AlSi7Mg0.3 (also referred with EN AC 42100) which is equivalent to A356.0. This

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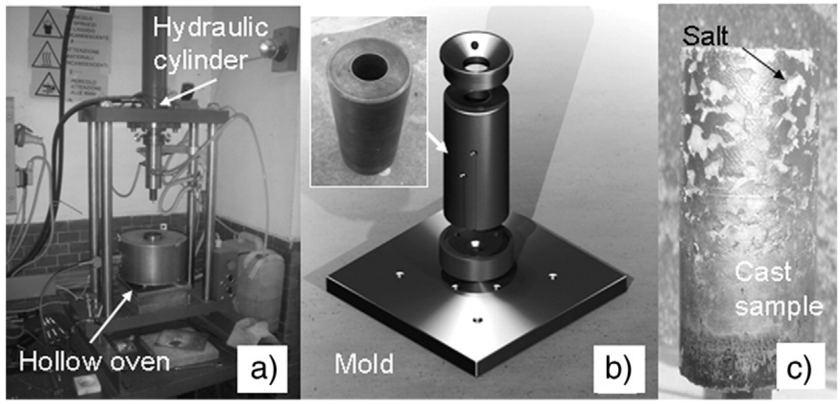

Fig. 1. Experimental apparatus for foam casting: a) the hydraulic press; b) the mold; c) a cast sample before the salt removal.

aluminum alloy is typical for gravity casting or pressure casting: in the former case sand molds or permanent molds can be used as well. A lot of parts of cars, motorcycles, engines, domestic appliances, and electric motors are made of this kind of alloy which can be considered as a reference for a lot of industrial applications.

Commercial NaCl (typical table and cooking salt) was used as precursor so as to reduce production costs: two different size distributions were used (fine and coarse). Salt particles in the range 1.2–5 mm resulted in the case of the coarse distribution, and 0.1–0.7 mm for the fine distribution. In order to simplify the fabrication procedure, precursor sintering was avoided and the salt particles were directly used as precursor after drying.

Salt infiltration was performed by means of the experimental apparatus of Fig. 1a. The mold (Fig. 1b) consisted of several parts so as to guarantee the correct execution of all the processing phases, from the salt pouring to the melt squeezing. The mold cavity had a cylindrical shape with a 28 mm diameter and a 100 mm height but the cast sample height depended on the quantity of the poured salt and melt. Generally, the casting process was designed to obtain samples with a height of 60 mm and a relative density about 40%. After cooling, the samples were extracted thanks to a screw which was fixed at the bottom of the squeezing plug.

A hydraulic cylinder was used to provide the pressure during the melt infiltration and solidification; a hollow thermostatic oven allowed to keep in temperature the mold. At each casting process, a sample (about 40 g) was cut from an aluminum alloy ingot, after it was put into a graphite crucible and molten in a muffle. In the same muffle, a second crucible was used to dry the same quantity of salt (40 g). The first step of the casting operation was pouring the salt particles in the mold: in the case of the coarse size distribution, the salt was sieved in a sieve with 1 mm mesh size so as to eliminate all the smaller particles. Subsequently, the melt was cast and the plug was rapidly moved to close the mold and infiltrate the melt in the salt bed. After infiltration, a pressure was applied by the hydraulic cylinder to reduce the cooling time. Samples were extracted (Fig. 1c) by means of the plug motion and put in water to dissolve the salt. The same process parameters were used for all the samples: a plug speed of 32 mm/s, a mold temperature of 500 °C, a melt temperature of 700 °C, a holding pressure of 25 bar, a holding time of 30 s.

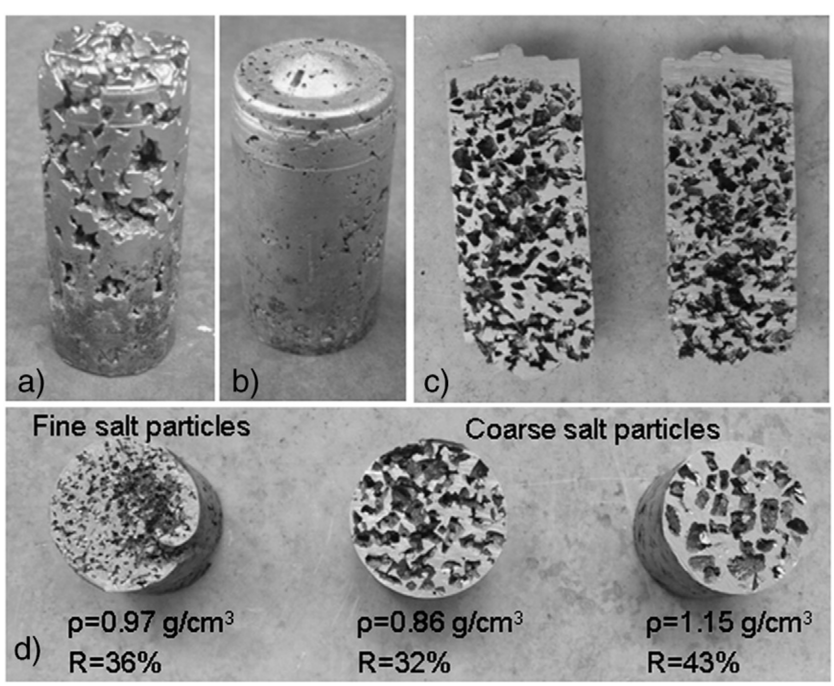

Fig. 2. Cast foams: a) typical sample; b) quasi-continuous skin; c) longitudinal sections; d) transverse sections.