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Production of cellular A2011 alloy from semi-solid state

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Materials

ABSTRACT

Purpose: The work investigates a new method to produce cellular A2011 alloy and analyses the influence of processing parameters on the quality of the product.
Design/methodology/approach: The proposed process involves pressing the alloy in the thixotropic semi solid state into a layer of space holder particles, which are removed after the forming operation. It is investigated the influence of the thixoforming temperature and the size of space holder particles, in the ability of penetration of the slurry in the porous pre-form as well as the structure of the obtained porous material. Products were analyzed by tomography and metallographic techniques.
Findings: The proposed process showed to be able to produce acceptable porous material in a simple and low cost technique; the cellular material produced was characterized as sponge, as presented open and interconnected porosity. The quality of the product depends rather on the processing temperature than on the size of space holder particles. Low liquid fraction in the thixotropic slurry can lead to incomplete infiltration and deformation of the pre-form. In the analyzed conditions influence of the size of space holder particles could be observed neither in the processing ability nor in the quality of the product. Density of produced porous material increases as processing temperature increases, due to the increase of cells walls thickness.
Research limitations/implications: The investigated process is suitable only for alloys with a significant solidification range.
Practical implications: The new method to produce cellular metals can represent energy savings and is highly operational when compared to conventional methods based on liquid infiltration, since lower temperatures are involved and no need of liquid handling is required.
Originality/value: The process proposed is a new one; no techniques based on thixoforming of the alloy into porous pre-forms are known so far.
Keywords: Metallic alloy; Cellular material; Metallic sponges; Thixoforming

1. Introduction

Metallic foams and sponges have been merging as a new class of engineering materials, due to their particular combination of properties: low specific weight, high stiffness, good energy absorption in impact, thermal and acoustic insulation, vibration damping, among others. Examples of commercial application of Al alloys foams and sponges can be found in the automotive industry, as panels, structural parts, components, impact absorbers [1]. Several manufacturing processes are available to produce cellular metals [2]; most popular techniques involve foaming of the metal by direct blowing of an inert gas or *in situ* dissociation of added blowing agents. Foams are highly unstable systems and difficulties in controlling the foaming parameters lead to the development of alternative routes to produce cellular metals, such as the solidification of liquid in confined spaces among particles of an inert material, which are removed after the metal solidification. The resulting product is characterized as open cells or sponges [3]. This work aims the investigation of producing porous A2011 alloy by infiltration of the metal in the thixotropic semi-solid state into a porous layer of removable space holders; therefore using lower processing temperatures.

2. Experimental procedures

A2011 extruded bars were used in the experiments. As space holders NaCl particles with dimensions of 1.6mm $>\phi_F >$ 1.0mm (fine), 3.15mm $> \phi_M >$ 1.6mm (medium) and $\phi_C >$ 3.15mm (coarse) were used. For thixoforming tests, sandwichs of two metallic disks with dimensions ϕ 44.5mm x h 10mm with an internal 20mm thick layer of NaCl particles were posicioned in a steel die inserted in a furnace on a press table. All assembly was heated to different temperatures within solidification range (from 620 to 640°C); after reaching the thixotropic condition samples were forged. After infiltration and total solidification of the alloy, particles of space holders were washed out in hot water, resulting in a porous product. Products were characterized concerning density, porous architecture and microstructure of cells walls. For metallographic preparation porous samples were infiltrated with transparent resin to allow cutting and polishing without destroying cells walls. Keller's etching was used. Porous architecture was analyzed by tomography; images of parallel sections were taken each 1.0mm.

3. Results and Discussions

3.1. General aspects of obtained products

Reliable porous products were obtained in almost all conditions tested; space holders were completely washed out of the porous product. Figure 1 shows typical samples produced: voids are interconnected, which characterizes the material as a sponge. Porous sizes present the same order of magnitude than sizes of space holder particles; coarse particles resulted in porosity with higher dimensions. The remaining compact Al alloy layers encapsulating the porous region present different thickness for different processing conditions, revealing different penetration ability of the semi-solid. As forming temperature increases, liquid fraction in the thixotropic slurry also increases, improving the infiltration, as observed comparing samples produced at 620°C and 640°C. In all conditions, the bottom layer of Al alloy was not infiltrated; temperature monitoring during processing showed that this region did not reached the required temperature to promote sufficient liquid fraction in the alloy.

General results on infiltration ability according to the processing parameters are presented in Figure 2. The ability of infiltration is evaluated according to the thickness of the layer of porous material. It is not shown results concerning the fine and medium space holder particles + lower temperature, since the products in these situations were too brittle to be handled.

Results show clearly the influence of temperature: higher the liquid fraction, higher the infiltration ability. On the other hand, the influence of dimensions of space holder particles can not be established in situations where the liquid fraction is high. However, in cases where liquid fraction is low, the utilization of space holders with small dimensions can jeopardize the success of the processing.

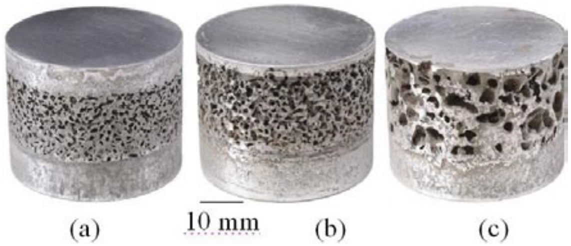

Fig. 1. Typical cellular A2011 produced by thixoforming into a layer of NaCl particles. a) and b) fine; c) coarse. Thixoforming conditions: (a) T = 620°C; (b) and (c) T=640°C

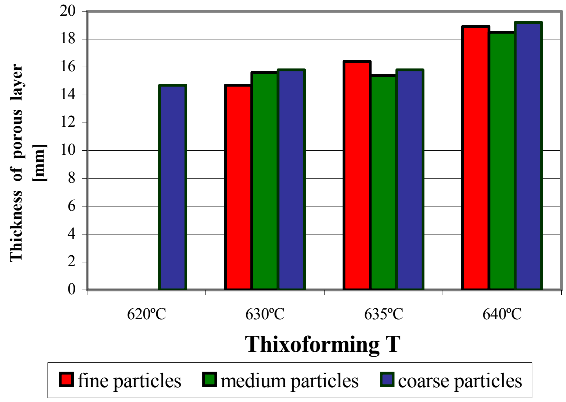

Fig. 2. Thickness of porous material x processing parameters

Therefore, the proposed process is suitable to produce reliable porous material in a wide range of operational conditions; however, special attention must be paid when dealing with low liquid fraction and fine space holder particles.

3.2. Architecture of porous

Cellular materials are characterized by the porous "architecture", i.e. their volume fraction, dimensions and distribution, as well as thickness of cells walls. These are the structural parameters generally used to correlate structure x properties of a porous material. The majority of cellular materials is inherently heterogeneous, showing variations in the architecture of porous and mass distribution; contains usually 70 to 90% of empty space and variable cells walls thickness.

Some typical results on internal architecture of produced porous materials are shown in Figure 3. It is possible to observe that porosity is interconnected; geometry of porous is highly irregular, somewhat difficult to be characterized. Cells walls present thickness varying from 0.1mm to 5.0mm.

Measurements show that the coarser the space holder particles used, coarser the thickness of cells walls, as expected. These values don't depend on the thixoforming temperature, indicating full infiltration of the semi-solid in all the analyzed samples, except when processing at the lowest liquid fraction + finest NaCl particles, where lack of infiltration was detected.

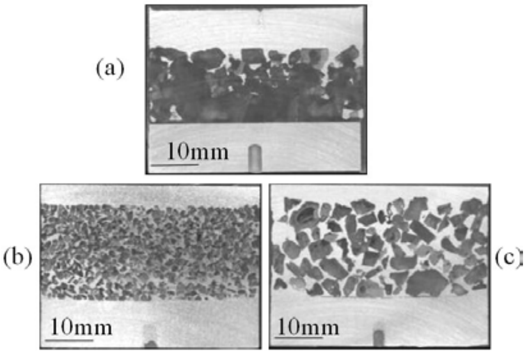

Fig. 3. Transversal sections of cellular A2011. Thixoforming conditions: (a) T = 620°C, coarse NaCl; (b) T = 640°C, fine NaCl; (c) T = 640°C, coarse NaCl

In all cases it could be observed some cavities with dimensions smaller than the particles used, indicating the possibility of their fragmentation in the forming process; as well as cavities with dimensions bigger than the original salt granules as a result of their agglomeration. Indeed, it can be observed in Figure 3 (a) that particles can be compressed against the bottom metallic layer. This situation could be observed when low liquid fraction was present in the semi-solid alloy, making it difficult to flow within the layer of space holder granules. As thixoforming temperature increases, the possibility of compression of the salt layer decreases, as well as the presence of big voids in the cellular product. Moreover, the thickness of the layer of the cellular material increases, as observed previously in the values shown in Figure 2.

All samples of cellular A2011 produced were submitted to X-Ray tomography. Typical results are presented in Figure 4. Images shown parallel consecutive plans, from top (1) – upper metallic disk, to bottom (10) – bottom metallic disk. It can be observed good dispersion of porous and reliable products, independent on the size of NaCl particles used.

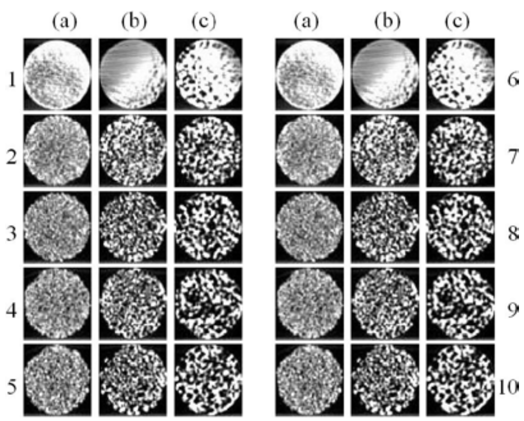

Fig. 4. Tomography images of cellular A2011 produced by thixoforming at 640°C, into a layer of space holder particles with dimensions: (a) fine; (b) medium; (c) coarse

As a general result, it could be confirmed that the porous are interconnected; distribution of porous can be considered, in general, reasonably homogeneous in the whole volume of porous material produced, except in some cases where the processing parameters allowed agglomeration of particles, leading to incomplete formation of cell walls: low liquid fraction in the semi-solid alloy + fine NaCl particles.

3.3. Microstructure of cells walls

In spite the usual characterization of mechanical properties of cellular materials related to the porous architecture, also the microstructure of the metallic component – cell walls – can exert significant influence in the materials performance [4].

Micrographies of three different regions of samples produced at different temperatures, using coarse NaCl particles, are shown in Figure 5. It can be observed that the structure of the upper metallic disk presents globular primary α phase surrounded by eutectic in all cases. It can be considered that at least the eutectic phase observed in the solidified material was liquid in the semi-solid state.

These structures are typical of thixotropic slurries produced by partial melting [5]. Average diameter of solid globules in the thixotropic slurry is in the range 320 to 340µm. These dimensions can be considered high when dealing with thixotropic metals, but still the slurry is perfectly viable of flowing among the space holder granules.

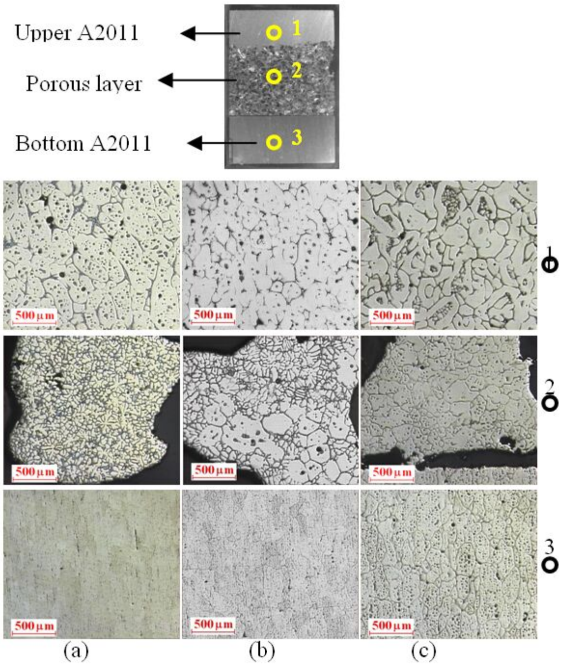

Fig. 5. Microstructures of cellular A2011 produced by thixoforming at: (a) T = 620ºC; (b) 630ºC; (c) 640ºC into coarse NaCl particles

It can be observed the effect of increasing processing temperature: higher the temperature, higher the liquid content (eutectic content after solidification) in the slurry to be infiltrated.

The microstructures of the bottom metallic disk present significantly lower liquid fraction for all temperatures used. Indeed only slight amount of liquid could be observed in samples treated at temperatures lower than 640°C. This explains the lack of infiltration from the bottom metallic disk observed; with appropriate heating control during processing it can be produced porous material with encapsulating metal layers of different thickness.

Microstructure in the porous region of the sample produced at the lower temperature shows fine α phase with dendritic morphology, a typical as-cast situation obtained from liquid solidification. This result shows that there was no infiltration of the slurry as a whole, but the liquid alone was pushed through the porous layer of NaCl granules. Segregation of liquid during thixoforming processing was already observed in forging operations [6] and can be reduced by increasing forming rate.

As forming temperature increases, microstructure of cells walls tend to be more similar to those of the thixotropic slurries from which they were formed, as shown in Figure 5 (b) and (c). It can be observed that microstructures produced by thixoforming at 630°C present α phase with morphologies both dendritic - resulted from conventional liquid solidification -, and globular, similar to that of the thixotropic slurry in the upper region. This result indicates less separation of solid and liquid phases during processing; the higher liquid content allowed the flowing of the slurry as a whole. Indeed, at the higher temperature the microstructure of cells walls is typical thixocast, similar to that of the compact metal layer at the top.

Although mechanical tests were not yet performed at this point of the ongoing work, it is possible to suppose that the deformation behavior of the produced porous material is high [7], as far as the cell walls are concerned. In addition, as neither any contamination of the metal by the space holder particles was observed, nor their entrapment in the porous material, nor hard particles from foams stabilizers are present it is possible to predict appropriate mechanical properties.

3.4. Density

Results on density of cellular A2011 produced by thixoforming show, for all conditions tested except one, a relative density of the cellular to the bulk material smaller than 0.30. The exceptional case was obtained for the highest temperature + coarsest granules of NaCl: in this case, thick cells walls produced lead to a density ratio of 0.35.

Concerning the influence of the processing variables it could be observed a tendency of higher values of density with increasing processing temperature, attributed to the increase of cells walls thickness with increasing the infiltration ability of the semi-solid.

Results on voids contents show values in general superior to 60% in all cases. Maximum value is 89% and minimum is 64%. It could be observed that with increasing processing temperature, voids content tends to decrease; as already detected in the density measurements, this situation leads to thicker cells walls and increase in density values.

4. Conclusions

Results showed that the proposed process to produce cellular A2011 based on thixoforming of the alloy into a layer of NaCl particles as space holders is perfectly feasible and can result in reliable products. Complete washing out of the particles is possible since the porous are interconnected. Density and volume of voids presented are those of typical cellular metals. In the analyzed conditions, the influence of the size of space holder particles in the infiltration of the thixotropic alloy was not sensitive, unless the liquid fraction in the semi-solid is low. A critical parameter to be controlled in the process is the liquid fraction in the semi-solid. In situations where liquid fraction is small, infiltration is jeopardized leading to incomplete filling and compression of the space holder particles, resulting in weak cells walls and the presence of voids with big dimensions in the material. Therefore, with proper temperature control, good quality products can be obtained in a simple, low cost and easily controllable process.

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