Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 25 (2020) 55–62

Structural Integrity Procedia

www.elsevier.com/locate/procedia

1st Virtual Conference on Structural Integrity - VCSI1

Mechanical behavior of PCMT and SDP Al foams: a comparison

Girolamo Costanza[a]*, Maria Elisa Tata[b]

[a]*Dipartimento Ingegneria Industriale – Università di Roma Tor Vergata, Via del Politecnico, 1 – 00133 Rome - Italy*
[b]*Dipartimento Ingegneria Civile e Ingegneria Informatica – Università di Roma Tor Vergata, Via del Politecnico, 1 – 00133 Rome - Italy*

Abstract

In this paper Powder Compact Melting Technique (PCMT) and Sintering and Dissolution Process (SDP) are compared and discussed. In the first process melting of the powders is required for the foam production. Mechanical characterization of Al foams produced with the two techniques has been performed by means of static compressive tests in order to make a direct comparison. The PCMT foams show higher mechanical properties in compressive tests if compared to the SDP foams and are ideal for structural applications in which energy absorption is the main task. When the control of the morphology as well functional properties (e.g. noise and vibration absorption) related to the interconnected porosity are fundamental, SDP foams are to be preferred.

Keywords: Aluminum foams; Mechanical properties; Compressive behavior.

1. Introduction

Metal foams belong to a particular class of metals with an interesting mix of mechanical and physical properties. Characterized by low density and high strength, metal foams show stiffness/weight ratio five times greater than the bulk material and a large plateau in the compressive stress-strain diagram. High toughness and ability to absorb sounds, vibrations and shocks allow metal foam to be increasingly widespread in many industrial applications. Many different

* Corresponding author. Tel.: +39 06 72597185
E-mail address: costanza@ing.uniroma2.it

10.1016/j.prostr.2020.04.009

metals and alloys can be foamed (for example Al, Ti, Cu, Fe, Zn, Superalloys) employing different production processes. A considerable interest has been placed towards Al foams, for the favorable combination of mechanical properties and density and for the relatively low melting temperature which allows easy production method. In this work two different manufacturing processes are compared in terms of physical and mechanical properties of the Al foams. The main attention has been focused on the relative density (ρ/ρ_0), on the absorbed energy and on the level of plateau stress and strength in compressive tests.

2. Production methods

Al foams can be manufactured with different production processes, allowing to obtain different kind of porosity (open, closed). More generally the production methods can be classified in four families, according to the state of the metal (Banhart 2001, Heim et al. 2018): from liquid, from solid (powder), from vapor and from ion metal. Foams properties depends from the base metal, the relative density, the porosity type (open or closed) and the porosity size. Many different metals and alloys can be foamed: Al, Ti, Cu, Fe, Zn, Superalloys (Costanza and Tata 2013, Costanza et al. 2015, Costanza et al. 2016, Costanza and Tata 2018). For any process employed the main goal is to obtain homogeneous and isotropic properties (Costanza et al. 2011). A neural network has been implemented too with the aim to foresee and correlate the morphology (and the mechanical properties) starting from the composition of the precursor (Costanza et al. 2008). In this paper the analyzed processes are: Powder Compact Melting Technique and Sintering and Dissolution Process. In the first process melting of the powders is required for the foam production. The process starts with powders mixing, with different amount, of three components: the base metal or alloy (Al), the foaming agent (TiH_2) which decomposes with gas releases (H_2) in the metal matrix and the stabilizing agent (SiC). In the successive step the mix is compacted in a mold at a pressure up to obtain a dense precursor. In the present work it is a cylindrical precursor (diameter 15 mm). Next step is foaming, inside a oven at a temperature higher than the melting point of the base metal. During this step gas release (H_2) allows pores to form inside the molten metal (Banhart 2001, Heim et al. 2018, Costanza et al. 2003, Costanza et al. 2005). In the last step gas bubbles remain entrapped in the metal during cooling in the water. In general metal foaming is characterized by three main phases: bubbles nucleation, bubbles growing and bubbles coalescence. In the third step the walls between bubbles reach a threshold value of thickness up to collapse and coalescence. To avoid this phenomenon a stabilizing agent (SiC for example) can be used to fix cell walls, increasing the melt viscosity and reducing the flow responsible of the cell walls thinning. Foams produced by this manufacturing process show closed cell morphology. The other method described in this work, SDP, is based on the adoption of NaCl or urea crystal as “filler” and the melting of the powder is not required. A sketch is reported in Fig. 1.

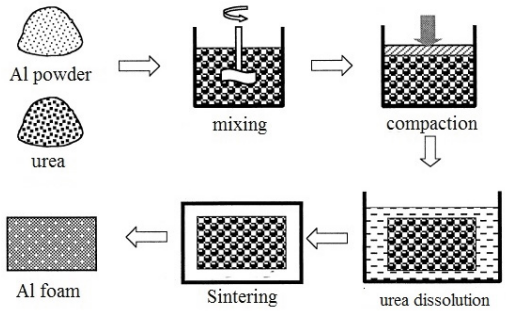

Fig. 1. Sketch of the SDP.

Nomenclature

PCMT	Powder Compact Melting Technique
SDP	Sintering and Dissolution Process

With SDP method open cell foams are manufactured and among all the processes is one of the least expensive due to the low cost of the materials and the equipment required. The main manufacturing steps are the following: mixing of the filler and the base metal powders, compaction, filler dissolution in water and sintering. Initially defined for Al foams, the method can be adopted for many other metals and alloys. The shape and size of the porosity are directly dependent on the morphologies of the filler which must be accurately selected. Foam density and mechanical strength are strictly connected to the amount of urea added to the metal powders. Also the compaction is fundamental due to the critical pressure required to break the thin aluminum oxide layer on the powders surface. Next step is urea dissolution in boiling water for 45 minutes: nevertheless the process sometimes is not completed, especially for NaCl crystals surrounded by Al. For this reason the porous structure is not fully interconnected and this phenomenon is more evident with lower filler content. The final step is sintering, performed at a temperature lower than the melting point of the metal. In particular for aluminum it is 640 °C for three hours.

3. Materials and experimental

Mechanical characterization of Al foams produced with the two techniques has been performed by means of static compressive tests in order to make a direct comparison. In the past the mechanical characterization has already been focused concerning Al foams (Costanza et al. 2012), AISI 316 tubes filled with Al foams (Costanza et al. 2015), AlSi foams (Brugnolo et al. 2015) and also the comparison between static and dynamic behavior (Costanza and Tata 2008). For the PCMT TiH_2 has been adopted as blowing agent: its typical decomposition temperature (400 °C) can be suitable employed for Al foaming. As stabilizing agent SiC powder has been adopted (Deqing and Ziyuan 2003). For the SDP Al powders have been mixed with urea $(NH_2)_2CO$ or salt (NaCl). Both of them are available, cheap and have spherical shape. After blending Al powders with urea or TiH_2 and SiC for PCMT, next step is mixing by means of a mechanical stirrer for 10 minutes up to obtain a uniform and homogeneous mix. In addition for the SDP a liquid agent (acetone) is employed as a binder agent between Al and urea due to the great difference in size (3 order of magnitude) which doesn't allow a uniform mixing. Acetone, inert with Al and urea, has been selected as binder agent thanks to its high volatility. Mixing is followed by compaction process inside a mold. 12 tons applied on 15 mm diameter precursor have been identified as adequate to break the thin oxide film on the Al powders surface. After compaction the precursor can be handled and the step processes are different. For the PCMT the precursor is placed in the oven at 700 °C inside a copper crucible. At this temperature H_2 release in form of bubbles which remain entrapped inside Al once melting. At the end of the expansion of the precursor the liquid foam is quenched in water and finally the Al foam is extracted from the crucible. For the SDP there are some differences from the one in literature (Zao and Sun 2001). The presence of urea, melting at 133°C and evaporating at 135 °C doesn't allow to perform sintering before dissolution. So urea particles dissolution in boiling water is maintained for 30 minutes. Successively sintering is performed in order to get adequate mechanical strength; time and temperature have been suitably modified after many attempts.

4. Experimental results

According to the PCMT Al foams the following amount of TiH_2 have been selected while the SiC content has been kept constant (2.8 weight %):

0.075 % TiH_2
0.1 % TiH_2
0.2 % TiH_2
0.4 % TiH_2.

Similarly for the SDP the following composition have been selected (volume %):

45 % Al – 55 % urea;
55 % Al – 45 % urea;
66 % Al – 34 % urea;
80 % Al – 20 % urea.

In Tab. 1 density and relative density of the manufactured foams as a function of the composition are reported.

Table 1. Composition, density, relative density of Al foams manufactured with PCMT and SDP methods.

Composition	ρ (g/cm^3)	ρ/ρ_0
0.075 % TiH_2 – 2.8 % SiC	1.00	0.37
0.1 % TiH_2 – 2.8 % SiC	0.87	0.32
0.2 % TiH_2 – 2.8 % SiC	0.65	0.24
0.4 % TiH_2 – 2.8 % SiC	0.60	0.22
45 % Al – 55 % urea	0.68	0.25
55 % Al – 45 % urea	0.92	0.34
66 % Al – 34 % urea	1.11	0.41
80 % Al – 20 % urea	1.89	0.47

The stress-strain diagram in static compression tests for Al foams manufactured by PCMT and SDP respectively are reported in Fig. 2 and Fig. 3.

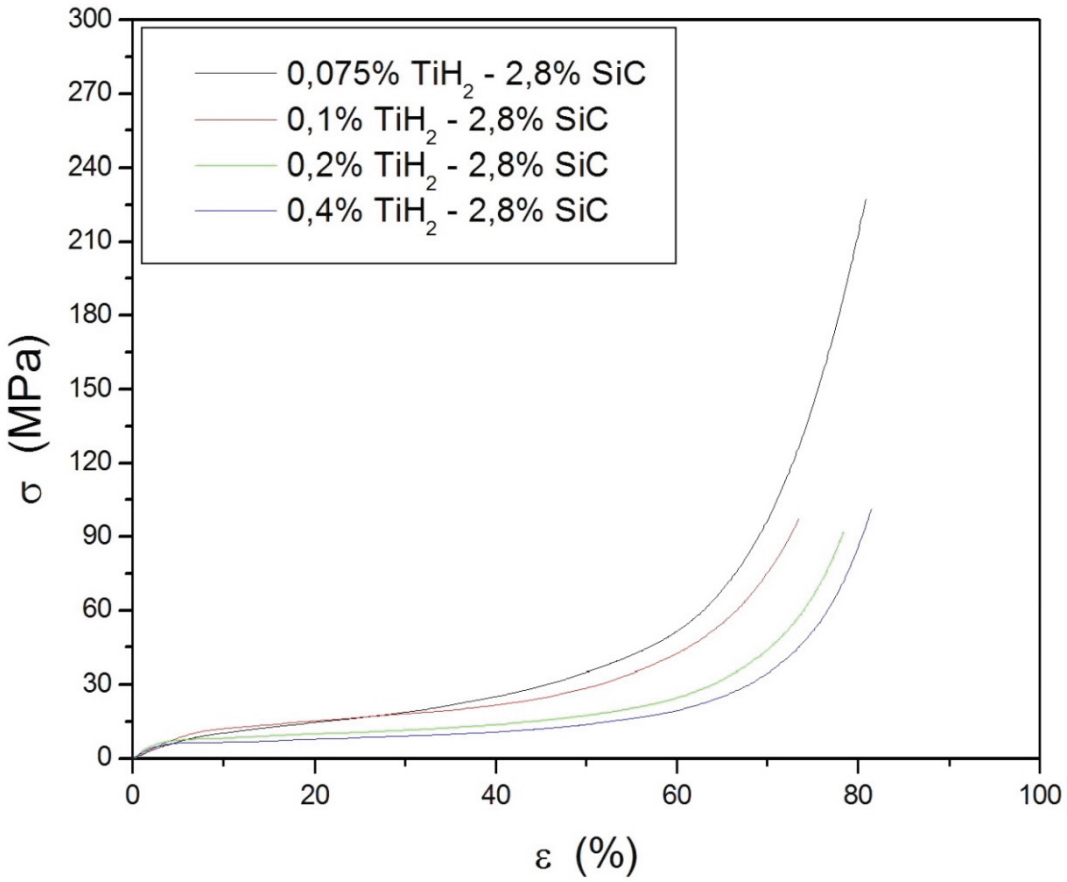

Fig. 2. σ-ε diagrams for Al foams manufactured by PCMT.

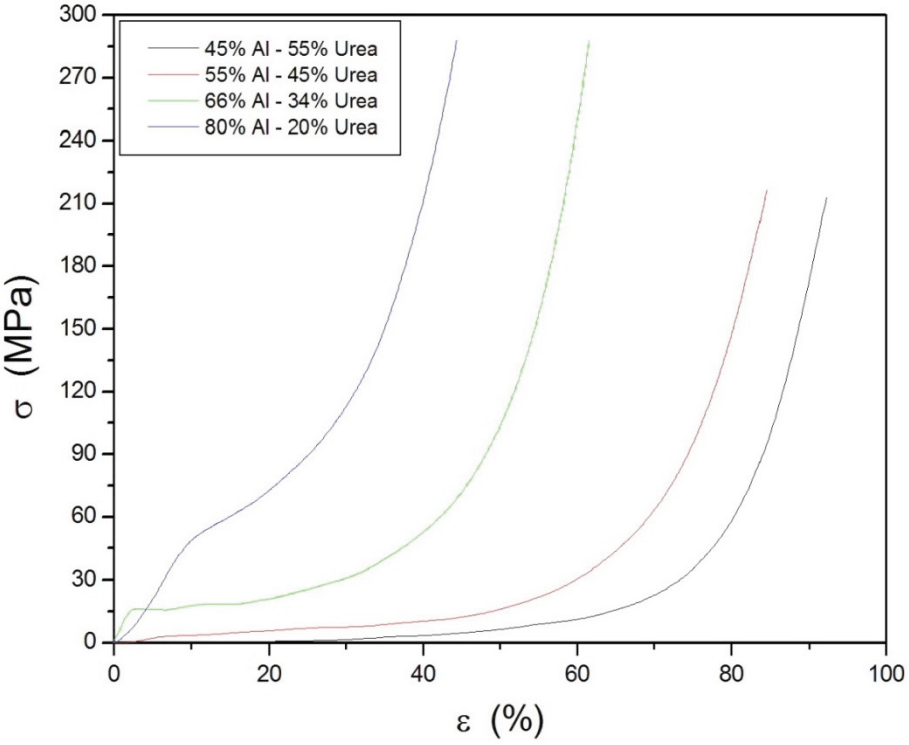

Fig. 3. σ-ε diagrams for Al foams manufactured by SDP.

5. Discussion

For PCMT Al foams the following considerations can be highlighted:
1) The lower the TiH_2 content, the higher the plateau stress;
2) The lower the TiH_2 content, the shorter the maximum strain till the complete densification of the foam;
3) The lower the TiH_2 content, the greater the slope of the densification curve.

Analogously for the SDP foams the following considerations can be highlighted:
1) The lower the urea content, the higher the plateau stress;
2) The lower the urea content, the shorter the maximum strain till the complete densification of the foam;
3) The lower the urea content, the greater the slope of the densification curve.

Application fields of these two kind of foams are quite different according to the different properties discussed in the following. Analyzing the trend relative density – composition (Tab. 1) it can be noticed that comparable values between the two different processes only reducing the amount of foaming agent up to the foamability limit and increasing the urea content up to more than 50% can be achieved.

Considering the particular applications in which metal foams can be employed it is possible to evidence that for light structures it is preferable to adopt PCMT foams because SDP ones require compositions not easy foamable. Looking at the energy absorbed by different foams (up to a threshold stress level of 50 MPa) it can be noticed that PCMT foams exhibit the maximum energy absorption for a content of 0.2% TiH_2 (Fig. 4) while for SDP foams the maximum energy absorption is obtained with 34% or 45% urea content (Fig. 5). Absolute values of absorbed energy are much lower in SDP foams if compared with the PCMT with the same dimensions of the foam samples.

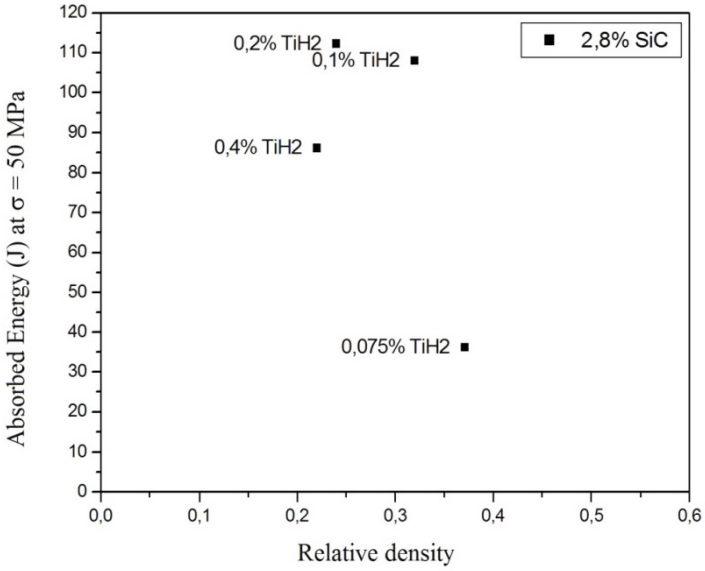

Fig. 4. Absorbed energy – relative density for PCMT foams.

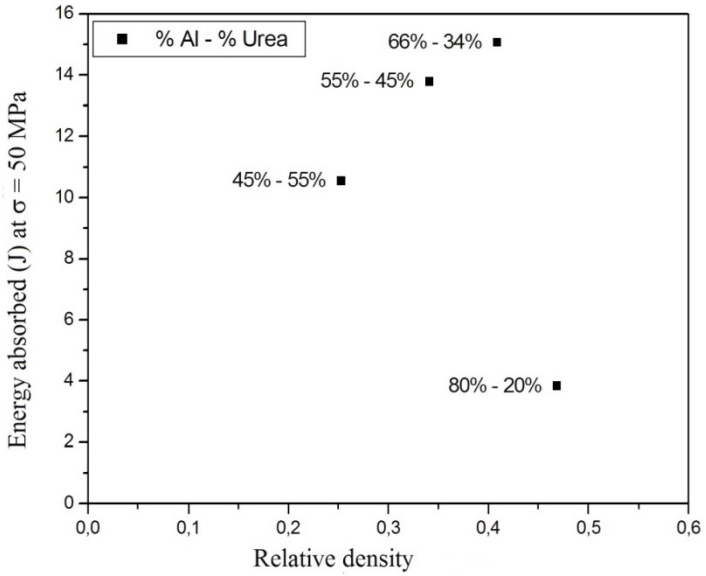

Fig. 5. Absorbed energy – relative density for SDP foams.

6. Conclusions

In the comparison between PCMT and SDP foams it is possible to highlight that absorbed energy, up to a threshold stress level (50 MPa), is much higher in the first ones (115 J) vs. the last ones (15 J). Consequently PCMT foams are to be preferred in that applications where energy absorption needs to be maximized. It is important to observe that different porosities size and shape (open or close) and consequently mechanical properties can be correlated to different manufacturing processes. As shown in Fig. 6 PCMT foams are characterized by closed-cell porosity. To evidence the porous structure a longitudinal cross-section has been cut along the foaming direction. This kind of foam is surrounded by a thin metal layer on the cylindrical surface which enhance the mechanical properties.

Fig. 6. Cross section view of a closed-cell foam manufactured by PCMT.

For what concerns the SDP foams the open cell porosity extends up to the surface as evidenced in Fig. 7.

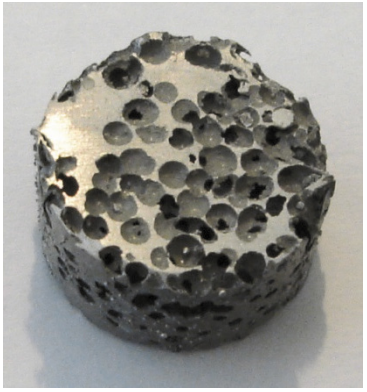

Fig. 7. Top view of a open-cell foam manufactured by SDP.

In conclusion PCMT foams show higher mechanical properties in compressive tests if compared to the SDP foams are ideal for structural applications in which energy absorption is the main task. When the control of the morphology as well functional properties (e.g. noise and vibration absorption) related to the interconnected porosity are fundamental, SDP foams are to be preferred.

References

Banhart, J., 2001. Manufacture, characterization and application of cellular metals and metal foams. Progress in Materials Science 46(6), 559-632.

Brugnolo, F., Costanza, G., Tata, M.E., 2015. Manufacturing and characterization of AlSi foams as core material. Procedia Engineering 109, 219-227.

Costanza, G, Gusmano, G., Montanari, R., Tata, M.E., 2003. Manufacturing routes and applications of metal foams. La Metallurgia Italiana 95(2), 31-35.

Costanza, G., Montanari, R., Tata M.E., 2005. Optimization of TiH_2 and SiC content in Al foams. La Metallurgia Italiana 97(6), 41-47.

Costanza, G., Gusmano, G., Montanari, R., Tata, M.E., Ucciardello, N., 2008. Effect of powder mix composition on Al foam morphology. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and applications 222(2), 131-140.

Costanza, G., Tata, M.E., 2008. Dynamic and static compressive behavior of aluminium foam, 4th International Structural Engineering and Construction Conference (ISEC 04) – Innovation in Structural Engineering and Construction 2, 919-922.

Costanza, G., Tata, M.E., 2011. Metal foams: recent experimental results and further developments. La Metallurgia Italiana 103(3), 3-7.

Costanza G., Mantineo, F., Missori, S., Sili, A., Tata, M.E., 2012. Characterization of the compressive behavior of an Al foam by X-ray computerized tomography. TMS Light Metals, 533-536.

Costanza, G., Tata, M.E., 2013. Recycling of exhaust batteries in lead-foam electrodes. Rewas 2013 Enabling Materials Resource Sustainability, 272-278.

Costanza, G., Sili, A., Tata M.E., 2015. Mechanical Characterization of AISI 316 tubes filled with Al alloy foams. La Metallurgia Italiana 107(3), 9-14.

Costanza, G., Dodbiba, G., Tata, M.E., 2016. Optimization of the process parameters for the manufacturing of open-cells iron foams with high energy absorption. Procedia Structural Integrity 2, 2277-2282.

Costanza, G., Tata, M.E., 2018. Lead and lead alloys foams production. Acta Metallurgica Slovaca 24(4), 347-352.

Deqing, W., Ziyuan, S., 2003. Effect of ceramic particles on cell size and wall thickness of aluminum foam. Materials Science and Engineering A 291(1-2), 45-49.

Heim K., Moreno F.G., Banhart J., 2018 Particle size and fraction required to stabilise aluminium alloy foams created by gas injection. Scripta Materialia 153, 54-58

Zao, Y.Y., Sun, D.X., 2001. Novel sintering-dissolution process for manufacturing Al foams. Scripta Materialia 44(1), 105-110.