**Metal Foam by Powder Metallurgy**

**Routes: A Review Paper**

***Mohd. Hassan, Sanjay Kumar Jha***\****, Vijay Pandey***

Department of Production Engineering, Birla Institute of Technology, Mesra,

Ranchi, Jharkhand, India

***Abstract***

*The aim of study is to evaluate and optimize the process parameters and several control factors of foaming because of their physical and mechanical properties such as, high stiffness, high compressive strength, and good energy absorption. Powder metallurgy is a method in which aluminum and aluminum alloy are mixed with TiH2 or other blowing agents for foam making process. Powder mixed is consolidated to obtain a high dense foam compact precursor like hot extrusion or pressing. The precursor is heated above the melting point to obtain the foam. Due to presence of oxide contents in the aluminum powder it plays a significant role in the expansion and stability of foam in PM routes. Their applications are in wide range of structural and functional products due to their exceptional mechanical, thermal, acoustic, electric, and offer great potential for light weight. The cellular structure and pore size also depends on the process parameter, size of the particles, and relative density.*

***Keywords:*** *Powder metallurgy, foaming, blowing agents*

\****Author for Correspondence*** E-mail: sanjujha@hotmail.com

**INTRODUCTION**

The term foam in its original sense is reserved for a dispersion of gas bubbles in a liquid, and is identified as a new class of materials of great interest due to their unique combination of properties, caused by their cellular structure and metallic behavior [1–5].

Different methods used for the production of metallic foams are as follows:

* Foaming of metals by gas injection (Hydro/Alcan).
* Foaming of metals with blowing agents (Alporas).
* Solid gas eutectic solidification (Gasar).
* Making of foam by powder compact method (Foaminal/Alulight).
* Making of metal foam through casting process containing blowing agents (Foam Casting).

Metal foams are new class of material with low densities and novel physical, mechanical, thermal, electrical and acoustic properties. Metal foams are produced by the combination of metals and alloys mixed with blowing agents [6–13]. The production of metal foam by powder metallurgy process begins with the mixing of metal powder-elementary metal powder, alloy powder or metal powder blends, with a blowing agent, after the compaction can be done by any technique that ensures that the blowing agents is embedded into the metal matrix without any notable residual porosity. Compaction can be done on the required shape of the precursor e.g. compaction methods are hot uniaxial or isostatic compression, rod extrusion or powder rolling.

The precursor is then kept on the pre-heated furnace at pre-determined temperature. The blowing agent, which is distributed within the metallic matrix, decomposes. The oxide content in the metals has been found to have a significant effect on the expansion and stability of foam. The time required for expansion and stability depends on temperature and size of the precursor ranging from a few seconds to several minutes.

The density of the solid metal foam can be controlled by percentage of blowing agents, temperature, and heating rates. For zinc and aluminium alloys, TiH2 and ZrH2 are used as blowing agents. This method is not restricted to aluminium and its alloys: zinc, brass, lead, gold and some other metals can also be formed by choosing appropriate blowing agents and process parameters [14–23].

Application of metal foam is most important in the automotive and transport industries, but also in other fields, where high surface area, low flow resistivity, high damping capacity, catalyst, light weight structure, and good thermal conductivity are required, as in aerospace, railway, ship, building, biomedical, and also in filter, heat exchanger, silencers, and for water purification etc.

**Methods for Characterizing Cellular Materials**

1. Non-destructive testing, and
2. Destructive testing.

***Non-destructive Testing***

* Density measurements,
* Dye penetration measurements,
* X-ray radiography and radioscopy,
* X-ray computed tomography,
* Eddy-current sensoring,
* Acoustic measurements,
* Vibrational analysis,
* Porosimetry and permeametry, and
* Electrical and thermal conductivity measurements.

***Other Methods***

* X-ray and neutron small angle scattering,
* Diffusive wave spectroscopy, and
* Ultrasound imaging.

***Destructive Testing***

* Optical image analysis,
* Corrosion testing, and
* Mechanical testing [5].

**REVIEW OF LITERATURE**

This study has identified some important issues for establishing the gap in literature, namely;

1. Definition of metal foam,
2. Process parameters,
3. Experiment procedure
4. Use of Al-TiH2 as blowing agents,
5. Use of Al-alloy and TiH2 as blowing agents,
6. Use of Al-alloy and other than TiH2 as blowing agents (eg.MgCO3 or zirconium oxide),
7. Size of the metal particles and size of the blowing agents,
8. Empirical evidences of metal foam coming from different researches,
9. Hot compaction of precursor,
10. Cold compaction of precursor,
11. Generated a closed cell metallic foam,
12. Generated open cell metallic foam,
13. Impact of metal foam on environment,
14. Effects of the oxides presents in the metal practices,
15. Mechanical damping of metal foam,
16. Mechanical properties and different tests of mechanical properties,
17. Characterization of foaming kinetics,
18. Characterization of cell morphology,
19. Cellular structure of metal foam,
20. Size of the pores,
21. X-ray radiography and radioscopy of metal foam,
22. Micro structure of metal foam,
23. Case study,
24. Structural application of metal foam in various industries sectors,
25. Barriers of metal foam practices, and
26. Graphical and curves representation of different test results (e.g. mass, volume, density, time, temperature).

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**CRITICAL APPRAISAL**

* Few researchers have attempted to define metal foam by powder metallurgy route [1, 25]. There seems no consensus on its definition.
* Many researchers used different process parameters and experiment procedures [1, 3, 4]. Insufficient ability to make foam of a constant quality with pre-defined parameters.
* Many researchers have given empirical evidences of metal foam [3, 14–16]. The thermal decomposition of titanium hydride powder is a complex process strongly modified by the powder particle size.
* Only few researchers have given mechanical damping of metal foam [3]. The precision of such measurement is not very high due to local density variations and the damping depends on the vibrational frequency.
* Many researchers use metal particle as Al and TiH2 as blowing agents [3, 14, 15]. In foam irreversible (plastic) deformation can occur at low stress.
* Few researchers have defined effects of the oxides presents in the metal particles [3, 4, 14, 16]. Oxide cluster were observed throughout the foam and they appeared as the broken surface films, as a result of shearing during compaction because they are free to move in the molten expanding precursor.
* Very few researchers have given the characterization of cell morphology [2, 7, 12]. Many of the designs and manufacturing features might influence the production of foam, which will be the subject of future investigation.
* Very few researchers have given the case study [1, 16]. When the metal foam is filled in the beam the absorbed energy is increased by 32% compared to the basic beam.

**PAPER REVIEWS**

* In this research different properties of solid metallic foam and applications of metallic foam are discussed. And also the manufacturing routes are described [1–3].
* This paper is focused on the newly developed technology which leads to an increased availability of production process for wide range of cellular metals and alloys and also improves the process control to produce better reproducibility and predictability [1, 3].
* Aim of this paper is to evaluate the properties and optimize the control factors of powder technique, correction between the final properties of the foam parts and the process parameter is still not complete, by using the ANOVA statistical analysis and MINI Tab software for plotting the effect of individual factors [2].
* In this paper a systematic study of the dehydrogenation behavior of TiH2 powder of different particle size distribution was under taken with the aid of thermo gravimetric analysis [14].
* In this paper the idea is to create metallic foam at lower temperature than the melting point of pure aluminum using a transient liquid phase that softens the matrix prior to bulk expansion [14, 15].
* This paper focuses on the reaction rate, which is quite effective to obtain highly porous specimen. The B4C powder reacts with titanium and generates large amount of reaction heat as;
  + 3Ti+B4C→2TiB2+TiC+761 KJ

Cell morphology has a significant influence on various physical and mechanical properties such as strength, impact energy absorption, thermal conductivity and sound absorption. For example, Miyoshi *et al*. reported that the strength of porous aluminum was improved by decreasing the average pore size, and Kitazono *et al*. reported that the thermal conductivity of porous materials strongly depended on the anisotropy of pore morphology [7, 8, 21].

* The heterogeneity in the structure could be explained on the basis of foam stability drainage in the cell walls and heat transfer during quenching [12].
* During foaming by dolomite, two stages of expansion were observed; the water vapor absorbed onto the AlSiCu powder surface and the decomposition of dolomite [20].
* Pores connectivity also plays an active role in other physical properties and related functional application dealing with fluids buoyancy permeability, acoustic control and thermal transport [22].
* In this paper study of the consistent thermodynamics calculation reveals that a wide liquid miscibility gap must exist between Ca and Ti rich melts above the monotecticre action, close to melting point of Ti at 1668°C [23].
* This paper presents the study of the challenges associated with titanium powder compaction:
  + - High reactivity of titanium powder material in air,
    - High hardness and inductile, it is difficult to press it into green bodies [24].
* The solidification shrinkage, the melting temperature, range and alloy are postulated to be the most important parameters to modify the pore connectivity grade [15].
* the solidification shrinkage, the melting temperature range and the H2 solubility of the alloys are postulated to be the most important parameters to modify the pore connectivity grade, the reduction in foaming temperature is believed to be the best result of the gradual and accelerated decomposition of TiH2 and the effective retention of generated H2(g) [8].
* This study is based on to investigate the role of parameters, foam making methods, microstructure, mechanical and physical properties and also pores size of metallic foam [9, 10].
* This paper presents study of the effect of ceramic particle addition on the foaming behavior, cell structure and mechanical properties of powder metallurgy ALSi7 foam. While the drainage reduced, more heterogeneous cell structure was observed [11].
* This paper presents study on how to investigate the compressive behavior of CMF. Hopkinson bar experiment was conducted on sample processed through powder metallurgy and casting technique [17, 18].
* The distribution of relative density within the aluminum foam bar is in a range of (0.2–0.3) by rapid cooling of pipe [8, 13, 19].

**CONCLUSION**

* + Cellular metals which can be produced now-a-days are less expensive, therefore are in great demand in the areas as in automotive industries, transport industries, aerospace, railway, ship, building, biomedical, and also in filter, heat exchanger, silencers, and for water purification etc.
  + In recent years several studies in literature have established to optimize the different parameters, size and shape, methods of metallic foam process, and also the morphology of design are improved.
  + Now a day in industrial applications new material are required for light weight, high damping capacity, catalyst, high surface area, low flow resistivity, high stiffness, high gas permeability, high thermal conductivity and good energy absorption characteristics.
  + Pores connectivity also plays an active role in other physical properties and related functional applications dealing with fluids buoyancy, permeability, acoustic control and thermal transport. Open and closed pore morphology and relative density are achieved.
  + The effect of ceramic particle addition on the foaming behavior, cell structure and mechanical properties of powder metallurgy ALSi7 foam. While the drainage is reduced more heterogeneous cell structure was observed.

**REFERENCES*,***

1. Banhart J. Manufacture, Characterization and Application of Cellular Metals and Metallic Foams. *Prog Mater Sci.* 2001; 46: 559–632p.
2. Rossella Suracea, De Filippisb Luigi AC, Ludovicoa Antonio D. *Proc Estonian Acad Sci Eng.* 2007; 13(2): 156–167p.
3. Banhart J, Baumeister J, Weber M. Fraunhofer-Institute for Applied Materials Research Bremen Birmingham, UK, (European Powder Metallurgy Association, Shrewsbury). 23. 25.10.1995; 201–208p.
4. Baumeister J, Banhart J, Weber M. Fraunhofer-Institute for Applied Materials Research, Powder Technology, Lesumer Heerstraße 36, 28717 Bremen, Germany. Received 16 Jun 1997; accepted 18 Jul 1997.
5. John Banhart. Fraunhofer-Institute for Manufacturing and Advanced Materials, Wiener Strasse 12,28359 Bremen, Germany. Received 16 Aug 1999; received in revised form 18 Dec 1999; accepted 1 Jan 2000.
6. Park C, Nutt SR. *Mater Sci Eng A*. 2000; 288: 111–118p.
7. Baldev Raj, Ranganathan S, Bhanu Sankara Rao K, *et al*. Frontiers in the Design of Materials. India: Universities Press (India) Limited; 2007.
8. Koza E, Leonowicz M, Wojciechowski S, *et al*. *Mater Lett.* 2003; 58: 132–135p.
9. Asavavisithchai S, Kennedy AR. *J Colloid Interface Sci.* 2006; 297: 715–723p.
10. Asavavisithchai S, Kennedy AR. Advanced Materials Research Group, School of Mechanical, Materials and Manufacturing Engineering, University of Nottingham, University Park, Nottingham NG72RD, UK. *Scripta Materialia*. 2006; 54: 1331–1334p.
11. Esmaeelzadeh S, Simchi A, Lehmhus D. *Mater Sci Eng A*. 2006; 424: 290–299p.
12. Edwin Raj R, Daniel BSS. Aluminum Melt Foam Processing for Light-Weight Structures. *Mater Manuf Processes.* 2007; 22(4): 525–530p.
13. Makoto Kobashi, Norio Inoguchi, Naoyuki Kanetake. *Intermetallics,* Elsevier Ltd*.* 2010; 18: 1039e–1045p.
14. Proa-Flores PM, Mendoza-Suarez G, Drew RAL. *J Mater Sci*. 2012; 47: 455–464p.
15. Lafrance M, Isac M, Jalilian F, *et al*. *Mater Sci Eng A.* 2011; 528: 6497–6503p.
16. Shih Jing-Shiang, Tzeng Yih-Fong, Yang Jin-Bin. *IEEE*. 2011.
17. Michailidisa N, Stergioudia F, Tsouknidas A. *Mater Sci Eng A.* 2011; 528: 7222–7227p.
18. Aguirre-Perales Lydia Y, In-Ho Jung, Drew Robin AL. *Acta Materialia.* 2012; 60: 759–769p.
19. Asavavisithchaia S, Kennedy AR. *Procedia Eng.* 2012; 32: 714–721p.
20. Takuya Koizumi, Kota Kido, Kazuhiko Kita, *et al*. *The Minerals, Metals & Materials Society and ASM International*. 2012.
21. Morsi K, Daoush Walid M. *Scripta Materialia*. 2015; [www.elsevier.com](http://www.elsevier.com)
22. La´zaro J, Solo´rzano E, Rodrı´guez Pe´rez MA, *et al.* *J Mater Sci*. 2015; 50: 3149–3163p.
23. Milan Hampl, Rainer Schmid-Fetzer. *J Mater Sci*. 2015; 50: 5822–5832p.
24. Ronald Machaka, Chikwanda Hilda K. *The Minerals, Metals & Materials Society and ASM International*. 2015.
25. Umashankar C, Kaushal Jha, Mahule KN. Research Article. Sep–Oct 2011; 322.

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