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Review article

Recent developments in the field of metal foam-polymer hybrid materials: A brief overview

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Abstract

In this paper, a brief overview of the various techniques employed for the preparation of metal foam-polymer hybrid/composite materials including infiltration/penetration and adhesive joining is given. Scanning electron microscopy (SEM) micro structural characterization method and various dependent mechanical properties such as stress-strain diagram, energy absorption etc is described. In addition, some possible applications of such materials are discussed. The paper intends to inform as well as educate the reader about the various aspects of this emerging field in a lucid manner.

1. Introduction

Metal foam-polymer hybrids are a new class of materials which combine the properties of metal foam and polymers into a single suitable material. Such materials which result from the hybridization of metal foams and polymers are widely reported to be quite versatile in the range of properties it displays. This is currently a very active area of research with many new developments reported in recent times. Such materials, although broadly similar, have been variously called by names such as hybrids [1-5], composites [6-9], interpenetrating phase composites (IPC) [10-13], metal-porous-polymer-composites (MPPC) [14-16] etc. However, to the best of the author's knowledge, studies summarizing the various developments in this field are quite rare. This paper while using 'hybrid' as a generic term, gives a brief overview of the different manufacturing techniques employed to synthesize metal foam-polymer combined materials. The resulting micro structural characterization via scanning electron microscopy (SEM) and various dependent mechanical properties are also described. In the end, some potential application areas are briefly discussed.

2. Methods for producing the hybrid material

A metal foam is typically a cellular structure with pores which are filled by either gas or air. These pores comprise a large portion of the total volume. These pores can be sealed type i.e. closed cell foam or interconnected type i.e. open cell foam. Metal foams retain some physical characteristics of their base metal. As metal foams mainly belong to two categories viz. open-cell type and closed-cell type, this section is divided into two parts for discussion.

2.1 Open cell metal foam-polymer combine

Open cell foam comprises of cellular material with interconnected pores such that a liquid can flow from one end to the other through them. These pores or voids can be filled with a liquid polymer under pressure to generate a hybridized material system. Aluminum based foams have been widely reported for such studies. Various polymers such as ethylene vinyl acetate [1], polymethyl methaacrylate [9], natural rubber [10], polyurethane [12], polyethylene [10-14], rubber [17-18], epoxy [14,16,19] and silicon rubber [20] have been infiltrated into the open pores of aluminum foams to fabricate the hybrid material. A schematic depicting the process is shown in Figure 1.

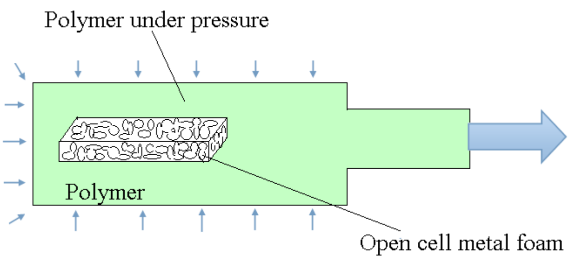

Figure 1. Schematic showing open cell metal foam-polymer hybridization.

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Solidification in vacuum conditions to enable full penetration of polymer into the open cells has also been reported [10,20]. However, Wang et al. [9] reported utilization of γ-ray radiation to initiate in-situ polymerization of monomers in cells of open cell aluminum foam to prepare the hybrid. Wang et al. [9] adopted this method as the other prevalent method viz. polymer infiltration is reportedly carried out under rigorous conditions of high temperature and pressure to achieve a viscous melt of polymers.

2.2 Closed cell metal foam-polymer combine

Closed cell metal foams have pores which are isolated from adjacent pores by means of cell walls and are therefore impervious to liquids. The voids enclosed by these pores can be substituted by polymers systems. Polymers such as polyethylene and epoxy have been hybridized with aluminum foam by drilling holes in the foam cells and application of uniform pressure to press the liquid polymer into the pores [6,21]. Same polymers as mentioned above have also been combined with stainless steel foam [21] in a similar way. A schematic depicting the process as shown in Figure 2.

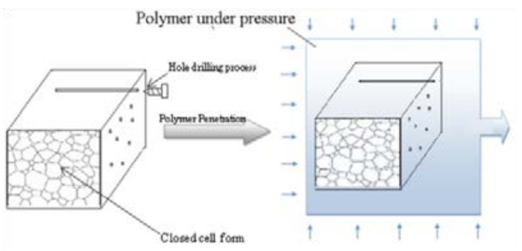

Figure 2. Schematic showing closed cell metal foam-polymer hybridization.

Another study [2] describes the fabrication of a hybrid structure of closed cell aluminum foam and Natural rubber by molding the polymer part around the centre core of foam material. An alternative technique describes spherical small volume aluminum foam elements joined together by adhesive bonding using a thermo-plastic polymer polyamide 12 [3].

2.3 Micro structural characterization via SEM

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons (see Figure 3.)

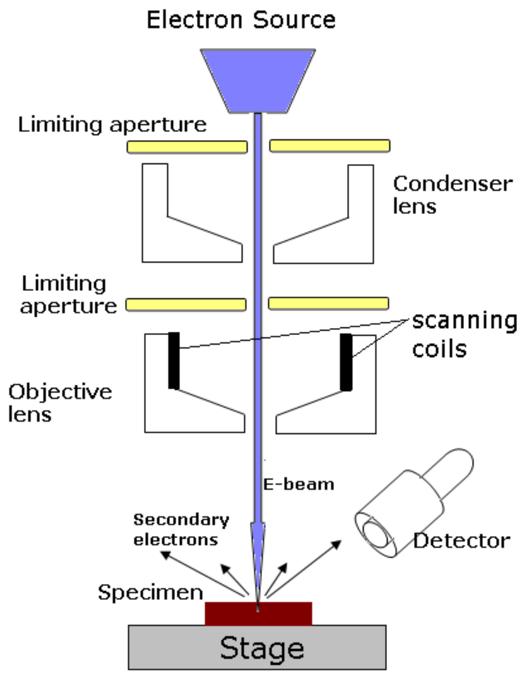

Figure 3. A schematic showing the scanning electron microscope.

The electrons interact with the electrons in the sample producing secondary electrons, back scattered electrons and characteristic X-rays that can be detected and that contain information about the samples topography and composition. SEM has also been utilized to study the micro structural details of metal foam-polymer hybrid systems [9,18,21]. It is important to note here that the success story of such hybrid systems relies essentially on the level of infiltration as well as the quality of bonding achieved at the interfaces among other things which is shown clearly by the SEM technique. SEM micrographs about such hybrid systems reveal interesting details such as the level of infiltration of the polymer into the pores of metal foam [10], interfacial bonding [10], separation of metal foam and polymer component and cracks [9,10,14] etc. In essence, SEM images can be used to throw light on the compatibility/incompatibility aspects of the parent materials of such hybrid systems e.g. a mis-matching coefficient of thermal expansion is likely to lead to a crack/residual stress which in turn will affect the mechanical properties. A typical SEM of metal foam-polymer hybrid material is as shown in Figure 4.

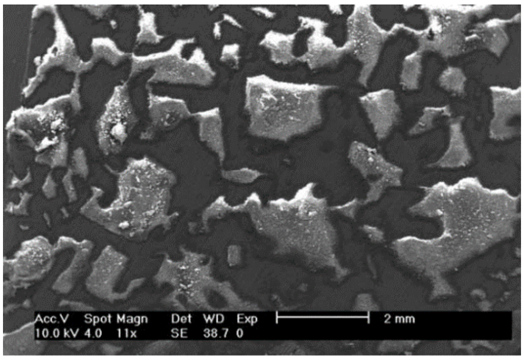

Figure 4. SEM image of an open-cell aluminum foam with silicate-rubber filler [18]. Reprinted with permission.

2.4 Mechanical properties

For a better understanding of various mechanical properties, a simplified stress-strain diagram is shown in Figure 5.

Such curves are generated by testing of material specimen on a universal testing machine.

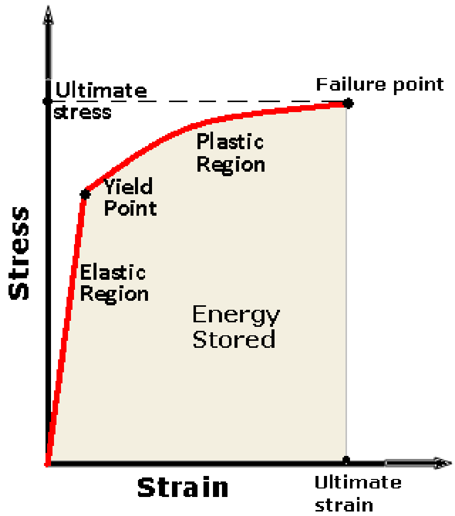

Figure 5. A simplified stress-strain diagram.

2.5 Compressive stress and Young's modulus

Stress is defined as the internal resistance set up by a body when it is deformed and signifies the load carrying capacity of a given material. Researchers have reported improvements in compressive stress as a result of hybridization of metal foam with polymers [2,9,16,19,21]. The compressive stress in a metal foam-polymer hybrid system is dependent on the interfacial bonding between the two parent monoliths [4,13] and found to deteriorate with defects along the interface [10]. The enhancement effect due to the polymer component also raises the compressive stress of the hybrid material, for example the compressive strength values of closed cell aluminum foam alone and with epoxy polymer injected are 1.7 MPa and 51.3 MPa, respectively [6]. Additionally, the truss of the foam material gets laterally elongated (due to lower volume compressibility) with increase in compressive strain which leads to higher stress levels [9]. Relatedly, the compressive stress of a material and its Young's modulus are interlinked as Young's modulus represents the slope of the stress-strain curve in the elastic region. The type and proportion of the polymer used affects the Young's modulus of the hybrid system which in general is improved by the introduction of polymers in pure foam [6,9,14,19]. Besides, improved bonding between the metal foam and polymer will lead to increased Young's modulus [4]. Flexural modulus, similar to Young's modulus, relates to the bending resistance offered by a material and is also found to improve in such hybrid materials [11]. Another study [22] concerning tribological composites for higher thermal conductivities reported improvements in heat dissipation aspects of 10 vol.% aluminum foam filled with a thermoplastic.

2.6 Energy absorption

The Energy absorption per unit volume (W) due to a strain ε is simply the area under the stress-strain curve and can be written as.

$$W = \int_0^{\varepsilon} \sigma(\varepsilon) d\varepsilon \qquad (1)$$

Where σ is the stress as a function of the strain. Utilizing equation (1), the energy absorption behavior of hybrid material is found to be superior to the parent materials [2,7,15,-18]. Yu el al. [14] report an energy absorption value of ≈ 50 MJ/m^3 at 40% strain for Al-EP composite compared to ≈ 10 MJ/m^3 for aluminum foam alone which is quite an improvement. Superior Energy absorption behavior is found repeating (for the same material) for two different rates of loading (viz. Quasi-static and Dynamic) [20]. Perisamy et al. [19] reported higher energy absorption under dynamic loading conditions than quasi-static loading conditions in their hybrid material with Doktor et al. [12] reporting as high as a 57% increase in energy absorption of metal foam-polymer hybrid at higher strain rates. The amount of absorbed energy is dependent on proportion of polymer, interfacial strength etc. [14]. This improved energy absorption behavior results from more compressive work needed to push material through the interfacial friction of metal foam-polymer systems.

2.7 Damping

Damping relates to the ability of a material to damp-out vibrational energy. For visco-elastic materials (such as metal foam-polymer hybrids) the loss factor is a measure of the energy lost expressed in terms of the recoverable energy and represents internal friction. Generally, polymers have a larger loss factor than metallic foams and hence the damping capacity of metal foam-polymer system scores better than bare metal foams [21]. Another study [5] reports an increase of ≈ 31% at 1 Hz in loss factor of the aluminum foam/rubber hybrid and links the increase in damping loss factor effect to the polymer's (rubber in this study) strong aversion to volumetric change after being confined inside metal foam cells.

3. Applications

The hybridization of metal foam with polymers can lead to the synthesis of a new class of material with improved mechanical behavior with many a research results suggesting properties such as energy absorption, compressive modulus and damping characteristics of metallic foams having been favorably modified by introduction of polymers in the cells or vice-versa. Favorable modification involves, among other things, improving upon properties e.g. resilience in a given metal foam specimen which was otherwise only "stiff" by introducing appropriate polymer content or vice-versa by improving the thermal conductivity/friction coefficient and thereby the overall wear resistance of a polymer based "solid lubricant" by adding foamed metal. Such materials are expected to find wide use in vibration and noise attenuation [8], effective impact protection systems [12,17], car bumpers [20], passive damping material [21], crash absorption systems for rail based vehicles [23], automotive industry [24] and as wear-resistant materials [25] among others.

4. Conclusions

This brief overview attempts to capture the recent developments in the field of metal foam-polymer combined materials and present the same to its readers in a simpler manner. As the industry demands of energy dissipation, damping etc become stringent to the extent that it cannot be met by a standalone material there will be a greater emphasis on developing such novel functional materials. Further research into materials behavior can fill the gap towards a better understanding of the underlying deformation mechanisms (especially along the interfaces) in such materials under various conditions of loading. Mathematical models which accurately predict the physical behavior of these materials need to be evolved to dispense with expensive experimentation wherever possible. In essence, metal foam-polymer combined materials will have a greater share among industrial products in the years to come.

References

[1] D. R. A. Cluff and S. Esmaeili, "Compressive properties of a new metal- polymer hybrid material," *Journal of Materials Science*, vol. 44, pp. 3867-3876, 2009.

[2] A. Chaturvedi, G. Sanyal, S. Chaturvedi, and A. S. Patil, "Compressive properties and imaging analysis of a new metal foam-natural rubber hybrid structure," *Journal of Minerals, Metallurgy and Materials*, vol. 26, pp. 27-30, 2016.

[3] K. Stobener, D. Lehmhus, M. Avalle, L. Peroni, and M. Busse, "Aluminum foam-polymer hybrid structures (APM aluminum foam) in compression testing," *International Journal of Solids and Structures*, vol. 45, pp. 5627-5641, 2008.

[4] Z. Yuan, N. Rayess, and N. Dukhan, "Modelling of the mechanical properties of a polymer-metal foam hybrid," *Procedia Materials Science*, vol. 4, pp. 215-219, 2014.

[5] S. Yin and N. Rayess, "Characterization of polymer-metal foam hybrids for use in vibration dampening and isolation," *Procedia Materials Science*, vol. 4, pp. 311-316, 2014.

[6] S. Kishimoto, Q. Wang, Y. Tanaka, and Y. Kagawa, "Compressive mechanical properties of closed-cell aluminum foam-polymer composites," *Composites: Part B.* vol. 64, pp. 43-49, 2014.

[7] L. Zhenrong, L. Yuan, and T. Yanfeng, "Analysis and experimentation research of the static compressive mechanical test of foam aluminum composite," *Advanced*

Materials Research, vol. 1030-1032, pp. 16-19, 2014.

[8] K. Stobener and G. Rausch, "Aluminum foam-polymer composites: processing and characteristics," *Journal of Materials Science*, vol. 44, pp. 1506-1511, 2009.

[9] M. Wang, H. Geng, X. Ge, J. Li, and D. Kou, "Polymer/Metal interpenetrating phase composites prepared via γ-Ray initiated In-situ emulsion polymerization," *Polymer composites*, vol. 30, pp. 1258-1264, 2009.

[10] K. Angamnuaysiri and S. Asavavisithchai, "Mechanical properties of inter- penetrating phase composites using open-cell Al foams with natural rubber and polyethylene," *Journal of Minerals, Metallurgy and Materials*, vol. 25, pp. 31-35, 2015.

[11] N. Dukhan, N. Rayess, and J. Hadley, "Characterization of aluminum foam-polypropylene interpenetrating phase composites: Flexural test results," *Mechanics of Materials*, vol. 42, pp. 134-141, 2010.

[12] T. Doktor, P. Zlamal, T. Fil, P. Koudelka, D. Kytyr, and O. Jirousek, "Properties of polymer-filled aluminum foams under moderate strain-rate loading conditions," *Journal of Materials Science and Technology*, vol. 49, pp. 597-600, 2015.

[13] Y. Su, Z. Li, X. Gong, Q. Quyang, Q. Guo, C. Guo, J. Zhang, and D. Zhang, "Structural modeling and mechanical behavior of Metal-porous-polymer composites (MPPCs) with different polymer fractions," *Composite Structures*, vol. 153, pp. 673-681, 2016.

[14] L. Yu and G. Xiao-lu, "Compressive behavior and energy absorption of metal porous polymer composite with inter-penetrating network structure," *Transactions of Nonferrous Metals Society of China*, vol. 16, pp. 439-443, 2006.

[15] X. L. Gong, Y. Liu, and J. Lu, "Manufacturing and low-velocity impact response of a new composite material: Metal porous polymer composite (MPPC)," *Journal of Materials Science*, vol. 20, pp. 65-68, 2004.

[16] J. Yuan, X. Chen, W. Zhou, and Y. Li, "Study on quasi-static compressive properties of aluminum foam-epoxy resin composite structures," *Composites Part B*, vol. 79, pp. 301-310, 2015.

[17] H. F. Cheng and F. S. Han, "Compressive behavior and energy absorbing characteristic of open cell aluminum foam filled with silicate rubber," *Scripta Materialia*, vol. 49, pp. 583-586, 2003.

[18] J. L. Yu, J. R. Li, and S. S. Hu, "Strain-rate effect and micro-structural optimization of cellular metals," *Mechanics of Materials*, vol. 38, pp. 160-170, 2006.

[19] C. Perisamy, R. Jhaver, and H. V. Tippur, "Quasi-static and dynamic compression response of a lightweight interpenetrating phase composite foam," *Materials Science and Engineering: A*, vol. 527, pp. 2845-2856, 2010.

[20] M. Vesenjak, L. Krstulovic-Opera, Z. Ren, A. Ochsner, and Z. Domazet, "Experimental study of open-cell cellular structure with elastic filler material," *Experimental Mechanics*, vol. 49, pp. 501-509, 2009.

[21] S. Kishimoto, T. Shimizu, F. Yin, K. Naito, and Y. Tanaka, "Mechanical properties of metallic closed cellular materials containing polymer fabricated by polymer penetration," *Materials Science Forum*, vol. 654-656, pp. 2628-2631, 2010.

[22] D. L. Burris and W. G. Sawyer, "Hierarchically constructed metal foam/ polymer composite for higher thermal conductivity," *Wear*, vol. 264, pp. 374-380, 2008.

[23] J. Banhart, "Metal foams-from fundamental research to applications," in *Frontiers in the Design of Materials*, B. Raj, S. Ranganathan, K. B. S. Rao, M. D. Matthew, and P. Shankar, Eds., Universities Press (India) Ltd., 2007, pp. 279-289.

[24] S. McKown and R. Mines, "Measurement of material properties for metal foam cored polymer composite sandwich construction," *Applied Mechanics and Materials*, vol. 1-2, pp. 211-216, 2004.

[25] K. Ji, Y. Xu, J. Zhang, J. Chen and Z. Dai, "Foamed-metal-reinforced composites: Tribological behavior of foamed copper filled with epoxy-matrix polymer," *Materials and Design*, vol. 61, pp. 109-116, 2014.