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COMPARATIVE STUDY ON NUMERICAL AND ANALYTICAL ASSESSMENT OF ELASTIC PROPERTIES OF METAL FOAMS

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Abstract: *Recently, titanium metal foams are being considered as a suitable replacement for substituting trabecular bone microstructure especially for their similar pore distribution. The most common methods for determination of compressive effective elastic properties of such materials involve different approaches based on finite element analysis (FEA) of their microstructure. The internal geometry is usually modeled by two different methods - directly on the basis of a series of CT scans or using one of discretization schemes. However, all these techniques require highly specialized hardware, software and significant amount of computational time. In this paper, the effective elastic properties of the metal foam are instead obtained by analytical modulus-porosity relations and results are compared with previous FE based analysis.*

Keywords: ***metal foams, modulus-porosity relations, finite element method, compressive behavior, effective elastic properties***

1. Introduction

Metal foams are highly porous materials that possess unique combination of mechanical, acoustic and electromagnetic properties. At very low specific weights and thus high specific stiffnesses, they are able to absorb significant amount of deformation energy while guaranteeing other properties such as high fire and heat resistance, noise attenuation and shielding of electromagnetic devices (Banhart, 2001). Combination of these characteristics attracts application of metal foams in many engineering fields from interior design and equipment to civil engineering and vehicle construction. Furthermore, open-cell metal foams manufactured from biocompatible materials (i.e. pure Titanium, Ti-Ni alloys, etc.) successfully mimic natural characteristics of human bones. Usage of titanium and its alloys as fusion implants is one of the most important developments in the field of biomechanics and biomaterials.

During the last decades, there has been much effort dedicated to understanding of the porosity dependence of the effective elastic constants of cellular metals. Numerous relations derived from various constitutive laws have been developed as a result of extensive theoretical and experimental work. In this paper, effective elastic properties in compression predicted by various models for modulus-porosity relations are compared to experimental and numerical results of compressive behavior of studied cellular materials. Experimental values of elastic modulus and porosity of Alporas foam were assessed on the basis of quasi static compressional loading and weighting of the sample respectively.

2. Materials and methods

Alporas®is a aluminium closed-cell foam primarily used as a noise damping a deformation energy absorbing material. Structure of this material is typically constituted by large inner pores of polyhedral shape with average size 4.5 mm. Optinium©open-cell biocompatible foam is manufactured using commercial grade CP4 titanium powder which is transformed to open-pore structure using a propellant (space holder technique) (Singh, 2009).

Porosity dependence of the effective elastic moduli is usually nonlinear. Open-cell foams deform by bending followed at large loads by the formation of plastic hinges within the cell walls while in closed-

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cell foams bending of the cell walls is accompanied by stretching of the cell faces (Gibson, 1997). Semi-empirical models have been developed by Gibson and Ashby on the base of these assumptions. Other relations considered in this paper are based on exponential and power laws and are the most commonly used for determination of modulus-porosity dependence of ceramic materials. In case of porous metals studied in this paper, the modified exponential relation, Mooney-type exponential relation, Archie type relation, Phani-Niyogi relation and Pabst-Gregorová relation are discussed.

3. Results

The hereinbefore mentioned relations were applied to prediction of relative elastic moduli of porous aluminium and titanium and results are listed in table 1.

Tab. 1: Studied relations of the porosity dependence behavior of Alporas and Optinium

		Alporas		Optinium	
Relation	Fit model	$[E]$	ϕ_{C}	$[E]$	ϕ_{C}
Archie	$E_{\mathrm{r}} = (1-\phi)^{[E]}$	2.11	–	2.20	–
Phani-Niyogi	$E_{\mathrm{r}} = \left(1-\frac{\phi}{\phi_{\mathrm{c}}}\right)^{[E]\phi_{\mathrm{c}}}$	2.11	1.01	1.89	0.92
Pabst-Gregorová	$E_{\mathrm{r}} = \left(1-[E]\phi+([E]-1)\phi^2\right)\frac{\left(1-\frac{\phi}{\phi_{\mathrm{c}}}\right)}{(1-\phi)}$	2.03	1.00	2.08	1.01
Modified exponential	$E_{\mathrm{r}} = \exp\left(\frac{-[E]\phi}{1-\phi}\right)$	0.88	–	1.37	–
Mooney	$E_{\mathrm{r}} = \exp\left(\frac{-[E]\phi}{1-\frac{\phi}{\phi_{\mathrm{c}}}}\right)$	1.60	1.29	1.37	1.01
Structure	Gibson-Ashby's fit model	C	φ	α	η
Open-cell	$E_{\mathrm{r}} = \alpha\left(\frac{\rho_{\mathrm{f}}}{\rho_0}\right)^{\eta}$	–	–	1.78	2.82
Closed-cell	$E_{\mathrm{r}} = C\varphi^2\left(\frac{\rho_{\mathrm{f}}}{\rho_0}\right)^2 + C(1-\varphi)\left(\frac{\rho_{\mathrm{f}}}{\rho_0}\right)$	1.03	2.14	–	–

4. Conclusion

Several exponential- and power-law equations have been introduced in order to obtain a master curve characterizing as precisely as possible the general trend of the porosity dependence of the elastic moduli. It has been shown that for materials with microstructure types investigated here, the modified exponential relation, Mooney type relation and Gibson-Ashby's closed-cell model provide in some cases unsatisfactory predictions of the actual porosity dependence.

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