ON THE USE OF SELF CONSISTENT THREE PHASE MODEL TO ESTIMATE ELASTIC PROPERTIES OF METAL FOAMS

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ABSTRACT

Metal foams are a relatively new class of materials which have drawn attention of engineers and materials scientists in the last decade of the 20^{th} century. The properties of these materials are still under investigation. Under experimental studies, it has been found that these materials possess low densities and extraordinary physical, mechanical, thermal, electrical and acoustic properties. Some potential applications of metallic foams are for lightweight structures, for energy applications and for thermal management.

The intention of present study is to investigate past studies and to evaluate the current need for a macroscopic constitutive relation of metallic foams with various internal structures. The main reason for not having a unique relationship is the variability of the assembly of the metallic foam material resulting from the method and conditions of producing it. The possibility of using a well established method which is already being introduced to evaluate the elastic properties of particulate composites is being investigated.

Keywords: metal foams, elastic properties, three-phase model

1. INTRODUCTION

The properties of foam materials are dependant not only on its constituent material properties but also on the geometry of the foam cell. Due to the lack of control of the processing methods of metal foams, there are different geometries in the resulting cells. Due to this reason, a large variability of properties has been observed and must be addressed in the endeavour of modelling. A proper relationship between different geometries and resulting properties can lead to establishing a guideline for metallic foam material manufacturers as well as for design engineers.

Due to the great potential of metal foams in industrial applications such as lightweight structures, sandwich cores, strain isolation, mechanical damping, vibration control, acoustic absorption, energy management, packaging at high temperatures, artificial wood, in heat exchangers, refrigerators, flame arresting, heat shields, biocompatible inserts, filters, electrodes, catalyst carriers, buoyancy applications etc., the mechanical, physical and electrical behaviour of these materials have been studied extensively during past two decades[1],[2]. Yet there is no unique way to express macroscopic mechanical properties of metallic foams.

In contrary to majority of the composite materials found (e.g. reinforced concrete) in day to day life, foam materials have cavities instead of rigid bodies, hence performing calculations with metal foams demands more than the simple homogenising methods used for most of the composite materials. The unit cell of the foam material has been approximated conveniently according to a simplified solution[3]. The simplified solution includes a three-phase model which represents the foam material as a composite material where the matrix phase is the solid and the inclusion phase is a cavity, and the third phase is the equivalent homogeneous media where the composite iterates. The analytical solutions obtained are compared with some experimental results and it is found that further refinements to the model are needed. It is suggested to expand this study to investigate the dependence and the bounds of mechanical properties attributed to the material's inner structure.

2. METHODOLOGY

Self Consistent Three Phase Model:

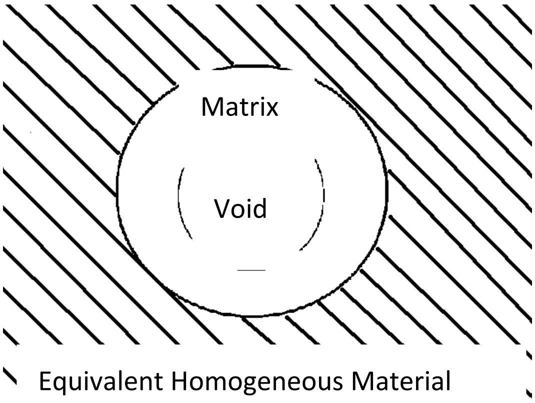


Fig. 1. Three phase model

Original three phase model was intended for composite materials[3] with uniformly distributed spherical inclusions. The inner phase is considered to be the inclusion while the middle phase is the matrix material. The surrounding phase represents the equivalent homogeneous medium. The figure 1 shows the modification of the three phase model to suit foam materials. Here the inclusions are assumed to be voids and the equivalent homogeneous medium corresponds to the foam material. The inclusion properties in the formulation of [3] are taken to be null. The inclusion surfaces are stress free while the displacement and the stresses are continuous at the interface of phase 2 and phase 3. Since it is assumed that the voids are uniformly distributed, the resulting foam also is assumed to have isotropic properties macroscopically. The resulting equations are solved to get elastic properties analytically. The equations simplify to:

$$\frac{k-k_m}{k_i-k_m}=\frac{c}{1+\left[(1-c)(k_i-k_m)/\left(k_m+\frac{4}{3}\mu_m\right)\right]}$$

(Eq. 1)

and

$$\underline{\mathbf{A}}\left(\frac{\mu}{\mu_m}\right)^2+\underline{\mathbf{B}}\left(\frac{\mu}{\mu_m}\right)+\underline{\mathbf{C}}=0$$

(Eq. 2)

In Eq. 1 the terms K ,K_m, K_i represent the bulk modulus of the foam material, the matrix material and the inclusion respectively, in this case K_i=0 , c is the volume fraction of the solid phase(matrix material) and □$_m$ is the shear modulus of the matrix material.

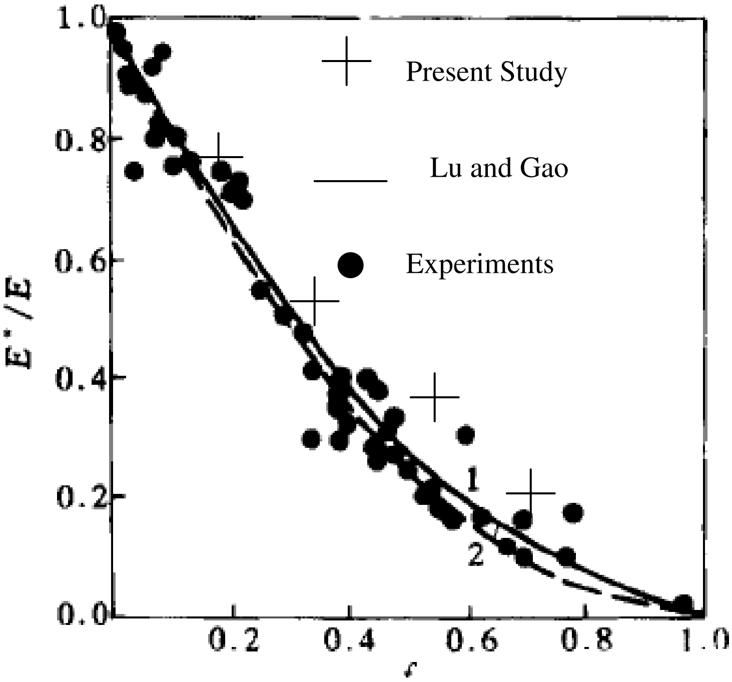
In Eq. 2 a quadratic equation is obtained by equating the determinant of a matrix (six simultaneous equations given in the three phase model) to zero. The terms in matrices $\underline{\mathbf{A}}$, $\underline{\mathbf{B}}$ and $\underline{\mathbf{C}}$ are values that depend on the Poisson's ratio, shear modulus, bulk modulus, volume fraction and the radius of the solid phase (matrix material).

The equations are solved for Al foams given in Table 1[4].

PROPERTY	Duocel Aluminium foam
Matrix Material	Aluminium
Density (Mg/m^3)	2.7
Elastic Modulus (GPa)	69
Shear Modulus (GPa)	26
Bulk Modulus (GPa)	67.6
Poisson's ratio	0.33

3. RESULTS

Figure 2 shows the results form this model in comparison with the experimental values and a previous analytical study[5].



Volume fraction of voids

Figure 2. Comparison with Previous Studies

4. CONCLUSION

The results for shear modulus and bulk modulus from this model agree well with previous studies done for polymer foam materials. This model is valid for metallic foams as long as the material behaves in a linear elastic manner and the structure is a closed foam one. A suitable unit cell for open cells is to be studied in a future study.

5. REFERENCES

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