FINITE ELEMENT SIMULATION OF ARRAYS OF HOLLOW SPHERES STRUCTURES

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
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JUNE 2014

To my beloved mother and father

ACKNOWLEDGMENT

I would like to take this opportunity to thank those who in some way contributed to the completion of this thesis. In particular, I wish to express my honest gratitude to my main thesis supervisor, Dr. Zair Asrar Bin Ahmad, for guidance, advices and friendship. I am also very thankful to my co-supervisors Professor Dr. Andreas Ochsner for his encouragement, critics, and advices.

ABSTRAK

Simulasi berangka bagi suatu model berulang daripada sel logam dibangunkan untuk siasatan asas kelakuan anjal bagi struktur sfera berongga. Morfologi sintaksis dan separa untule konfigurasi struktur sfera berongga ditetapkan menggunakan syarat-syarat sempadan yang sesuai dengan unit sel dan kekisi seluruh sfera berongga. Berdasarkan cadangam rajah modulus young relatif melawan ketumpatan relatif, tingkah laku struktur sfera berongga dengan mana-mana saiz dan bentuk dapat diterangkan tanpa mengambil kira sifat-sifat elastik.

ABSTRACT

The numerical simulation of a repetitive model of a cellular metal is developed for fundamental investigation of elastic behaviour of hollow sphere structures. Syntactic and partial morphologies of simple cubic configurations of hollow sphere structures are prescribed under boundary conditions corresponded to unit cell and whole hollow sphere lattice. Based on the proposed plotted diagram consists of relative Young's modulus versus relative density it is possible to explain behaviour of hollow sphere structure with any size and shape disregarded to its basic elastic properties.

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LIST OF ABBREVIATIONS

BCC	-	Body centred cubic
CAD	-	Computer aided design
CAE	-	Computer aided engineering
DMA	-	Dynamic mechanical analysis
DSC	-	Differential scanning calorimetry
FCC	-	Face centred cubic
FEA	-	Finite element analysis
FM	-	Finite element method
HEX	-	Hexagonal
HSS	-	Hollow sphere structure
PC	-	Primitive cubic
PHS	-	Porous stacking of hollow sphere
PHSS	-	Perforated hollow sphere structure
SC	-	Simple cubic
TMA	-	Thermo mechanical analysis

LIST OF SYMBOLS

A	-	Areas of the corresponding surfaces of the finite element models
E	-	Young's modules
F	-	Nodal forces
l	-	Half length of the unit cell
u	-	Displacement of nodes
ε	-	Engineering strains
σ	-	Macroscopic engineering stress
ρ	-	The density of the hollow sphere structure
V_{free}	-	Free volume
V_S	-	Volume of the solid material
V_{Sp}	-	Volume of sphere
V_{Ma}	-	Volume of matrix
V_{UC}	-	Volume of the unit cell
ρ_{ave}	-	Average density
ρ_{rel}	-	Relative density
ρ_S	-	The density of the solid material

CHAPTER 1

INTRODUCTION

1.1 General Overview and Background

Hollow spheres structures (HSS) are used widely in many different applications e.g. lightweight composite material, sound and thermal insulation walls, gas and chemical storage container, encapsulation, fiber optic sensors, and laser-fusion (Scheffler, Colombo 2005).

They are employed regularly by nature for establishing load bearing and weight optimized structures. For example natural materials such as wood, cork, bones, and honeycombs perform their practical task as well as functional demands. The exceptional properties of biological materials has simulated the development of artificial cellular materials for technical applications.

Today many parts of technology use foams made of polymeric material particularly. Other typical application areas are the fields of heat and sound absorption. Hollow sphere structure are separate from traditional dense metals by the combination of specific mechanical and physical properties.

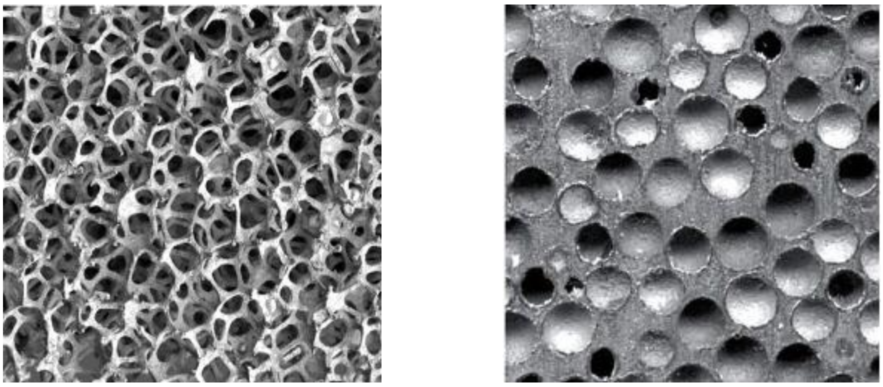
Cellular metals present a large number of important properties. Multifunctional requirements, high stiffness, very low specific weight, high gas permeability and high thermal conductivity are advantages of these material. Different arrangements and forms of cell structures compose a wide range of cellular materials (Öchsner, Augustin 2009). Figure 1.1 shows an example of metallic hollow spheres structure with partial configuration.

Figure 1.1 Aluminum profile filled with hollow sphere structures particles (Fraunhofer IFAM 2014)

These characteristics can create highly integrated applications. First high porosity of the HSS gives it capability to compress at high strains. In the stress strain diagram of a HSS, a stress region exists which indicate the ability of the structure to absorb energy at a low stress level and high strains.

This property provides the application of HSS in energy absorbing structures, e.g. crash components in the automotive industry. Damping of mechanical and acoustical oscillations is another clear aspect of cellular structures. This property recommends the application in elements where high accelerations exist because of their low density. The small amount of accelerated bulk can damp oscillations and reduce energy consumption.

It has been exposed that there is a significant potential of hollow sphere composite structures in machine tools. Moreover, cellular metals perform as sound suppressors and acoustic insulators. A low thermal conductivity is shown by cellular metals in comparison to their metallic base materials. Adhesively bonded metallic hollow sphere structure shows very low thermal conductivities because of the insulating effect of the adhesive matrix between the metallic shells of the spheres. Particularly, metallic hollow sphere structures can be used as thermal insulators. Figure 1.2 shows two different types of hollow spheres structure the left one is sintered metallic hollow sphere and the right one is syntactic configuration of metallic hollow sphere structure.



(a) (b)

Figure 1.2 a) Open-cell $\mathrm{M-Pore}^{®}$ aluminum foam b) Cross section of metallic hollow sphere structures (The University of Newcastle, Australia 2014)

1.2 Problem Statement

The mechanical properties of hollow spheres structures are depended on many factors such as morphology, configuration and basic material. The complexity of stochastic structure and too many involved variables prevent to investigate characteristics of this types of materials by ordinary approaches. Study of porous material should be simplified by considering and focusing on mechanical properties of their unit cells. The effects of the morphology, topology, joining technology and material composition on their mechanical properties could be numerically investigated (Öchsner, Augustin 2009).

The shape and size of hollows inside a structure determine the mechanical properties of it porous structure. In order to investigate the mechanical properties, the finite element method is applied. This survey addresses the simplified approach for evaluating the elastic properties of hollow sphere structures.

1.3 Objectives

The objectives of this study are to determine the Young's modulus of hollow sphere structures and its corresponding unit cell for different morphologies and dimensions. The effect of different joining techniques on the Young's modulus of unit cell and hollow spheres structure could be also investigated. In addition the influence of various types of material for joint and sphere on the macroscopic Young's modulus could be explored.

1.4 Scope of Study

The study is conducted through:

1. The literature review about history, background and related research for hollow spheres structures.
2. The generation of suitable finite element model for simulation general types of hollow sphere structures and their corresponding unit cells.
3. Simulation in computer aided engineering software (finite element analysis software) to evaluate macroscopic Young's modulus of hollow sphere structure and its corresponding unit cell. The simulation should cover two different morphology (syntactic and partial) of one configuration (primitive cubic) for

two different types of joining spheres (identical material for joint and sphere and different materials for joint and sphere)

4. Evaluation of elastic properties like Young's modules.
5. Documentation.

1.5 Significance of Study

The study introduces the finite element analysis method for demonstration the difference of relative Young's modulus for various types of unit cells by changing their geometrical shapes and sizes. Then it compares the results with relative Young's modulus of the whole hollow sphere material. In other worlds, the research focused on the difference between relative Young's modulus of whole hollow spheres structure and its corresponding unit cell for different configuration, joining techniques and materials. In addition the research is conducted to find a general description model for predicting relative Young's modulus of every types of hollow sphere structures disregarded to its basic material.

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