NUMERICAL CHARACTERISATION OF HOLLOW SPHERE COMPOSITES BASED ON PERFORATED INCLUSIONS

MOHD AYUB BIN SULONG

UNIVERSITI TEKNOLOGI MALAYSIA

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ABSTRACT

Metallic hollow sphere structures (MHSS) are a new type of reinforced materials and can be classified as an advanced composite material. A modified metallic hollow sphere MHS geometry which introduced the perforation becomes the main model in this research. This structure is called a perforated hollow sphere structures (PHSS) which is opened to be infiltrated by the matrix to fully embed it and form a composite. PHSS composites offer a new field of mechanical properties compared to cellular structures studied by other researchers. Emphasis will be given to determine the influence of the modified perforation diameter of PHSS composite in terms of macroscopic mechanical properties (e.g. Young's modulus and Poisson's ratio). In addition, the mechanical properties of PHSS composites were also compared to hollow sphere (HS) composites (with and without filled matrix). A perforation introduced in the sphere shells obviously changes the mechanical properties of the PHSS composite, e.g. Young's modulus and Poisson's ratio. The result of the investigation revealed that these values decrease as the perforation diameter increases. PHSS composite models were simulated based on the unit cell approach by means of the Finite Element (FE) method. This method can reduce the costs of experimental tests and provides more information on possible mechanical properties of perforated hollow sphere structures (PHSS) composites. Nevertheless, experimental tests are still necessary and should be conducted in the future for validation purpose.

ABSTRAK

Struktur Sfera Logam Berongga adalah jenis baru bahan pengukuh dan boleh dikelaskan sebagai bahan komposit termaju. Geometri Sfera Logam Berongga yang telah diubahsuai iaitu mempunyai lubang menjadi model utama bagi kajian ini. Struktur ini dipanggil sfera berongga berlubang terbuka untuk dimasuki oleh matriks untuk menerapkan sepenuhnya dan membentuk bahan rencam. Komposit sfera berongga berlubang menawarkan satu sifat baru mekanikal berbanding struktur sel yang dikaji oleh penyelidik lain. Tumpuan kajian ini adalah untuk menentukan pengaruh diameter penembusan komposit sfera berongga berlubang yang telah diubahsuai dari segi ciri-ciri makroskopik mekanikal (contohnya modulus Young dan nisbah Poisson). Di samping itu, sifat-sifat mekanik komposit sfera berongga berlubang juga dibandingkan dengan komposit sfera berongga (dengan atau tanpa matriks isian). Penembusan yang diperkenalkan dalam cengkerang sfera merubah sifat-sifat mekanik komposit sfera berongga berlubang dengan ketara, contohnya Modulus Young dan nisbah Poisson berkurangan kerana kenaikan diameter penembusan. Model komposit sfera berongga berlubang disimulasikan berdasarkan pendekatan sel unit dengan menggunakan analisis kaedah unsur terhingga. Kaedah ini boleh mengurangkan kos ujian ujikaji dan memberikan maklumat lanjut mengenai sifat-sifat mekanikal yang mungkin bagi komposit sfera berongga berlubang. Walau bagaimanapun, ujikaji sebenar masih diperlukan dan perlu dijalankan pada masa hadapan bagi tujuan pengesahan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CFRP	-	Carbon fiber reinforced plastic
MHSS	-	Metallic hollow sphere structures
FCC	-	Face-centered cubic
BCC	-	Body-centered
PC	-	Primitive cubic
Hex	-	Hexagonal
SPHB	-	Split Hopkinson Pressure Bar
HSS	-	Hollow sphere structures
PHSS	-	Perforated hollow sphere structures
SSP	-	Spherical sphere structures
MHSC	-	Metallic hollow sphere composites
LMC	-	Lattice Monte Carlo
RVE	-	Representative Volume Element
UCs	-	Unit cells
ave	-	Average
ma	-	Matrix
eff	-	Effective
sp	-	Sphere

Ep	-	Epoxy resin
FEM	-	Finite element method
Al	-	Aluminium
St	-	Steel
AISI	-	American Iron and Steel Institute
TPS	-	Transient Plane Source
CT	-	Computed tomography

LIST OF SYMBOLS

Latin minuscules

a	-	Bond gap (the thickness of epoxy matrix between the spheres)
b_s	-	the radius of sintered contact area
d_l	-	Perforation hole diameter
ε	-	Strain
$\varepsilon_{\text{trans}}$	-	Transverse strain
$\varepsilon_{\text{axial}}$	-	Axial strain
Δx	-	Distance between two surfaces
σ	-	Total reaction stress from the applied displacement (MPa)
l	-	Length of specimen
Δl	-	Applied displacement (boundary condition) or displacement obtained from the applied load
Δl_x	-	Displacement resulted from the applied load in x-direction
k	-	Thermal conductivity
r_i	-	Shell inner radius
r_s	-	Shell outer radius
r_o	-	Shell outer radius
t	-	Shell thickness
υ	-	Poisson’s ratio

x	-	Coordinate in the unit space
ρ_{ave}	-	Average density
ρ_{rel}	-	Relative Density
ρ_{so}	-	Density of the sphere shell material

Latin capitals

$\dot{Q}_{\mathrm{tot}}$	-	Total heat flux
$\dot{Q}_{\mathrm{conv}}$	-	Convective heat flux
$\dot{Q}_{\mathrm{cond}}$	-	Conductive heat flux
A	-	Area for heat flux calculation
E	-	Young's modulus (MPa)
K	-	Kelvin
GB	-	Gigabyte
RAM	-	Random access memory
T_1, T_2	-	Constant temperature boundary conditions
V	-	Volume
V_{free}	-	Total volume of the void(s) inside the unit cell
V_{ma}	-	Total volume of the matrix inside the unit cell
V_{rel}	-	Relative volume of the voids
V_{so}	-	Total volume of the solid material inside the unit cell
V_{sp}	-	Total volume of the spherical shell(s) inside the unit cell
V_{UC}	-	Volume of the unit cell

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

The idea of artificial cellular and porous materials originated from nature which creates structural optimization with respect to weight and load-carrying capacities. Bones, cork, wood, honeycombs and foams are natural materials to name a few, structured to have the wonderful properties according to their needs. Due to their unique cellular structure, for years people have been working on the development of artificial cellular materials in order to fulfill the potential materials demand in the near future. Starting in 1960s, the geometry of honeycombs was identically converted into aluminium structures as cores of lightweight sandwich panels in the aviation and space industries [1]. In 1970, the concept of porous and cellular metals first emerged [2-4]. The combination of specific mechanical and physical properties in the cellular materials makes the *newfound* composite varying from the ordinary dense metal. Cellular metals are being thoroughly investigated since they have a wide range of different possible arrangements and forms of cell structures. Open- and closed-type classical metal foams were illustrated in Figure 1.1 taken from literature [5-6].

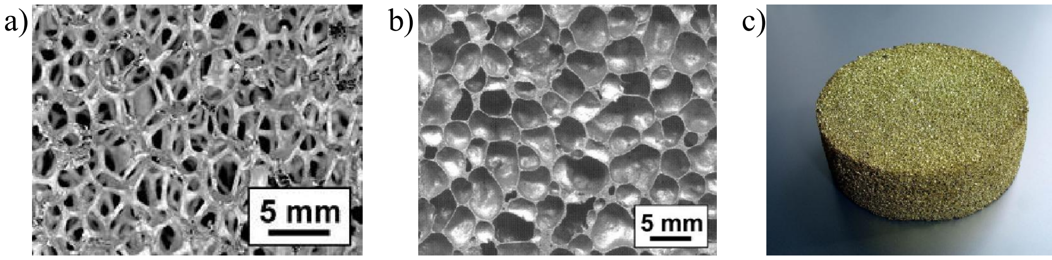

Figure 1.1: Cellular metals: a) M-Pore® (aluminium sponge); b) Alporas® (aluminium foam); c) Brass foam [5-6] .

The usage of composite materials in various industries including marine, aerospace and chemical process plant shows that this alternative material is capable to replace traditional ferrous materials. Composite materials comprise of the reinforced phase bounded within a matrix or binder, e.g. Carbon Fiber Reinforced Plastic (CFRP) and Fibre glass. There are various reinforcing materials in terms of shape such as fibers, whiskers, cloth, braids, dispersed particles, and flakes [7-9]. For this research project, the characteristic of hollow spheres immersed in a polymer matrix was investigated.

1.2 Problem Identification

Classical engineering materials utilized in many industrial fields reach their limitations in properties thus, new developments are required. The increasing demands can be satisfied in many fields with introducing advanced structured materials. For instance, syntactic foams are of a promising candidate in this context. The prediction and optimization of physical properties require the development of accurate and justified computational models from which constitutive equations and material properties can be derived. By means of an advanced commercial finite element analysis code, this research has comprehensively investigated the trend and behavior of hollow sphere structure composites based on perforated inclusions.

1.3 Objective

The primary objective of this thesis is to develop adequate computational models based on different unit cell approaches. Optimized meshes should be determined based on mesh refinement analysis. The following physical parameters should be predicted for different geometrical properties and material sets;

i. Average mechanical properties (i.e. elastic properties) and
ii. Average heat transfer properties (i.e. heat conductivity).

1.4 Scope of Study

The scope of this research is as follows:

i. Generate finite element models for the hollow sphere composites;
ii. Run simulations for different parameters;
iii. Evaluation and interpretation of the numerical results.

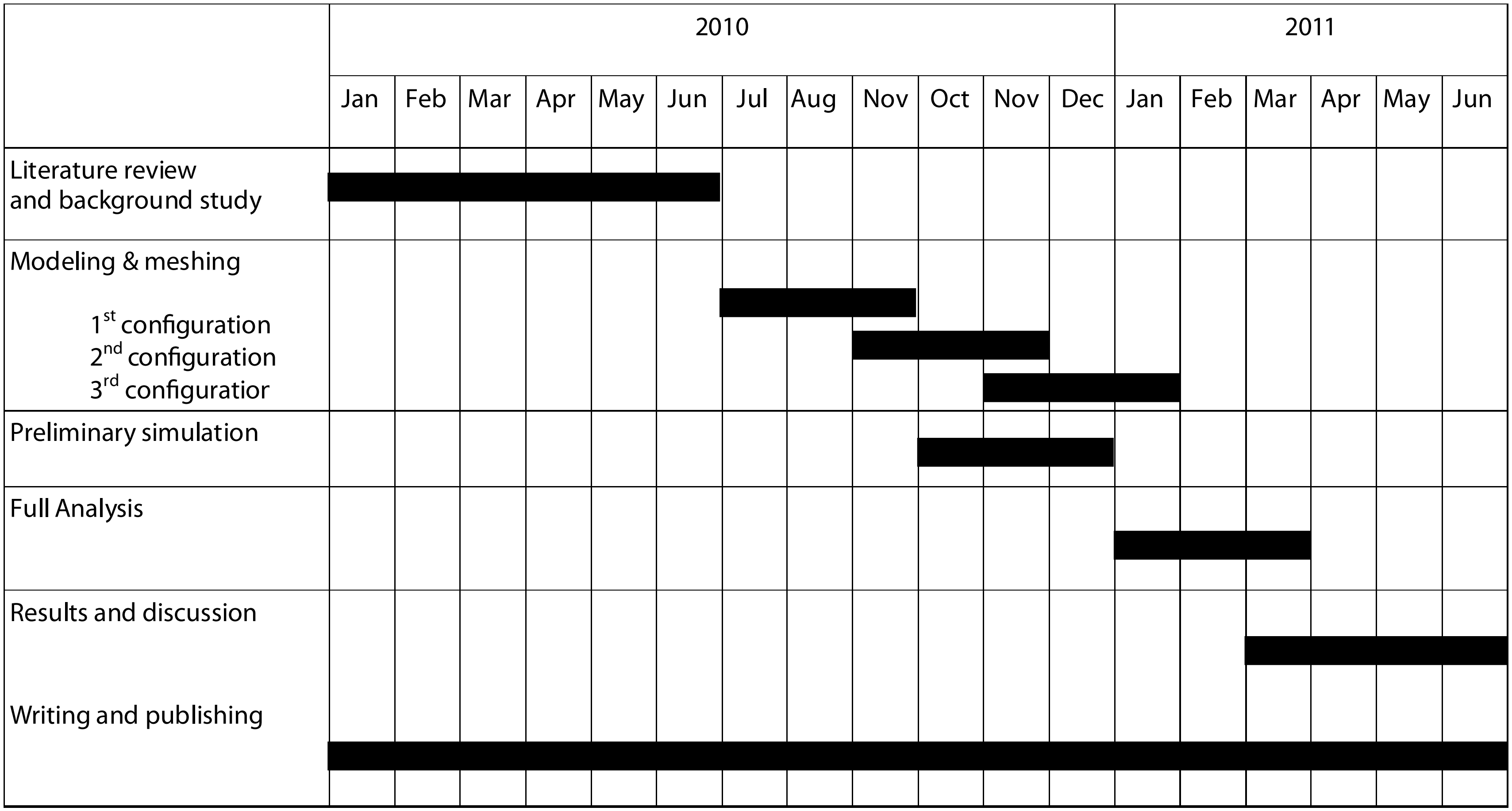

Figure 1.2: Gantt chart

1.6 Summary

This chapter introduces the past and current development on hollow sphere structures. Initiating with successfully transformed natural honeycombs geometry with aluminium core, the investigation on the advanced materials continues rapidly with the novel PHSS. The shell of the HSS with the perforated structure offers a variety of specific mechanical and physical properties to be explored. The scopes and objective of this research were also highlighted in this chapter. Last but not least, the Gantt chart for this thesis was also included.