# VIBRATION ANALYSIS OF BCC LATTICE STRUCTURE MATERIALS USING FINITE ELEMENT METHOD

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**STUDENT DECLARATION**

I declare that this project report entitled "Vibration analysis of BCC Lattice Structure Material Using Finite Element Method" is the result of my own work except as cited in the references

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**SUPERVISOR'S APPROVAL**

I have checked this report and the report can now be submitted to JK-PSM to be delivered back to supervisor and to the second examiner.

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| Signature | : | .......................................... |
| Name | : | Dr. Rainah Binti Ismail |
| Date | : | ........................................... |

## DEDICATION

To Allah s.w.t, Alhamdulillah for your blessing.

To my beloved mother and father.

Thank you for your love, support and understand.

May Allah grant us a forever Jannah.

To supervisor,

Thank you for your knowledge, guidance, patience and support.

May Allah grant you goodness and blessings.

# ABSTRACT

Lattice structure has increasing interest amongst researchers due to its vast advantages features such as lightweight properties, high mechanical strength and high energy absorbance. In this report, the effect of strut diameter design parameter of quatrefoil shaped BCC lattice structure on its natural frequency is investigated. The quatrefoil shape BCC lattice structure bar sample with different strut diameter sizes were made by using the fused deposition modelling (FDM) additive manufacturing (AM) technique. The bar sample were subjected to vibration testing with set up consist of fabricated test rig, accelerometer, impact hammer and signal generator/analyzer. Likewise, FEM models using ABAQUS software are also constructed to investigate their natural frequency and deformation numerically. From the vibration testing, the sample with highest strut diameter produced highest natural frequency value due to increased stiffness. It is found that the numerical results are in good agreement with less than 17% error with the experimental results. Using the experimentally validated FEM model the effect of strut diameter to the stiffness of lattice structure are further investigated to support the findings in vibration testing. The stiffness obtained shows similar increasing trend like that of in the vibration testing as the strut diameter size increase. The conclusion that can derived from this study are the size of strut diameter are affected the natural frequency also the stiffness of lattice structure bar sample. Therefore, the information of lattice structure in this study are shows that lattice structure is suitable use in dynamic application.

**ABSTRAK**

Struktur berbentuk kekisi telah meningkatkan minat para penyelidik kerana kelebihannya yang luas seperti sifat ringan, kekuatan mekanikal yang tinggi dan penyerapan tenaga yang tinggi. Dalam laporan ini, kesan parameter reka bentuk ukur lilit jejari struktur kekisi BCC berbentuk 'Quatrefoil' pada frekuensi semula jadi telah disiasat. Bentuk 'Quatrefoil' BCC struktur kekisi dengan saiz jejari yang berbeza dihasilkan dengan menggunakan 'Fused Deposition Modelling' (FDM) kaedah pembuatan secara tambahan. Sampel bar tertakluk kepada ujian getaran yang disediakan terdiri daripada rig ujian, 'accelerometer', tukul kesan dan penjana isyarat/penganalisis. Begitu juga, model FEM yang menggunakan perisian 'ABAQUS' juga dibina untuk menyiasat frekuensi semula jadi dan ubah bentuk secara berangka. Dari ujian getaran, sampel dengan ukur lilit jejari tertinggi menghasilkan nilai frekuensi semula jadi yang tinggi disebabkan oleh peningkatan kekakuan. Daripada keputusan berangka yang terhasil adalah dalam persetujuan yang baik dengan kurang 17% ralat dengan hasil eksperimen. Selanjutnya, menggunakan model FEM yang disahkan secara eksperimen, kesan ukur lilit jejari kepada kekakuan struktur kekisi akan dikaji selanjutnya untuk menyokong penemuan dalam ujian getaran. Kekakuan yang diperoleh menunjukkan trend peningkatan yang sama seperti dalam ujian getaran kerana saiz ukur lilit jejari meningkat. Kesimpulan yang boleh dibuat dari kajian ini adalah saiz ukur lilit jejari mempengaruhi frekuensi semula jadi juga kekakuan sampel bar struktur kekisi. Oleh itu, maklumat struktur kekisi dalam kajian ini menunjukkan bahawa struktur kekisi sesuai untuk penggunaan dalam aplikasi dinamik.

## ACKNOWLEDGEMENT

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| | | |
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| **ABS** | **-** | Acrylonitrile Butadiene Styrene |
| **AM** | **-** | Additive Manufacturing |
| **BCC** | **-** | Body Centered Cubic |
| **CF** | **-** | Clamped Free |
| **CFRP** | **-** | Carbon Fiber Reinforced Polymer |
| **CM** | **-** | Condition Monitoring |
| **EBM** | **-** | Electron Beam Melting |
| **FDM** | **-** | Fused Deposition Modeling |
| **FEA** | **-** | Finite Element Analysis |
| **GFRP** | **-** | Glass Fiber Reinforced Polymer |
| **MSD** | **-** | Mass Spring Damper |
| **SLA** | **-** | Stereolithography |
| **SLM** | **-** | Selective Laser Melting |
| **SLS** | **-** | Selective Laser Sintering |
| **3D** | **-** | Three Dimension |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Research

Previously, most manufacturers in the automotive and aerospace industries used solid bulk materials to make component which produced heavy body part. As the result, the fuel efficiency is lower besides higher gas emission to the environment. Due to this, nowadays, many manufacturers are shifting materials for lighter body parts or making improvements to the engines or motors. In order to get lighter body parts, this can be done by either using lighter weight materials such as carbon fiber reinforced polymer (CFRP), glass fiber reinforced polymer (GFRP), or using lower density structure such as lattice structures. However, lattice is lightweight materials thus lighter material produce more vibration. Thus, lack of study on the suitability and limitations of this structure can lead to unwanted instances of high vibration. Overtime, vibration effects can have long-term as well as short-term damaging effects on the structure. Such phenomenon's are potentially dangerous as they can create complete unbalance of the structure which can then ultimately fail.

Lattice structure is multi-functional material that can offer good balance of strength, stiffness, cost, durability and relative static and dynamic properties (Ozdemir et al., 2015). The lattice structure material is one of the types of architectured material that can be defined as "a combination of two or more materials, or of material and space, assembled in a way as to have the attributes not offered by any one material alone"(Ashby, 2013). Lattice structure can be used as an alternative for material that has lightweight properties. It can make many advantages for example make lighter aeroplane and thus reduce the uses of fuel for aeroplane (Azman, 2017). There are many types of topological designs of the lattice structure material. The topological designs are based on its elementary of lattice structure or commonly called 'unit cell' (Azman, 2017). Example of common lattice structure topological designs are octet-truss, kagome, body centred cubic (BCC) and pyramidal etc.

Lattice structures in nature have been used by human since thousands of years. Before the emerging of additive manufacturing (AM), conventional manufacturing methods such as investment casting (Mun et al., 2015), expanded metal sheet (Kooistra and Wadley, 2007), metallic wire assembly (Queheillalt and Wadley, 2005) and snap fit (Dong et al., 2015) are used to fabricate lattice structure.  Nowadays, the use of AM is preferable to fabricate lattice structure materials (Hadi et al., 2015). Examples of previously reported AM methods used to fabricate lattice structure materials are selective laser sintering (SLS), selective laser melting (SLM), stereolithography (SLA), and electron beam melting (EBM) and fused deposition modeling (FDM). Using AM methods allows a significantly higher design complexity of lattice structure to be manufactured as opposed to conventional manufacturing methods due to limitation of the conventional machine (Crupi et al., 2017). Besides that, using AM can saves much time to fabricate lattice structure as it requires shorter process chain.

## 1.2 Problem Statement

New global progress of regulation regarding fuel efficiency and gas emission of vehicle has led to motivation on weight reduction of vehicle (Abdollah and Hassan, 2013). The development can be made either by using lower weight materials such as CFRP and GFRP composites or using low density structure material such as lattice structure. If the lattice structure is to be used in dynamic applications such as body parts for moving machines and devices due to its lightweight properties that it can be highly beneficial, thus dynamic testing is essential to evaluate the suitability of this structure in such applications. However, there are limited numbers of studies focusing on the dynamic behavior of additively manufactured lattice structure. Recently, Elmadih et al., (2017) and Syam et al., (2018) explored the dynamic behavior of lattice structure fabricated using laser powder bed fusion (LPBF) experimentally and numerically for application isolator vibration control. Next, Azmi et al., (2018) investigated the dynamic behavior of fused deposition modeling (FDM) on lattice structure experimentally for load bearing application. But, the studies on dynamic behavior of the lattice structure that fabricated AM method especially numerical approach are limited, so this study will investigate the dynamic behavior of lattice structure using numerical method and compare to the result obtained experimentally.

## 1.3 Objective

The objectives for this research are:

1. To obtain vibration characteristic of solid and lattice structure material bar using finite element analysis.
2. To validate the result obtain with experimental method.

## 1.4 Scope of Study

The scopes of study are listed as below:

1. This study includes the draw and design of the BCC lattice bar model with strut diameter size 1.0 to 1.8 mm.

2. This study analyze vibration characteristic of solid and BCC lattice bar models from ABS, titanium and stainless-steel materials using finite element method (FEM).

3. This study analyze static deflection of solid ABS and lattice ABS bar models using finite element method (FEM).

4. This study conduct modal testing of solid and BCC lattice ABS bar samples with strut diameter size 1.4 to 1.8 mm experimentally.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview

In this chapter will be focusing on reviewing about the lattice structure material, vibration analysis, finite element method (FEM)

## 2.2 Lattice Structure Material

Lattice structure is a type of architectured material, which is a combination of monolithic material and space to generate a new structure which has the equivalent mechanical properties of a new monolithic material (Ashby, 2013).

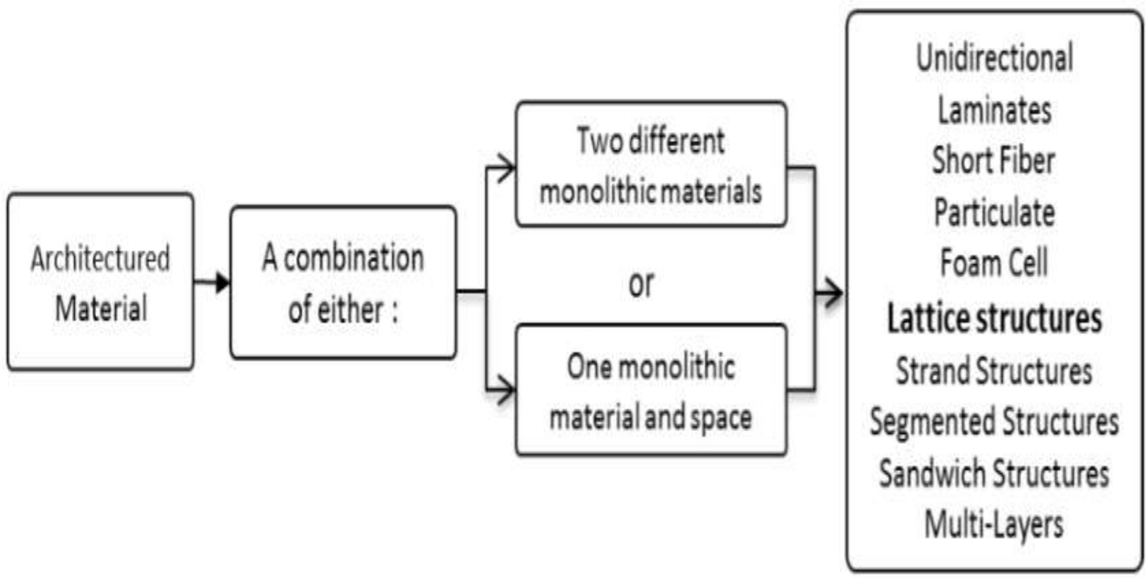


Figure 2.1:Flow of architectured materials according to (Ashby, 2013).

Figure 2.1 illustrates the combination and types of architectured materials. Other name for architectured materials is cellular structures. The word “cell” get from a latin word that call “cella”, which means enclosed space or small compartment (Gibson and Ashby, 1999).

Cellular structures come from the clusters of a cell. Wood, cork and sponges are the most common cellular structures we used in daily life. These structures have existed for ages and human beings have benefited from their various uses.

### 2.2.1 Lattice Structure in Nature

In nature, a lot of materials that contain lattice structure design. The materials are lightweight structures. Natural tabular structures often have honey- comb like or foam like core, that can increase the resistance of the shell to local buckling failure and supports denser outer cylindrical shell (Gibson,2005).

To form lightweight high strength materials, the configurations of lattice structure can refer from the materials. Hexagonal lattice structure is one of example that have some similarities with cellular structure of the wood. The behavior such as stiffness and strength of a species wood depends on its density and applied load. If applied load same direction with the wood, the stiffness and strength will higher be compared if the applied load across the wood. Another example is the trabecular bone. The structure of the bone is adapted to the loads applied to it. It grows in response to the magnitude and direction of the load applied (Gibson, 2005).

There are two categories divided for architectured materials which is stochastic and periodic structures. For materials that can characterize by a unit cell that can be translated through the structure are known as periodic materials (Wadley, 2002).

Cellular materials that cannot be defined by a single unit cell area are referred to as stochastic foams. Periodic cellular structures are divided into two types. First, periodic materials defined as unit cells are translated into two dimensions are known as prismatic