DETERMINATION OF MECHANICAL PROPERTIES OF HUMAN BONE

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Yoga Nyana Sittar Om Sri Raja Yoga Guru Saranam

To my beloved parents Sothi a/l Muthusamy and Sarathambal a/p Narayanasamy. Not to forget to my beloved sisters Sandana Kumari and Kasthuri. This thesis is a token of appreciation for your sacrifice and encouragement you all give me.

bandhur ātmātmanas tasya,
yenātmaivātmanā jitah,
anātmanas tu śatrutve,
vartetātmaiva śatruvat

Bhagavad Gita*; Chapter 6-Verse 6*

For the being who has conquered the mind;
That beings mind is the best of friends;
But for one whose mind is uncontrolled;
That very mind acts as the worst of enemies.

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ABSTRACT

Human bones are a bioceramic composite material which has very unique properties and structure. The mechanical properties of the bone are to be determined in this project using state-of-the-art finite element model. The geometry of finite element model was constructed in SolidWorks mechanical CAD package. The micron size pores were created using spline-feature-extrude method to include porosity as close as possible to that of the natural bone. The computational domain was determined through trial-meshing by which the model than can be successfully discretized was obtained. Mechanical properties were based on compression type of loading. Essential properties to incorporate into the FE modeling and realistic range of compressive load were obtained from the compression test done with the synthetic specimen. Special fixture was developed for holding very delicate specimen and to eliminate possible errors during the compression test. Compression test was carried out until the bone specimen fractured. The same load range applied in the experiment was defined in the FE model and compression analysis was performed to virtually determine mechanical properties. The FE model was validated by experimentally found mechanical properties. The properties used to validate is the Young's Modulus. The experimental value of the Young's modulus is 5202 MPa while the FE analysis gives a value of 5290 MPa. The percentage of error is calculated to be 1.7%. The FEM model is validated as its percentage of error is less than 10%. Hence, the mechanical properties by FEM were found to be Young's Modulus of 5290 MPa and Poisson ratio of 0.3. The proposed FE model can be used to analyze the response of the human bone under various loading.

ABSTRAK

Tulang manusia merupakan satu bahan komposit bioseramik yang mempunyai sifat dan struktur yang unik. Dalam projek in sifat mekanikal tulang manusia ditentukan menggunakan model tulang yang canggih melalui teknik '*Finite Element*' (FE). Struktur tulang manusia ini dibentuk menggunakan perisisan 'CAD' *SolidWorks*. Liang-liang tulang yang bersaiz mikro dibentuk menggunakan cara '*spline-feature-extrude'* dimana struktur model dipastikan hampir sama dengan struktur tulang sebenar. Julat kiraan ditentukan dengan percubaan '*mesh*' yang dilakukan dan saiz model yang bersesuaian dikenalpasti. Sifat mekanikal ditentukan dengan mengunakan daya mampatan. Sifat yang penting untuk digunakan dalam model 'FE' dan juga julat daya mampatan yang realistik diperolehi daripada ujian kemampatan terhadap tulang manusia tiruan. Sebuah pemegang khas dibuat untuk memegang tulang untuk mengelakan ralat semasa ujikaji. Ujian kemampatan dilakukan sehingga specimen tulang menjadi rapuh. Julat daya yang sama digunakan dalam analisa kemampatan dalam perisian untuk mencari sifat mekanikal tulang. Model tulang ini disahkan dengan mengunakan nilai daripada sifat mekanikal yang diperolehi melalui eksperimen. Sifat yang digunakan untuk mengesahan adalah modulus Young. Nilai eksperimen modulus Young adalah 5202 MPa manakala analisa 'FE" memberikan nilai 5290 MPa. Peratusan ralat yang kira antara kedua-dua nilai adalah 1.7 peratus. Model tulang ini disahkan kerana mempunyai peratusan ralat yang kurang daripada 10 peratus. Oleh yang demikian sifat mekanikal tulang manusia iaitu modulus young melalui analisa 'FE' adalah 5290 MPa dan '*Poisson ratio*' adalah 0.3. Model tulang manusia ini boleh digunakan dalam menganalisis sifat tulang dalam daya yang berlainan.

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LIST OF SYMBOLS

E	Young’s Modulus
σ	Stress
ε	Strain
L	Length
D	Diameter
α	Drucker-Prager Yield Function Alpha
β	Drucker-Prager Yield Function Beta
C	Damping Coefficient
k	Stiffness Matrix
v	Relative Velocity
δy	Yield Stress
F	Force

LIST OF ABBREVIATIONS

ASM	American Society for Metals
BC	Boundary Conditions
CAD	Computer Aided Design
DOF	Degree-of-freedom
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
FYP	Final Year Project
MES	Mechanical Event Simulation

CHAPTER 1

INTRODUCTION

1.1 Introduction

Human bones can be considered as a composite material where testing can be carried out to find out its mechanical properties. Generally there is lack of information about the properties of bone. This situation arises because of few studies conducted on the human bone as it is not easy to get the specimen. Studies about the mechanical properties of the bone are very scarce and most studies are conducted to find the behavior of the bone rather than the properties of it. As for it the knowledge about the basic mechanical properties are limited. The properties of the bone can be found using standard material tests such as tensile test.

The properties of the bone that have been found will beneficial to the many sectors most importantly to the medical sector. This allows for a better treatment and diagnose for bone related diseases- development of artificial or synthetic bone. Besides that innovation for a better protective gear can also be benefited by the study about human bone properties. Finite Element Analysis (FEA) plays a bigger role in the analysis and testing of materials virtually using FEA software such as ALGOR, ABAQUS and COSMOS. The advantage of using FEM is that it is economical by reducing the number of experiment FEA allows a more intricate analysis of material besides making it easy to conduct different tests to a material (Hutton, David V., 2004). In this project FEA is used to find out the mechanical properties of the human bone and also its behavior.

1.2 Problem Statement

Generally the project is to identify how the human bone's response to external loads. Fundamentally its response to external load is unknown, so in order to find out this response, knowledge of mechanical properties of the bone is important. Moreover accurate data about the bones properties are very difficult to obtain as there is lack of accurate computer models or a very well established experiment.

1.3 Objective

Primary objective of this project is to determine the mechanical properties of human bone using Finite Element Method (FEM). In order to support the main objective, other objectives are identified as follows:

i. To investigate mechanical properties of the bone by using a standard material test.
ii. To develop Finite Element Modal that can predict human bone properties.

1.4 Project Scope

The project has two level of study about the properties of human bone. The first level of study will be the determination of human bone properties using a common compression test. The specimen is a synthetic bone substitute which is claimed to have properties as natural bone. From the test that will be conducted the properties such as the Young Modulus, Yield strength and the Poisson ratio will be obtained.

The second level will be modeling and analysis of human bone using FEM. The properties obtained from the test compression test will be used as input data to the FEM. Then the model is validated by comparing the results from FEM with the properties obtained from the compression test. After the validation additional simulation for various compressive loads will be carried out.

1.5 Flow Chart

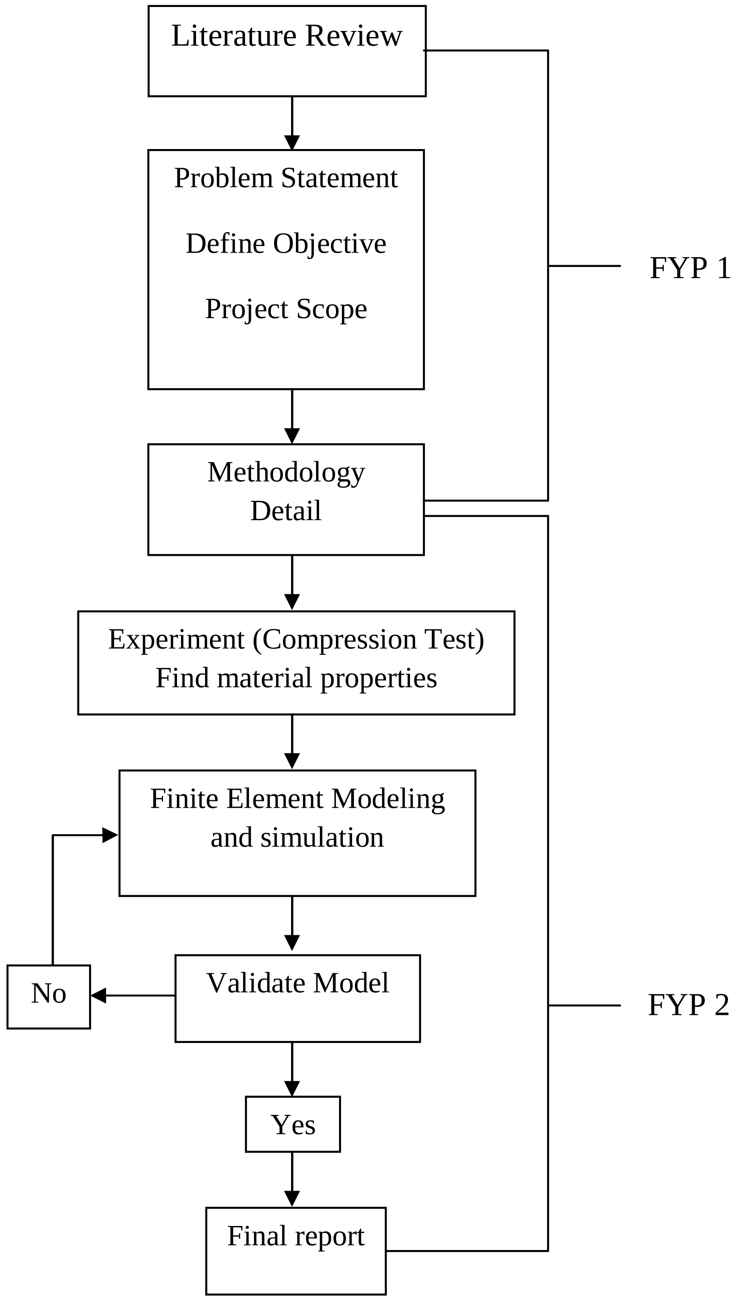

Figure 1.1: Flow Chart of FYP 1 and FYP 2

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

As a part of the project, the analysis of literature is important as to have a further understanding the project. The materials that used for the literature review are from journals, books, past studies and from the internet web pages. The review is to find out the relevance of the project and it must have a significant relation to the project.

2.2 Bone

Human bones are a rigid organ which is a part of human endoskeleton, it functions to enable movement, provide support and also to protect vital organs as it has a very hard feature. Besides that, human bones also function to store minerals, produces red and white blood cells (Enderle, John D., Bronzino, Joseph D.,and Blanchard, Susan M., 2005). Bones has many shapes and has a very complex structure both internal and external. Bone tissue or osseous tissue makes up as the element of bone structure which gives its rigidity and honeycomb internal structure (Wikipedia/Bone).

2.2.1 Function

Fundamentally the bone has eight main functions (Wikipedia/Bone). Every living organism has evolved to have its protection system such as shells and bones. Human bone also serves to this function that is to protect the internal organs such brains, heart and lungs. Bones provide support to the body and maintain the shape. Important mineral such as calcium and phosphorus are reserved in the bone where the bone functions as mineral storage. Bone marrow which located in long bones produces blood cells. Movement is another function of bones where it is used to transfer motion to individual parts. Bones help in keeping the body’s acid base balance by absorbing and releasing alkaline salts. Foreign elements and toxic metals can be stored in bone to detoxify the blood. Last but not least bone also help in sound transduction aspect of hearing.

2.2.2 Types of bone

Basically the human bone has many shape, it have been classified into five types (Wikipedia/Bone). Even though it has different shape it has the same composition and structure. The first type of bone is the long bones where it has a shape of long shaft. Generally it is very thick and most of the bone is contains in limbs. Short bones roughly cube shaped with most of the structure consist of Trabecular bone with thin layer of cortical bone. Wrist and ankle are considered as short bone. The third type of bone is the flat bone where it consists of trabecular bone sandwiched in between two layer of cortical bone. Another type of bones is the irregular bones as for the name the bones are shaped irregularly. The spine and hip are example of irregular bones. The fifth type of bone is sesamoid bones where the bones are embedded in tendons such as the patella.

2.2.3 Structure and Characteristic

Human bone can be considered as a composite material with a complex structure. Bones are made of osseous tissues primarily; this contributes to its hardness and lightweight (Wikipedia/Bones).The bone is made up of calcium phosphate as its main structural material. Human bone is generally classified into two types that are: cortical (compact) bone and Trabecular or Cancellous bone (www.engin.umich.edu/class/bme456/bonestructure) as shown in figure 2.1. It is classified based on its porosity level and microstructure. Generally the compact bone or cortical bone has a very denser structure and its porosity level is ranging from 5%

to 10%. From overall human body’s bone mass, cortical makes about 80% of it. Cortical bone is very compact and has a very high strength. Thus it forms the outer layer around the Trabecular bone in shaft of long bones. Trabecular or cortical bone is much porous with porosity level in between 50% to 90%. It accounts for the remaining 20% of the total bone mass and has almost ten times of the surface area of compact bone (Wikipedia/bone).

The cortical bone as other biological tissues has a hierarchical structure that is bone contains many different structures. On general it has been classified into three main type based on its microstructure organization (www.engin.umich.edu/class/bme456/bonestructure). Bone has up to seven hierarchical level of organization from the microstructure of the mineral crystals to the microstructure of cancellous and cortical bone (Huajian Gao, Baohua Ji, 2003). This means the cortical bone has different structure layers similar to a Russian dolls (Enderle, John D., Bronzino, Joseph D.,and Blanchard, Susan M., 2005) .

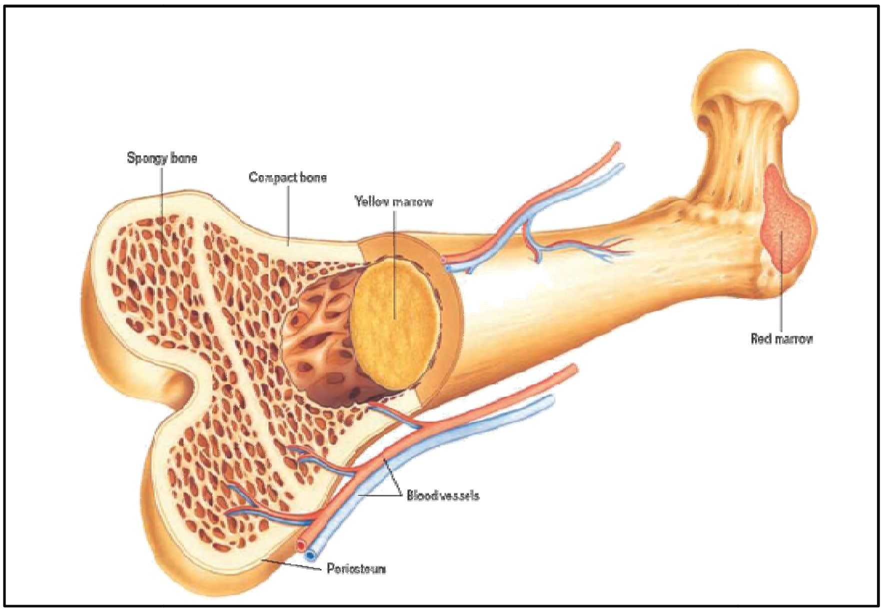

Figure 2.1: Human Bone Structure

2.2.4 Bone properties

Bone is a hybrid of organic and inorganic composite containing protein and mineral with superior hardness, strength and fracture toughness (Huajian Gao, Baohua Ji, 2003).

2.3 Mechanical properties

The developments of science in material analysis have given some method to measure certain properties of materials. Technology in material science allows the determination of materials properties even before it has been manufactured (Gedney, Richard T, 2007). Mechanical properties that are taken into account are such as hardness of material, yield strength, Young Modulus, Poisson Ration, Stress, Strain and many others. These properties are important to ensure further understanding and help in the analysis of the material.

2.3.1 Stress

Consider a material is subjected to an external load such as in a tensile test. The force will tend to fail the material by breaking the internal bonds. Stress is the internal resistance to oppose the breaking of materials (Meyers, Marc A., and Chawla, Krishan Kumar, 1999). Basically a uniaxial stress is defined as the force (F in Newton) acting on Area (A in m^2) or simply F/A denoted by a symbol σ (Benham, P.P., Crawford, R.J., and Arsmstrong, C.G., 1996). Stresses can be exerted as three states that are Compressive Stress, Tensile Stress and Shear Stress. Compressive stress happens when a material is subjected to pushing or compressing force where the material tends to compact it self. Compressive stress usually leads to bucking of the material. When a material is subjected to pulling force it will produce tensile stress. The value for the compressive stress is always higher to the value of tensile stress. Meanwhile when a material fails along a plane parallel to the force applied it will have a Shear Stress.

2.3.2 Strain

Strain is related to the deformation of material. It is measured by dividing the difference of length by the original length. Strain does not have any specific unit and it can be calculated not only in the elongation of material but also any other geometrical chance such as thermal expansion.

2.3.3 Modulus of Elasticity

Generally the Modulus of elasticity or Young Modulus is the value obtain when stress is divided by strain.

$$E = \frac{\sigma}{\varepsilon}$$

The unit for Young Modulus is as same as the unit for Stress, which is N/m^2. This property can be used to determine the stress and strain relationships

2.3.4 Poisson's Ratio

Poisson's Ratio is defined as the ratio between lateral and longitudinal strains in the elastic regions (Meyers, Marc A., and Chawla, Krishan Kumar, 1999). The value of Poisson's ratio is always in the range of 0 to 0.5 for stable material (Dowling, Norman E., 2007).

2.3.5 Elasticity

Ability of material to return to its original shape after the stress on it released is termed as elasticity. Elastic region is always the straight line a stress-strain relationship plot. Thus it is a directly proportional quantity.