SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Structure and Materials)"

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Date :

EFFECT OF YEAST CONTENT AS FOAMING AGENT ON THE MECHANICAL PROPERTIES OF TITANIUM FOAM

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DECLARATION

"I hereby declare that the work in this thesis is my own except for summaries and quotations which have been duly acknowledged."

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Date :

Dedicated to my family
especially for my mother and father

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ABSTRACT

Nowadays, metal foam has gained interest in industry and became so popular. Its physical and mechanical properties are believed to give various benefits to various industries such as automotive, aerospace and biomedical application. Mechanical properties of metal foam such as light-weight structure, energy absorption, high stiffness and low Young's modulus has entrusted the researchers to study the nature of the metal foam deeper for future benefits. This research succeed to achieve the research objectives which is to determine the effect of yeast content on the mechanical properties of titanium foam and study the effect of yeast content on the size of micro pores. Yeast as new organic foaming agent is proved as a replacement for existing foaming agent. Yeast weight percentage that have been used are 15, 25 and 30 wt. %. Titanium foam was made up with slurry technique with yeast as foaming agent and ethylene glycol as binder. The yeast decomposed during the sintering process and thus, it is environmental friendly. Different ratio of titanium powder to yeast was used to obtain the best result of titanium foam. The microstructure of the titanium foam was analysed using inverter microscope and image analyser was used to obtain the details of microstructure of titanium foam result. The pore size of titanium foam obtained was in range of 395.63 to 546.78 µm while the strut size obtained was in the range of 223.13 to 300 µm. The porosities of titanium foam lead to 60.5 until 75.5%. Furthermore, mechanical testing such as compression test was carried out. From the compression stress held, Young's Modulus can be known. Compression stress of 2.41 to 4.56MPa and Young's Modulus of 0.218 to 0.267GPa were obtained. All the results obtained fulfil the requirements of human cancellous bone.

ABSTRAK

Pada masa kini, logam berbusa telah mendapat tarikan daripada industri dan menjadi begitu popular. Sifat-sifat fizikal dan mekanikal yang dipercayai memberi pelbagai manfaat untuk pelbagai industri seperti aplikasi pada automotif, aeroangkasa dan bioperubatan. Sifat mekanikal logam berbusa seperti struktur ringan, penyerapan tenaga, kekakuan tinggi dan modulus Young yang rendah telah memberi kepercayaan pada para penyelidik untuk mengkaji sifat logam berbusa dengan lebih mendalam untuk faedah masa depan. Kajian ini berjaya mencapai objektif kajian iaitu untuk menentukan kesan kandungan yis pada sifat-sifat mekanikal titanium berbusa dan mengkaji kesan kandungan yis kepada saiz liang mikro. Yis sebagai ejen berbuih organik baru terbukti boleh digunakan untuk menggantikan ejen berbuih sedia ada dan peratusan berat yis telah digunakan adalah 15, 25 dan 30%. Busa titanium dibuat dengan teknik buburan dengan yis sebagai ejen berbuih dan etilena glikol sebagai pengikat. Yis mengurai semasa proses pensinteran dan dengan itu, ia adalah mesra alam sekitar. Nisbah serbuk titanium kepada yis yang berbeza akan digunakan untuk mendapatkan hasil titanium berbusa yang terbaik. Mikrostruktur titanium berbusa telah dianalisis dengan menggunakan *inverter* mikroskop dan penganalisis imej telah digunakan untuk mendapatkan butir-butir mikrostruktur hasil titanium berbusa. Saiz liang busa titanium diperolehi ialah dalam julat 395.63-546.78 μm manakala saiz tupang yang diperolehi adalah dalam julat 223.13-300 μm. Keporosan busa titanium yang diperolehi adalah antara 60.5 sehingga 75.5%. Tambahan pula, ujian mekanikal seperti kekuatan mampatan telah dijalankan. Daripada ujian tekanan mampatan yang dijalankan, Modulus Young dapat diketahui. Tekanan mampatan bernilai 2.41 hingga 4.56MPa dan Modulus Young bernilai 0.218 hingga 0.267GPa telah diperolehi. Semua keputusan penyelidikan yang diperolehi memenuhi keperluan tulang *cancellous* manusia.

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ρ^*	= density of foam
ρ_s	= density of solid material
$\emptyset$	= porosity
V_{PS}	= volume of pore space
V_T	= total volume of sample

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CHAPTER 1

INTRODUCTION

1.0 BACKGROUND

Porous materials are easy to be found in the natural structure such as cork, wood, bone and sponge. All of these natural structures have a great structural strength yet lightweight. Therefore, man has applied this natural condition to the man-made porous material from metal and ceramics. Those made have been widely exploited because of the unique combination of physical and mechanical properties offered by porous metals [1].

The characteristic of metallic foam is a combination of properties of metal and foam. Metal foam is a gas bubble-filled substance made out of metal. It is a structural material that contains a high volume of porosity within a metal and typically very lightweight due to the low density [2]. Metal foam has been widely used around the world involving aerospace, automotive, structural and biomedical. Their applications are still promising and perspective even it had been introduced over half of the centuries. It gives many beneficial in term of mechanical properties, for instance, high impact energy absorption, high stiffness, high strength to weight ratios, high gas permeability, and high thermal conductivity [2].

The physics of metal foaming contains five stages which are making the precursor, initial pore formation, pore inflation, foam degradation and solidification. Mixture of metal powder and gas-releasing foaming agent is compacted to make the precursor. While the precursor is on heating, gas evolves in the precursor and process of pore formation begins to start. Pore formation is continually enlarged as the foaming agent is decomposed. The ongoing gas supply from the decomposition of foaming agent boosts the pore formation. Degradation begins while pores are being inflated. Drainage occurs due to the downward flow of liquid through Plateau border under gravity and bubbles coalesce as films become thin and unstable. The metal has to be solidified quickly at the right time to prevent this unstable foam from collapse. Deformation of films or crack may occur in the cell walls due to sudden solidification [2].

The pore characteristics are divided into pore morphology, porosity and pore size. Pore morphology is divided into open and closed pores. The difference between both of it is in term of permeability where fluid can penetrate. Open pores are penetrating pores while closed pores are non-penetrating. Open pores are very important for separation-filtration while closed pores are beneficial for light-weight materials and heat insulating materials [3].

The porosity means the fraction of pore volume to the total volume. Higher porosity leads to lower Young Modulus. Thus, metal foam with smaller pores generally has better elastic of modulus than metal foam with larger pores at an equivalent porosity. Range of porosity will also influence thermal and electrical conductivity, thermal shock resistance and gas permeability besides mechanical properties [3].

1.1 PROJECT OBJECTIVES

The objectives of this research is to determine the effect of yeast content on the mechanical properties of titanium foam and study the effect of yeast content on the size of micro pores.

1.2 PROBLEM STATEMENT

Nowadays, use of titanium in biomedical application became so attractive and popular due to its great corrosion resistance, biocompatibility and high strength to weight ratio. However, elastic modulus of titanium, which is 110.3 GPa, is too high compared to elastic modulus of human bone, which is in the ranges of 0.09–1.5 GPa while for its compressive yield strength is 40–150 MPa [4]. This condition may lead to stress shielding to the bone. Stress shielding is occurred due to the mismatch of Young's Modulus between the bone and metallic implants [5].

Hence, porous titanium is introduced to reduce the Young's modulus and thus, increased the productivity of titanium use in biomedical application. In this research, a method of titanium foam preparation with yeast as foaming agent is introduced and its mechanical properties in term of Young modulus and strength is investigated; thus, study size of micro pores affected by yeast content. Heat causes yeast to decompose and release gas, which then propels the foaming process. The porous titanium had been fabricated using mixture of yeast and titanium powder by controlling the ratio of yeast to titanium powder [6]. The mechanical properties and pore structure of titanium foam obtained from this research could be mimicking to those of the human bone.

1.3 PROJECT SCOPE

This research studied about the effect of yeast content as pore foaming agent on the micro pores and mechanical properties of titanium foam as macro-porous materials. In this research, the method used to prepare titanium foam is slurry method. Titanium foam was being produced by preparing slurry of titanium powders mixed with yeast as foaming agent. Preparation of slurry had started by mixing up of yeast with titanium powder and ethylene glycol as binder. Certain amount of distilled water was added to the mixture of titanium powder, yeast and binder for stir mixing. Then, the slurry was mixed until the compounds were distributed evenly. After that, the slurry was poured into the PVC mold and allowed it to dry under the room temperature. The process was followed by sintering process with the temperature of 1250^{o}C for 2 hours and with sintering rate of 5^{o}C/min.

Different ratio of yeast to titanium powder was the processing parameter that should be taken care during production of titanium foam to achieve these objectives. This research investigated the suitability of production of titanium foam from the mixture of titanium powder and yeast through slurry method. In determining the mechanical properties, the compressive test had been carried out, the microstructures of sintered porous materials were observed and the pores sizes were measured. The mechanical properties and pore structure of titanium foam were investigated to ensure it was closely resemble those of the human bone.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

In 8 May 1943, Benjamin Sosnick is the person who had invented metal foam. He had filed a patent entitled “Process for making Foam like Mass of Metal”. He first melted a mix of 90 parts of aluminium, Al, to 10 parts of mercury, Hg, in a closed chamber or under conditions to prevent the mercury vapour to escape. When Hg in the mixture is stabilized, the pressure was released. This led to volatilizing of Hg in the mass and thus, foam was formed [2, 7].

Nowadays, the application of metal foam becomes so popular and plays an important role in industries due to its advantages. It is applied in a wide range of sectors and industries which include transportation, defense, architecture, aviation, marine, energy and process industries.

Metal foam is introduced to improve crash energy absorption at crash boxes and bumper beams in the automotive industry. Besides, in Korea, some foam has also been deployed in muffler system to reduce noise compared to regular muffler[8].

In aerospace, metal foam structural parts are being considered for turbine component and as reinforcement for load bearing structures in satellites. Boeing also had evaluated the use of large aluminium and titanium foam sandwich parts for tail booms of helicopter [8]. The application of metal foams in railway is concerning lightweight construction, energy absorption and damping insulation. In Japan, to improve crash energy absorption, the trains has been fitted out with a 2.3 m^3 block of “Alporas” foam [9].

Moreover, open porosity metal foam also is applied as heat exchanger. Heat can be removed from or added to gases or liquids by letting them flow through the porous structure and cooling or heating the foam at the same time [10].

While in biomedical application, metal foam has been applied for orthopaedics and dental implants. Metal foam gives advantages in porosity, strength and appearance very similar to cancellous bone. By modifying some mechanical properties of solid metal into metal foam, metal can have similar characteristics with the bone which can replace the bone and prevent stress shielding [9, 11].

2.1 BIOMEDICAL APPLICATION OF METAL FOAM

The fabrication of porous materials has been actively researched since 1943, when B. Sosnik attempted to introduce pores into aluminium by adding mercury to the melt. In 1972, Weber and White have introduced the concept of porous metal in the biomedical application for osseointegration. Numerous investigations into porous materials where subsequently initiated in the early 1970’s involving porous ceramic, polymeric and metallic materials which showed in animal studies to be potential candidates for porous implants that would enable bone ingrowth [11].

2.1.1 Mechanical Properties of Cancellous Bone

Bone is an open cell composite material composed of a complex vascular system and a significant fraction of protein-related materials. Bone contains two types of different tissues tightly packed together. The outer shell is called cortical bone, while the inner core is comprised of porous cellular which called cancellous or trabecular bone [12]. Figure 2.1 shows the structure of femur.

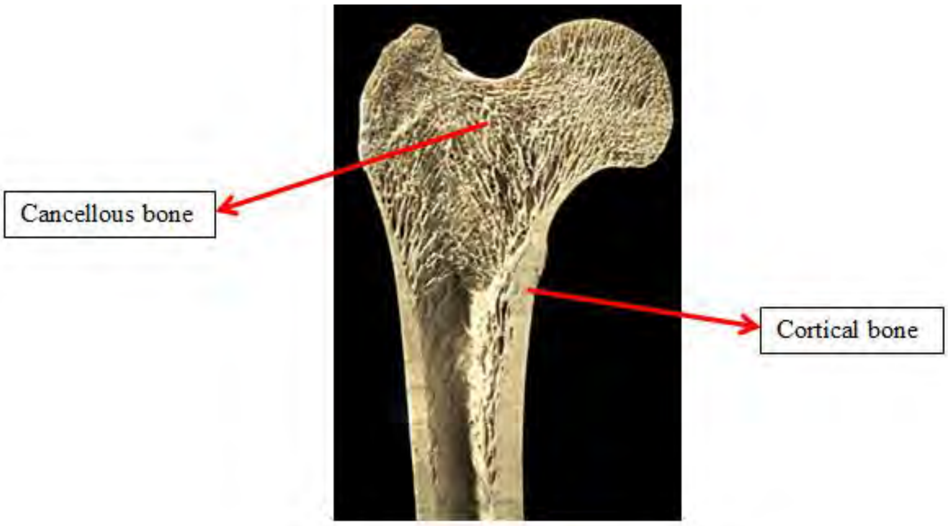

Figure 2.1: Cancellous bone and cortical bone [13]

Cancellous bone is the spongy type of bone, which is found in vertebral bodies and femoral head as in Figure 2.2. The porous space left free by the bone material is filled with marrow and living cells. Cancellous bone is highly porous, consisting of an interconnected and loose network of trabeculae which is in the range about 50 – 300 μm in diameter. The typical thickness of the trabeculae is having a size of approximately 200 μm in diameter with an orientation that depends on the load distribution in the bone. Cancellous bone has the porosity ranges between 75% and 90%. It can be considered as foam like network of bone trabeculae [12, 14].

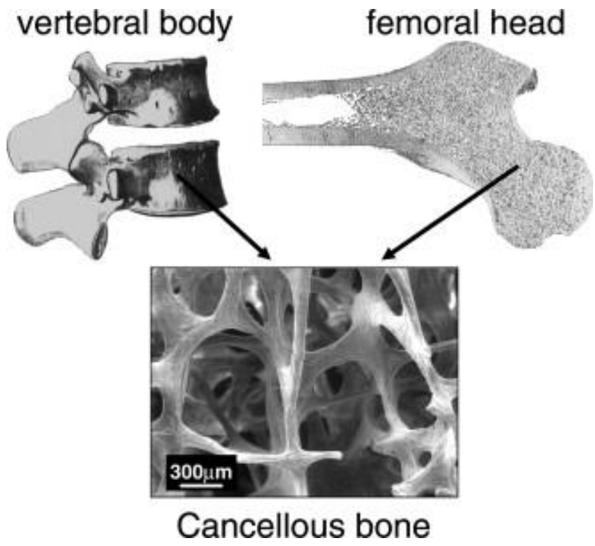

Figure 2.2: The vertebra and the end of femur are filled with a spongy structure called cancellous bone [14]

Cancellous bone gives supporting strength to the ends of the weight-bearing bone. Figure 2.3 shows x-ray of a femur which the thick cortical bone and the trabecular bone are shown. The bone arrangement is to withstand the stresses from usual standing and walking. Compressive stresses happen when weight pushing the bone down while tensile stresses happen when the muscles pulling the bone apart [2, 13]. The mechanical properties of cancellous bone are shown in Table 2.1 [15].

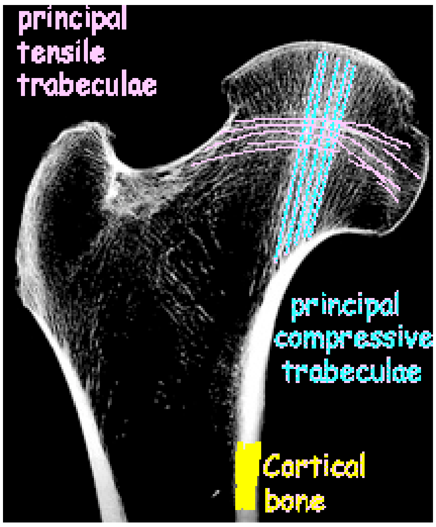

Figure 2.3: X-ray femur which shows cortical bone and cancellous bone [13]