DEVELOPMENT OF STAINLESS STEEL FOAM WITH HA BIO ACTIVE CERAMIC ADDITION USING SLURRY METHOD

YARSHINE RANI A/P RAJASAKARAN

A thesis submitted in

fulfillment of the requirement for the award of the

Degree of Master of Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering

Universiti Tun Hussein Onn Malaysia

JANUARY 2023

ACKNOWLEDGEMENT

All grace to the Almighty God, for allowing me to complete my thesis. This dissertation would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study.

First and foremost, it is with immense gratitude that I acknowledge the support and help of my thesis Supervisor, Professor Madya Dr. Sufizar Binti Ahmad, who has the attitude and the substance of a genius; she continually and convincingly conveyed a spirit of adventure in regard to the research and an excitement in regard of teaching. She has made available his support in a number of ways and which this thesis would not have been possible without. I also want to convey gratitude to my Co-Supervisor Dr.Fazimah Binti Mat Noor for her continuous encouragement and information sharing as well as expertise throughout the supervisory sessions.

Besides my advisor, I would like to thank the rest of my thesis committee panel: Prof. Madya Ts. Dr. Hamimah Binti Abd Rahman and Ts. Dr Mohd Azham Bin Azmi, for their encouragement, insightful comments, and hard questions. Nobody has been more important to me in the pursuit of this project than the members of my family. I would like to thank my parents, whose love and guidance are with me in whatever I pursue. They are the ultimate role models. Most importantly, I wish to thank my loving and supportive friends, who provide unending inspiration.

Last but not the least; I would like to express my gratitude to all the good souls who are involved directly or indirectly in order to complete this dissertation. Thank you.

ABSTRACT

This present study focuses on fabricating of Stainless-Steel Foam with Bio Active Ceramic addition using slurry method. The mechanical and physical properties of stainless steel is still not perfectly adequate for medical implants requirements. Therefore, the slurry method is mainly focused on increasing the mechanical and physical properties of the stainless-steel foams with hydroxyapatite addition. The samples wereproduced with different compositions of SS316L and HA powders were mixed together with binders which were polyethylene glycol (PEG) and carboxymethyl cellulose (CMC) to prepare slurry solution for impregnation of polyurethane (PU) sponge as the template. SS316L-HA foam were fabricated by slurry method and sintered at various sintering parameters. The physical and mechanical properties were determined for each sample of SS316L-HA foam by analysis of shrinkage, apparent porosity, apparent density, compressive strength and microstructure analysis. Following optimization, the SS316L-HA foam produced was found to have attractive mechanical andphysical properties much like human bone. The suitable percentages of HA via slurry method are 1%-5%. Notwithstanding, this included the average shrinkage occurs at the sintering temperature of 1350°C with 1wt% of Hydroxyapatite are 26.54%. The average porosity was obtained at temperature 1150˚C with 59.88% of 3wt% of HA. The average density obtained for SS316L-HA foam are 3.83g/cm^3, sintered at 1350˚C of 1wt.% HA. The maximum value of yield strength was 18.85Mpa with 10wt.% HA, sintered at temperature 1300°C. The maximum value of modulus elasticity was 0.49GPa with 10wt.% HA, sintered at temperature 1150°C. The average pore size for all SS316L-HA foam samples are in the range of 310 µm to 386µm. These results are fulfill the objectives of development of stainless-steel foam with bio active ceramic addition using slurry method.

ABSTRAK

Kajian ini memfokuskan kepada SS316L dengan penambahan Seramik Bio Aktif menggunakan kaedah buburan. Sifat mekanikal dan fizikal keluli tahan karat masih tidak mencukupi untuk keperluan implan perubatan. Oleh itu, kaedah buburan terutamanya tertumpu pada peningkatan sifat mekanikal dan fizikal buih keluli tahan karat dengan penambahan HA. Objektif kajian ini adalah pertama, mengenal pasti peratusan HA yang sesuai melalui kaedah buburan. Kedua, optimumkan suhu pensinteran yang sesuai untuk SS316L-HA. Ketiga, pengaruh pengesahan penambahan HA dan suhu pensinteran ke atas sifat fizikal dan mekanikal buih SS316L-HA selepas proses pensinteran. Sampel telah dihasilkan dengan komposisi berbeza serbuk SS316L dan HA dicampur bersama pengikat iaitu polietilena glikol (PEG) dan karboksimetil selulosa (CMC) untuk menyediakan larutan buburan untuk impregnasi span poliuretana (PU) sebagai templat. Buih SS316L-HA telah direka dengan kaedah buburan dan disinter pada pelbagai parameter pensinteran. Sifat fizikal dan mekanikal ditentukan untuk setiap sampel buih SS316L-HA dengan analisis pengecutan, keliangan ketara, ketumpatan ketara, kekuatan mampatan dan analisis struktur mikro. Berikutan pengoptimuman, buih SS316L-HA yang dihasilkan didapati mempunyai sifat mekanikal dan fizikal yang menarik seperti tulang manusia. Peratusan HA yang sesuai melalui kaedah buburan ialah 1%-5%. Walau bagaimanapun, ini termasuk pengecutan purata berlaku pada suhu pensinteran 1350°C dengan 1wt% Hydroxyapatite ialah 26.54%. Purata keliangan diperoleh pada suhu 1150˚C dengan 59.88% daripada 3wt% HA. Purata ketumpatan yang diperolehi untuk buih SS316L-HA ialah 3.83g/cm3, disinter pada 1350˚C 1wt.% HA. Nilai maksimum kekuatan hasil ialah 18.85Mpa dengan 10wt.% HA, disinter pada suhu 1300°C. Nilai maksimum keanjalan modulus ialah 0.49GPa dengan 10wt.% HA, disinter pada suhu 1150°C. Purata saiz liang untuk semua sampel buih SS316L-HA adalah dalam julat 310µm hingga 386µm. Keputusan ini memenuhi objektif pembangunan buih keluli tahan karat dengan penambahan seramik.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATION

SS316L	-	Stainless Steel
HA	-	Hydroxyapatite
PU	-	Polyurethane
PEG	-	Polyethylene Glycol
CMC	-	Carboxymethyl Cellulose
SEM	-	Scanning Electron Microscope
UTHM	-	University Tun Hussein Onn Malaysia
CaP	-	Calcium phosphate
CDA	-	Calcium-deficient apatite
β-TCP	-	Beta-tricalcium phosphate
Ti	-	Titanium
W_W	-	Wet weight
W_d	-	Dry weight
W_S	-	Soak weight
ρw	-	Density of water
$l_\circ$	-	Length before sintering
l_1	-	Length after sintering
ε	-	Strain
σ	-	Stress

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Stainless steel (SS316L), like titanium and titanium combinations, is generally utilised as the most well-known loading-bearing implant for its high corrosion resistance, low cost, mechanical properties, and excellent biocompatibility (Thanh *et al.,* 2013). Since 1660, implants have been used for several purposes. The current use of implants in dentistry and medicine began in 1960 (Kurgan *et al.*, 2012). Stainless steel 316L (SS316L) remains widely used and extends from cardiovascular to otorhinology and dental. SS316L is used as an orthopaedic bone fixation implant, orthodontic wire, cardiovascular stent implant and prostheses in dentistry. SS316L is well known for producing biomedical applications (Hermawan 2011; Ding *et al.,* 2010; Roguska *et al*., 2011).

The concept of bioactive material is intermediate between inert and resorble materials. Although several definitions of biological activity have been reported, one is particularly simple Shi *et al.* (2021) describing the properties of an implanted material which allows it to bind to living tissues. Bio ceramics describe a host of ceramics (including bioactive glasses) specially designed and manufactured for the repair and reconstruction of diseased, damaged, missing or worn-out parts of the body" (Fu *et al.,* 2020). Calcium phosphate (CaP) bioceramics include an intimate mixture of calcium-deficient apatite (CDA), hydroxyapatite (HA), beta-tricalcium phosphate (β-TCP) and biphasic calcium phosphate (BCP) – an intimate mixture of HA and β-TCP. Bioactive bioceramics are available as powders, granules, pellets, and blocks

(dense or porous), as cement (CPC), as composites (CaP/polymer), and as coatings on orthopedic and dental implants (Bala *et al.*, 2017).

Biomaterial research, according to Williams, is a study of the structure and properties of biomaterials, the mechanisms that interact with biological systems, and their clinical outcomes. Biomaterial are defined as materials intended to interface with biological systems for evaluating, treating, improving, or replacing body tissue, organ, or function (Manam *et al.,* 2017). Hydroxyapatite (HA) is a ceramic made of calcium phosphate, which has a similar shape and composition to human bones and teeth. Hydroxyapatite is commonly used as a bone replacement or dental implant because of its good properties, such as high biocompatibility, osseo conductivity, and bio affinity to living tissues. HA's low mechanical properties, such as its brittleness and low fracture durability, limit its use in load-bearing applications. Therefore, metallic materials are used to enhance the mechanical properties of metal-ceramic composites (Ramli *et al*., 2014).

In order to replace the cancellous bone, there are specific features that generally need to be fulfilled by metal implants that include interconnecting pores of about 30-90 percent with a pore size of 100-600 μm to provide room for cell migration and new growth tissue, and a young module that is close to the cancellous bone, <3 GPa (Cachinho *et al.,* 2007). If a hard implant is inserted into hard tissues (e.g., bones), the bones is ultimately exposed to a minimized mechanical stress that contributes to bone absorption. Therefore, this phenomenon is known as a stress shielding effect that results in the death of bone cells (Leel *et al*., 2013).

Several composites of metal-hydroxyapatite were tested. Particular attention is paid to composites materials such as titanium and austenitic stainless steel. Based on an analysis of the results obtained, it can be assumed that the application of SS316L stainless steel to hydroxyapatite results in an increase in stiffness and strength compared to pure bioceramic hydroxyapatite. However, it resulted in improved biocompatibility, corrosion resistance, and stainless-steel hardness and wear resistance (Szewczyk-Nykiel, 2015).

For a wide range of applications, metal foams with visible, and interconnected pores is very attractive. For example, in the automotive industry, as a catalytic converter, as a heat insulator in an industrial furnace, and as a bone implant in biomedical. Aluminium foam with open pore structures can be produced using several manufacturing methods, including the space holder process, combustion replication

methods, liquid deposition, and rapid prototypeing. The sponge replication process has been shown that in all ways foam with open interconnected holes close to the spongy bone structure can be produced (Noor *et al*., 2019).

Replication, or slurry dipping, is a simple and common way to produce porous and interconnected foam using a ceramic slurry. With the presence of the central space in the struts and microspores and micro-cracks due to uneven ceramic slurry coating, this process creates scaffolding with weak mechanical properties (Muthutantri *et al*., 2018). The preparation of stainless-steel foam from the slurry of stainless steel is not simple. During the slurry preparation, there are many parameters are involved that affect the viscosity of the slurry, such as the composition of the material, the mixing method, the type of binder, and the type of solvent used. Particularly when using the sponge replication method to fabricate the foam, it is important to produce a stainless slurry with sufficient stability and viscosity. Full impregnation of stainless-steel slurry on PU foam templates could only be achieved with specific slurry viscosity. It is very difficult to produce stainless-steel slurry with low viscosity and high solid quality. A low viscosity slurry is required to allow the slurry to penetrate easily into the pores of the PU foam and require a high solid content is required to improve mechanical stability during sintering. (Noor *et al*., 2019).

1.2 Problem Statement

Stainless steel was used as an important material in surgical field.Stainless steel is a generic term for many different steels mainly used for their resistance to a wide range of caustics (Patel *et al.*, 2012). Metals have generally been used in large orthopedic load-bearing applications (Park *et al*., 2002). Some non- metallic materials have also been proposed as artificial bone candidates, but a wide range of applications have not been identified.

In the production of metal foam structures, there are many methods that can be used to produce metal foams. However, there is no detailed method that can be used to produce foam metal depending on the type of metal used. Some methods are not suitable for the use of substances. Therefore, it is essential to select a method suitable for the production of foam metal. The formation of cavities in the density, size, shape, and properties of metal foams has been one of the often-noted problems in metal foam production. Slurry method is a commonly used technique because it is one of the

techniques that has many advantages in the production of metal foams. This way you can produce good quality products. According to Yu *et al*. (2021), slurry method is one of the methods for producing metal foams. This method is very suitable for producing uniform bubbles and open cells. This slurry method is expected to produce high-quality products in the formation of SS316L-HA.

Figure 1.1 shows the elastic modulus of most materials that are currently used in biomedical applications. The diagram clearly shows that the elastic modulus of cancellous and cortical bone is very low compared to the elastic modulus of metal implants, especially in stainless steel. This causes stress shielding that occurs on interfaces that affect the long-term stability of the implant (Shah *et al*., 2019). In addition, porous metal can provide space for bone ingrowth to achieve biological fixation. Nowadays, several metallic implants have been replaced by ceramic and polymer implants due to their superior biocompatibility properties compared to metallic implants.

However, the use of metal implants is essential for implants that require high strength and durability. Until now, stainless steel grade 316L, cobalt alloy, pure commercial titanium, and Ti-6Al-4V alloy were the most widely used metal biomaterials in implant devices. These materials have high corrosion resistance, biocompatibility, and excellent mechanical properties, in particular titanium and titanium alloys (Joy Anne *et al.*, 2019). However, titanium and titanium alloys are more expensive than stainless steel and have less wear resistance than others. In addition, compared to Ti and Co-Cr alloys, SS316L has the longest history of biomedical implant applications, has good workability, fracture toughness, low cost, and easy availability (Nauri *et al*., 2021). In fact, the success of the application of stainless steel 316L as an implant material in human life has long been proven.

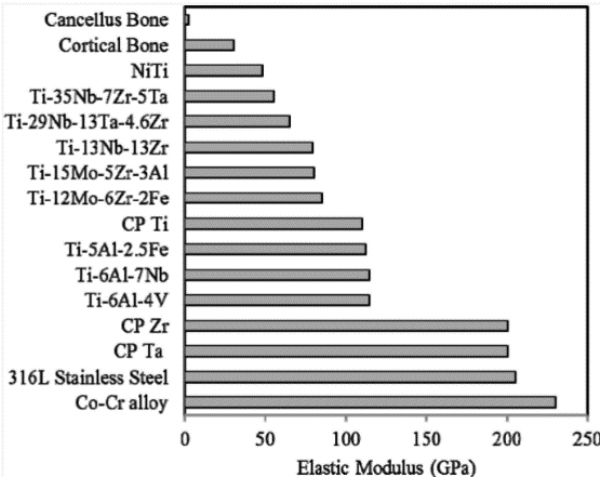

Figure 1.1 shows the elastic modulus of most materials currently used for biomedical applications (Li *et al*.,2014).

Metal implant is stronger than the human bone based on the modulus elasticity as shown in Fig. 1.1. The large difference of the modulus elasticity between the bone and metal implant can result in stress shielding effect and metal implant failure. Therefore, slurry method with HA addition has been explored to improve the properties.

1.3 Objective of Study

The main purpose of the research is to fabricate stainless-steel foam by adding bio-active ceramics using the slurry method. The objectives of this research are:

i. To identify the suitable percentage of bioactive ceramic HA via slurry method.
ii. To optimize the suitable sintering temperature to produce SS316L-HA foam.
iii. To verification the influence of HA addition and sintering temperature on the physical and mechanical properties of SS316L-HA foam after sintering process.

1.4 Scope of Study

Various ranges and parameters are analyzed and defined to conduct laboratory studies for foam manufacturing. The scope of this study can be divided into several points that are material use, fabrication, and eventually characterization of SS316L-HA foam; the scope of this study is as follows.

i. The raw material used in the study consisted of stainless steel (SS316L), Hydroxyapatite (HA), Polyurethane (PU) foam, Polyethylene Glycol (PEG), Carboxymethyl Cellulose (CMC) as binders and distilled water.
ii. The method of producing the SS316L-HA foam is a slurry method of 60wt.% and HA compositions with 1wt.%, 3wt.%, 5wt.%, 7wt%, and 10wt%. A composition for binders where PEG and CMC is 2.5 wt.% and distilled water. Sintering temperatures are performed at 1150°C, 1200°C, 1250°C, 1300°C and 1350°C.
iii. The physical properties of the foams SS316l-HA studied in the Archimedes principle on porosity and density according with the standard ASTM C20-00.
iv. The mechanical properties of the SS316l-HA foam were studied by compressive strength, yield strength and modulus elasticity testing by universal testing machine according standard ISO 13314:2011.
v. To characterize the microstructure and morphology of SS316l-HA using SEM.

1.5 Significant of Study

There are two types of orthopaedic implants that are temporary implants and permanent implants. Plates and screws are examples of temporary implants. Usually accompanied by replacement of the knee, shoulder, spine, hips, fingers, and feet for permanent implants. In the case of permanent implants, it is very important to ensure that the binding between the implant material and the living tissue is sufficient and safe. This strong bonding can be achieved by the internal growth of the tissue of the open and interconnected pores of the implant material (Ryan *et al.*, 2006). There are many implants made with the SS316l, but it is temporary. However, there are still some weaknesses in current metal implants. Therefore, the addition of hydroxyapatite (HA) helps to enhance the mechanical and physical properties that can be used for permanent implants.

1.6 Organization of Thesis

This thesis is divided into three chapters: introduction, literature review, and research methodology. Chapter 1 reviews the background of the study, problem statement, objectives, scope of study, significance of study, and finally the structure and organisation of the thesis.

Chapter 2 explains more details about Chapter 2: explores and describes what biomedical implants are, common features of natural bones, and the application of porous materials towards biomedical implants. Describe the technique of the foam replication method. This report discusses the properties of stainless steel, the use of stainless steel as an implant material, and methods used in previous works to process stainless-steel foam. The characteristics of hydroxyapatite and the uses of hydroxyapatite as implant materials. The parameters used throughout the sintering process are also discussed.

Chapter 3 further discusses the preparation of samples and the international standards used in the testing of samples. All of the raw materials used in this study have explanations. The details of the parameters studied and analysed in the experiments are also described in this chapter.

In Chapter 4, the results, and discussions of the mechanical and physical properties of SS316L-HA foam produced by the replication method are presented. Also, the microstructural analysis was conducted. Finally, chapter 5, which presents the results and findings that are summarized along with the suggestions for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Mechanical disorders in the human body can often be repaired by surgical implantation of synthetic replacement parts called biological implants. Clinicians and engineers have spent a lot of research over time studying the physical and mechanical properties of all types of human bones and implants to treat various injuries with bone replacement. Many factors influence the success of bone replacement surgery with implants, including the physical and mechanical properties of implant materials, biocompatibility with human body and implant materials, patient health, and the expertise of surgeons performing surgeries. Currently, implant materials only survive in the human body for about 12-15 years and cannot function well. This condition causes re-surgery to monitor the condition of the implant, the patient's health, and to replace the implant. Re-surgery and replacement of the implants will involve additional cost to the patient. The causes of implant failure depend on mechanical, chemical, biocompatible, implant design, surgery, tribology, etc.

2.2 Biomedical Implant

According to Williams, biomaterials study is an analysis of the nature and properties of biomaterials, the processes by which they communicate with biological systems and their success in clinical applications. Biomaterial is described as material intended to interact with biological systems for the evaluation, diagnosis, enhancement, or

replacement of any tissue, organ, or feature of the body (Barrere *et al.*, 2008). Biomaterials are also implanted biomedical materials. Biomaterials can be either naturally existing or artificial materials, such as cotton and bone (Abdalla, 2013). A biomedical implant is a particular tool, system, or component that is implanted into the body. The human body is responsible for removing or supporting some portion of the internal body that does not function and for improving the patient's capacity and health, Domb & Khan (2014).

Thus, the biocompatibility of medical devices covers both the materials used and the design of the device (e.g., geometry, mechanics, and electrical control) of the device. In fact, many clinical failures of joint replacements, for example, are due to suboptimal mechanics of the device, rather than problems with the material properties (Liu *et al*., 2015). Non-material issues are beyond the scope of this review article as well as this journal. As for the biocompatibility of implant materials, not only the chemical interactions of the implanted material with the host physiological system (e.g., corrosion of alloys and toxicities of metal ions) but also the physical impacts of the implanted material on the surrounding tissues (the mechanical properties of the material), although the former is the more common and primary concern.

Conception of implants for the purpose of bone surgery is strongly affected by the advances achieved in biomaterial engineering. Attempts were made to obtain biomaterials that would meet stringent requirements for biofunctionality, mechanical ability, degradation resistance, or biocompatibility (Vaccaro & A.R. 2002; Dewidar *et al.*, 2006; Mudali *et al*., 2003). However, the word "biomaterial" is used with a number of meanings in the authorised and scientific population. Medical devices in the legal field mean any apparatus, instrument, machine, implement, implant, appliance, in vitro reagent calibrator, material, software, or other related or similar articles intended for use in production, in combination or on their own, according to Huebsch & Mooney (2009). Figure 2.1 shows the types of biomaterials.

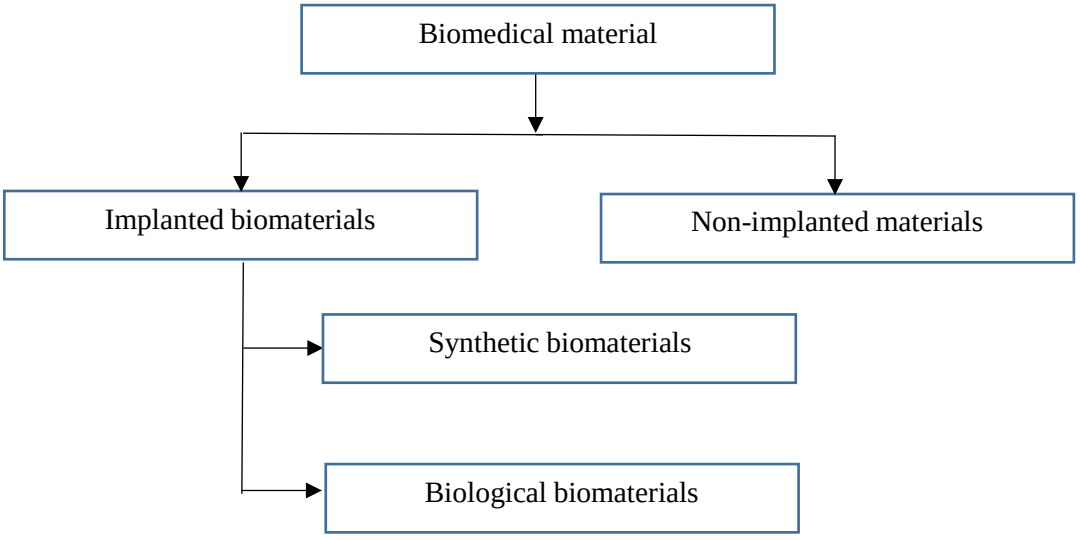

Figure 2.1: Shows the definition of biomaterials. (Chen *et al*., 2015)

Compared to the other materials, bioactive glasses are highly biocompatible and have a greater chance of integrating with human tissue than the metal implants mentioned above, making them a good option for improving the biocompatibility and bioactivity of these metals. Bioactive glass offers the following benefits: replacing damaged bone and tissue that will integrate well with the body's environment, facilitating tissue regeneration, and degrading at a similar rate of tissue regeneration (Jie *et al.*, 2021).

2.3 Properties of Natural Bone

The bone form classification is based on bone density, porosity, and metabolic function (Polo-Corrales *et al*., 2014). In addition, Lu stated that the pores can be divided into three groups. The first type of grouping is in the inner area of the bone, the second is in the wall of both the macrospores, whereas the third group is in the cortical bone's dense exterior layer, which is sometimes referred to as cortical bone. Compact skeleton, whereas the elastic inner centre is known as a cancellous, which is sometimes recognised as a trabecular and spongy tissue (Lu *et al*., 2003). It performed a microstructure study of natural bone using a scanning electron microscope (SEM) where the findings are seen in Figure 2.2.

The physical and mechanical properties of the natural bone vary depending on size of the bone. Subject, i.e., age, gender, health status, bone types, and different regions of the same bone (Kato *et al.*, 2013). The nature of the bone, consisting of bone

REFERENCES

Abdalla, S. (2013). Growth of colloidal nano-particles: new biomaterials. *J Material Sci Eng*, *2*, e107.agglomeration on mechanical properties of porous zirconia fabricated by partial sintering. *Journal of the American Ceramic Society*, *85*(8), 1961–1965.

Ahmad, S. (2012). *Kesan parameter pensinteran terhadap sifat mekanikal dan fizikal aloi titanium berbusa menggunakan Kaedah Taguchi* (Doctoral dissertation, Universiti Tun Hussein Onn Malaysia).

Ahmad, S., Muhamad, N., Muchtar, A., Sahari, J., Jamaludin, K. R., Ibrahim, M. H., & Murtadhahadi, I. (2008). Producing of titanium foam using titanium alloy (Al3Ti) by slurry method. In *Brunei Int. Conf. of Eng. And Techn.(BICET)* (pp. 3-4).

Ahmad, S., Rosli, M., Abdul Manaf, N. S., Mahammad Rafter, M. F., & Mat Noor, F. (2016). The Formation of Cobalt Chromium Molybdenum (CoCrMo) Foams Fabricated By Slurry Method. In *Materials Science Forum* (Vol. 840, pp. 197-201). Trans Tech Publications Ltd.

Akram M, Ahmed R, Shakir I, Ibrahim WAW, Hussain R. Extracting hydroxyapatite and its precursors from natural resources.J Mater Sci 2013;49(4):1461–1475.

Ali, M., & Ahmad, F. (2019). A review of processing techniques for Fe-Ni soft magnetic materials. *Materials and Manufacturing Processes*, *34*(14), 1580-1604.

Amirjan, M., & Khorsand, H. (2014). Processing and properties of Al-based powder suspension/slurry: A comparison study of aqueous binder systems, stability and film uniformity. *Powder technology*, *254*, 12-21.

Andrews, N., Giourntas, L., Galloway, A. M., & Pearson, A. (2014). Effect of impact angle on the slurry erosion-corrosion of Stellite 6 and SS316. *Wear*, *320*, 143-151.

Arifvianto, B., & Zhou, J. (2014). Fabrication of metallic biomedical scaffolds with the space holder method: a review. *Materials*, *7*(5), 3588-3622.

Babu, R. D., Prakash, P., & Devaprakasam, D. (2017). Review on Emerging Applications of Nanobiomaterials in Dentistry and Orthopaedics. *Trends in Biomaterials & Artificial Organs*, *31*(4).

Bakan, H. I. (2006). A novel water leaching and sintering process for manufacturing highly porous stainless steel. *Scripta Materialia*, *55*(2), 203-206.

Balasubramanian, S., Gurumurthy, B., & Balasubramanian, A. (2017). Biomedical applications of ceramic nanomaterials: a review. *International journal of pharmaceutical sciences and research*, *8*(12), 4950-4959.

Barrere, F., Mahmood, T. A., De Groot, K., & Van Blitterswijk, C. A. (2008). Advanced biomaterials for skeletal tissue regeneration: Instructive and smart functions. *Materials Science and Engineering: R: Reports*, *59*(1-6), 38-71.

Bekoz, N., & Oktay, E. (2013). Mechanical properties of low alloy steel foams: Dependency on porosity and pore size. *Materials Science and Engineering: A*, *576*, 82-90.

Biswal, D. R., & Singh, R. P. (2004). Characterisation of carboxymethyl cellulose and polyacrylamide graft copolymer. *Carbohydrate Polymers*, *57*(4), 379–387.

Brand, R. A., Mont, M. A., & Manring, M. M. (2011). Biographical Sketch: Themistocles Gluck (1853–1942). *Clinical Orthopaedics and Related Research®*, *469*(6), 1525-1527.

Cachinho, S. C. P. and Correia, R. N. Titanium porous scaffolds from precursor powders: rheological optimization of TiH2 slurries. Powder Technology.2007. 178(2):109– 113.

Ceramic Society, *35*(13), 3559–3566.

Chen, Q., & Thouas, G. A. (2015). Metallic implant biomaterials. *Materials Science and Engineering: R: Reports*, *87*, 1-57.

Chen, Q., Mohn, D., & Stark, W. J. (2011). Optimization of Bioglass® scaffold fabrication process. *Journal of the American Ceramic Society*, *94*(12), 4184-4190.

Chen, X., Liu, J., Feng, Z., & Shao, Z. (2005). Macroporous chitosan/carboxymethylcellulose blend membranes and their application for lysozyme adsorption. *Journal of applied polymer science*, *96*(4), 1267-1274.

Chu, Y. J., Hao, B. X., Liu, P., & Zhang, Y. B. (2019). Effect of Solid Solution Temperature on Microstructure and Corrosion Resistance of CoNiCrMo Alloy. *Materials Research*, *22*.

Davis, J. R. (2003). *Handbook of materials for medical devices*.

Deng, Z. Y., Yang, J. F., Beppu, Y., Ando, M., & Ohji, T. (2002). Effect of

Dewidar, M. M., Khalil, K. A., & Lim, J. K. (2007). Processing and mechanical properties of porous 316L stainless steel for biomedical applications. *Transactions of Nonferrous Metals Society of China*, *17*(3), 468-473.

Dewidar, M. M., Yoon, H. C., & Lim, J. K. (2006). Mechanical properties of metals for biomedical applications using powder metallurgy process: a review. *Metals and Materials International*, *12*(3), 193.

Ding, M.H., Wang, B.L., Li, L., Zheng, Y.F. 2010.Preparation and characterization of TaCxN1−x coatings on biomedical 316L stainless steel. 2519–2526

DiRienzo, A. L., Yakacki, C. M., Frensemeier, M., Schneider, A. S., Safranski, D. L., Hoyt, A. J., & Frick, C. P. (2014). Porous poly (para-phenylene) scaffolds for load-bearing orthopedic applications. *Journal of the mechanical behavior of biomedical materials*, *30*, 347-357.

Domb, A. J., & Khan, W. (Eds.). (2014). *Focal controlled drug delivery*. Springer Science & Business Media.

Dutta, S. R., Passi, D., Singh, P., & Bhuibhar, A. (2015). Ceramic and non-ceramic hydroxyapatite as a bone graft material: a brief review. *Irish Journal of Medical Science (1971-)*, *184*(1), 101-106.

Eliaz, N. (2019). Corrosion of metallic biomaterials: a review. *Materials*, *12*(3), 407.

Falamaki, C., Afarani, M. S., & Aghaie, A. (2004). Initial sintering stage pore growth mechanism applied to the manufacture of ceramic membrane supports. *Journal of the European Ceramic Society*, *24*(8), 2285-2292.

Fathi, M. H., Hanifi, A., & Mortazavi, V. (2008). Preparation and bioactivity evaluation of bone-like hydroxyapatite nanopowder. *Journal of materials processing technology*, *202*(1-3), 536-542.

Faure, R., Rossignol, F., Chartier, T., Bonhomme, C., Maître, A., Etchegoyen, G

Ferraris, S., Yamaguchi, S., Barbani, N., Cazzola, M., Cristallini, C., Miola, M& Spriano,S.(2020).Bioactive materials: In vitro investigation of different

mechanisms of hydroxyapatite precipitation. *Acta biomaterialia*, *102*, 468-480.

Fey, T., Betke, U., Rannabauer, S., & Scheffler, M. (2017). Reticulated replica ceramic foams: Processing, functionalization, and characterization. *Advanced Engineering Materials*, *19*(10), 1700369.

Fu, L., Engqvist, H., & Xia, W. (2020). Glass–ceramics in dentistry: A review. *Materials*, *13*(5), 1049.

Fu, Q., Rahaman, M. N., Bal, B. S., Brown, R. F., & Day, D. E. (2008). Mechanical and in vitro performance of 13–93 bioactive glass scaffolds prepared by a polymer foam replication technique. *Acta biomaterialia*, *4*(6), 1854-1864.

Fu, Q., Saiz, E., Rahaman, M. N., & Tomsia, A. P. (2011). Bioactive glass scaffolds for bone tissue engineering: state of the art and future perspectives. *Materials Science and Engineering: C*, *31*(7), 1245-1256.

Gary, D. (2011). Alumina foam catalyst supports for industrial steam reforming processes. *Journal of the European Ceramic Society*, *31*(3), 303–312.

German, R. M. (1991). *Fundamentals of sintering. ASM International, Engineered*

German, R. M. (2010). Thermodynamics of sintering. In *Sintering of Advanced Materials* (pp. 3–32).

Giordani, E. J., Jorge Jr, A. M., & Balancin, O. (2006). Proportion of recovery and recrystallization during interpass times at high temperatures on a Nb-and N-bearing austenitic stainless steel biomaterial. *Scripta Materialia*, *55*(8), 743-746.

Gomez, M. A., & Nahum, A. M. (2002). Biomechanics of bone. In *Accidental injury* (pp. 206-227). Springer, New York, NY.

Gómez, S. Y., Alvarez, O. A., Escobar, J. A., Rodrigues Neto, J. B., Rambo, C. R., & Hotza, D. (2012). Relationship between Rheological Behaviour and Final Structure of Al**2**O**3** and YSZ Foams Produced by Replica. *Advances in Materials Science and Engineering*, *2012*.

Gurappa, I. (2002). Development of appropriate thickness ceramic coatings on 316 L stainless steel for biomedical applications. *Surface and Coatings Technology*, *161*(1), 70-78.

Hadi, A., Emadi, R., Baghshahi, S., & Naghavi, S. H. (2015). Mechanical strength enhancement of open-cell alumina foams using optimum concentration of deflocculant. *Ceramics–Silikáty*, *59*(2), 90-95.

Han, Y. S., Li, J. B., Wei, Q. M., & Tang, K. (2002). The effect of sintering temperatures on alumina foam strength. *Ceramics international*, *28*(7), 755-759.

Hermawan, H., Dubé, D., & Mantovani, D. (2010). Developments in metallic biodegradable stents. *Acta biomaterialia*, *6*(5), 1693-1697.

Hermawan, H., Ramdan, D., & Djuansjah, J. R. (2011). Metals for biomedical applications. *Biomedical engineering-from theory to applications*, 411-430.

Huebsch, N., & Mooney, D. J. (2009). Inspiration and application in the evolution of biomaterials. *Nature*, *462*(7272), 426-432.

Ibrahim, M., Labaki, M., Giraudon, J. M., & Lamonier, J. F. (2020). Hydroxyapatite, a multifunctional material for air, water and soil pollution control:A review. *Journal of hazardous materials*, *383*, 121139.

Jha, K., Verma, J., & Prakash, C. (2019). Fabrication and In Vitro Corrosion Characterization of 316L Stainless Steel for Medical Application. In *Biomaterials in Orthopaedics and Bone Regeneration* (pp. 215-226). Springer, Singapore.

Jin, M., Shi, J., Zhu, W., Yao, H., & Wang, D. A. (2021). Polysaccharide-Based Biomaterials in Tissue Engineering: A Review. *Tissue Engineering Part B: Reviews*.

JoSHi, S., Gupta, G. K., SHArMA, M., TelAnG, A., & MAHrA, T. (2015). Synthesis and Characterization of Stainless Steel Foam Via Powder Metallurgy Taking Acicular Urea As Space Holder. *Material Science Research India*, *12*(1), 43-49.

Joy-anne, N. O., Su, Y., Lu, X., Kuo, P. H., Du, J., & Zhu, D. (2019). Bioactive glass coatings on metallic implants for biomedical applications. *Bioactive materials*, *4*, 261-270.

Juanli, J., Yang, J., Zeng, Q., & Huang, Y. (2013). Effect of carboxymethyl cellulose addition on the properties of Si3N4 ceramic foams. *Ceramics International*, *39*(3), 2775-2779.

Jun, I. K., Song, J. H., Choi, W. Y., Koh, Y. H., Kim, H. E., & Kim, H. W. (2007). Porous hydroxyapatite scaffolds coated with bioactive apatite–wollastonite glass–ceramics. *Journal of the American Ceramic Society*, *90*(9), 2703-2708.

Kato, K., Yamamoto, A., Ochiai, S., Wada, M., Daigo, Y., Kita, K., & Omori, K. (2013). Cytocompatibility and mechanical properties of novel porous 316 L stainless steel. *Materials Science and Engineering: C*, *33*(5), 2736-2743.

Kennedy, A. (2012). Porous metals and metal foams made from powders. *Powder Metallurgy*, *2*, 31-46.

Kim, I. S., & Kumta, P. N. (2004). Sol–gel synthesis and characterization of nanostructured hydroxyapatite powder. *Materials science and Engineering: B*, *111*(2-3), 232-236.

Kränzlin, N., & Niederberger, M. (2015). Controlled fabrication of porous metals from the nanometer to the macroscopic scale. *Materials Horizons*, *2*(4), 359-377.

Kurgan, N. (2014). Effect of porosity and density on the mechanical and microstructural properties of sintered 316L stainless steel implant materials. *Materials & Design*, *55*, 235-241.

Kurgan, N., Sun, Y., Cicek, B., & Ahlatci, H. (2012). Production of 316L stainless steel implant materials by powder metallurgy and investigation of their wear properties. *Chinese science bulletin*, *57*(15), 1873-1878.

Kushairi, A. H. B. A. (2018). Effect of using different solvent in SS316l slurry on the SS316l foam properties prepared by sponge replication method.

Learmonth, I. D., Young, C., & Rorabeck, C. (2007). The operation of the century: total hip replacement. *The Lancet*, *370*(9597), 1508-1519.

LeBeau, J. M., & Boonyongmaneerat, Y. (2007). Comparison study of aqueous binder systems for slurry-based processing. *Materials Science and Engineering: A*, *458*(1-2), 17-24.

Leel J, Leel J, Kim M, Hyun S. Fabrication of Porous Titanium with Directional Pores for Biomedical Applications. 2013.54(2):137-142.

Li, Y., Yang, C., Zhao, H., Qu, S., Li, X., & Li, Y. (2014). New developments of Ti-based alloys for biomedical applications. *Materials*, *7*(3), 1709-1800.

Liu, Y., Bao, C., Wismeijer, D., & Wu, G. (2015). The physicochemical/biological properties of porous tantalum and the potential surface modification techniques

to improve its clinical application in dental implantology. *Materials Science and Engineering: C*, *49*, 323-329.

Lu, W. W., Zhao, F., Luk, K. D. K., Yin, Y. J., Cheung, K. M. C., Cheng, G. X.& Leong, J. C. Y. (2003). Controllable porosity hydroxyapatite ceramics as spine cage:fabrication and properties evaluation. *Journal of Materials Science: Materials in Medicine*, *14*(12), 1039-1046.

Ma, J., Xie, Z., Miao, H., Huang, Y., & Cheng, Y. (2002). Gelcasting of ceramic suspensioninacrylamide/polyethyleneglycol systems. *Ceramics international*, *28*(8), 859-864.

Mad Rosip, N. I., Ahmad, S., Arpawi, N. L., Jamaluddin, K. R., & Mat Noor, F. (2013).The effect of sintering temperature and composition for density and porosity of SS316L foam. *Applied Mechanics and Materials*, *465–466*(December), 988–992.

Mahmoud, D., & Elbestawi, M. A. (2017). Lattice structures and functionally graded materials applications in additive manufacturing of orthopedic implants: a review. *Journal of Manufacturing and Materials Processing*, *1*(2), 13.

Manam, N. S., Harun, W. S. W., Shri, D. N. A., Ghani, S. A. C., Kurniawan, T., Ismail, M. H., & Ibrahim, M. H. I. (2017). Study of corrosion in biocompatible metals for implants:A review *Journal of Alloys and Compounds*, *701*, 698-715.

Manivasagam, G., Dhinasekaran, D., & Rajamanickam, A. (2010). Biomedical implants: corrosion and its prevention-a review. *Recent patents on corrosion science*.

Mat Noor, F. (2018). *Foam replicated porous 316l stainless steel based on taguchi method for biomedical applications* (Doctoral dissertation, Universiti Tun Hussein Onn Malaysia).

Mat Rosip, N. I., Ahmad, S., Jamaluddin, K. R., Mat Noor, F., & Mohd Taib, H. (2014). Morphological analysis of SS316L foam produced by using slurry method.*Materials Handbook* (Vol. 4).

Matos, M. J., Dias, S., & Oliveira, F. C. (2007). Macrostructural changes of polymer replicated open cell cordierite based foams upon sintering. *Advances in applied ceramics*, *106*(5), 209-215.

Miao, X. (2008). Modification of porous alumina ceramics with bioinert and bioactive glass coatings. In *Advanced Materials Research* (Vol. 32, pp. 211-214). Trans Tech Publications Ltd.

Monno, M., Negri, D., Mussi, V., Aghaei, P., Groppi, G., Tronconi, E., & Strano, M. (2018). Cost-Efficient Aluminum Open-Cell Foams: Manufacture, Characterization, and Heat Transfer Measurements. *Advanced Engineering Materials*, *20*(8), 1701032.

Mudali, U. K., Sridhar, T. M., Eliaz, N., & Raj, B. (2003). Failures of stainless steel orthopedic devices-causes and remedies. *Corrosion reviews*, *21*(2-3), 231-268.

Muthutantri, A., Huang, J., & Edirisinghe, M. (2008).Novel method of preparing hydroxyapatite foams. *Journal of Materials Science: Materials in Medicine*, *19*(4), 1485-1490.

Mutlu, I., & Oktay, E. (2013). Characterization of 17-4 PH stainless steel foam for biomedical applications in simulated body fluid and artificial saliva environments. *Materials Science and Engineering: C*, *33*(3), 1125-1131.

Navarro, M., Michiardi, A., Castano, O., & Planell, J. A. (2008). Biomaterials in orthopaedics. *Journal of the royal society interface*, *5*(27), 1137-1158.

Noor, F. B. M. (2018). *Foam Replicated Porous 316l Stainless Steel Based On Taguchi Method For Biomedical Applications* (Doctoral dissertation, Universiti Teknologi Malaysia).

Noor, F. M., Bakar, M. I. A., Mohamad, Z., Ismon, M., Ahmad, S., Abd Wahab, H., & Sanusi, S. H. (2019).Composition and Type of a Binder Effects on the Stainless Steel Foam Microstructure Prepared by Sponge Replication Method. *International Journal of Integrated Engineering*, *11*(7), 90-94.

Nouri, A., & Wen, C. (2021). Stainless steels in orthopedics. In *Structural Biomaterials* (pp. 67-101). Woodhead Publishing.

Nouri, A., Hodgson, P. D., & Wen, C. E. (2010). *Biomimetic porous titanium scaffolds for orthopaedic and dental applications* (pp. 415-450). InTech.

O'Mahony, A. M., Williams, J. L., Katz, J. O., & Spencer, P. (2000). Anisotropic elastic properties of cancellous bone from a human edentulous mandible. *Clinical Oral Implants Research*, *11*(5), 415-421.orthopaedics. *Journal of the Royal Society, Interface / the Royal Society* . 2008.5(27):1137–58.

Panda, S., Biswas, C. K., & Paul, S. (2021). A comprehensive review on the preparation and application of calcium hydroxyapatite: A special focus on atomic doping methods for bone tissue engineering. *Ceramics International*.

Park, J. B., & Bronzino, J. D. (Eds.). (2002). *Biomaterials: principles and applications*. crc press.

Patel, N. R., & Gohil, P. P. (2012).A review on biomaterials: scope, applications & human anatomy significance. *International Journal of Emerging Technology and Advanced Engineering*, *2*(4), 91-101.

Pityana, S. L., Baloyi, N., Tlotleng, M., & Popoola, P. (2019). Laser surface deposition of niobium and titanium-niobium on Ti6A14V substrates for biomedical applications. *Journal of the Southern African Institute of Mining and Metallurgy*, *119*(4), 385-389.

Polo-Corrales, L., Latorre-Esteves, M., & Ramirez-Vick, J. E. (2014). Scaffold design for bone regeneration. *Journal of nanoscience and nanotechnology*, *14*(1), 15-56.

Priyadarshini, B., Rama, M., Chetan, & Vijayalakshmi, U. (2019). Bioactive coating as a surface modification technique for biocompatible metallic implants: a review. *Journal of Asian Ceramic Societies*, *7*(4), 397-406.

Purnama, A., Hermawan, H., Couet, J., & Mantovani, D. (2010). Assessing the biocompatibility of degradable metallic materials: state-of-the-art and focus on the potential of genetic regulation. *Acta Biomaterialia*, *6*(5), 1800-1807.Check

Quadbeck, P., Kümmel, K., Hauser, R., Standke, G., Adler, J., & Stephani, G. (2010). Open cell metal foams-application-oriented structure and material selection. *Proceedings of the CELLMAT*.

Quadbeck, P., Kümmel, K., Hauser, R., Standke, G., Adler, J., Stephani, G., & Kieback, B. (2011). Structural and material design of open-cell powder metallurgical foams. *Advanced Engineering Materials*, *13*(11), 1024-1030.

Quadbeck, P., Stephani, G., Kümmel, K., Adler, J., & Standke, G. (2007). Synthesis and properties of open-celled metal foams. In *Materials Science Forum* (Vol. 534, pp. 1005-1008). Trans Tech Publications Ltd.

Rafter, M., Faridah, M., Ahmad, S., Ibrahim, R., Hussin, R., & Taib, H. M. (2015). Development of stainless steel (SS316L) foam with different composition using compaction method. In *Advanced Materials Research* (Vol. 1087, pp. 86-90). Trans Tech Publications Ltd.

Ramli, M. I., Sulong, A. B., Muhamad, N., Muchtar, A., & Arifin, A. (2014). Stainless steel 316L–hydroxyapatite composite via powder injection moulding: rheological and mechanical properties characterisation. *Materials Research Innovations*, *18*(sup6), S6-100.

Ramli, M. I., Sulong, A. B., Muhamad, N., Muchtar, A., Arifin, A., & Park, S. J. (2019, April). Processing of Stainless Steel (SS316L)-Hydroxyapatite (HA) Powder Composite through Powder Injection Molding. In *Journal of Physics: Conference Series* (Vol. 1198, No. 4, p. 042017). IOP Publishing.

Roguska, A., Hiromoto, S., Yamamoto, A., Wozniak, M.J., Pisarek, M., Lewandowska, M.2011.Collagen immobilization on 316L stainless steel surface with cathodic deposition of calcium phosphate. 5037–5045.

Royer, A., Gelin, J. C., & Barrière, T. (2015). Development and Characterization of Polymer Mixture (Binder) Based on Polyethylene Glycol (PEG) for a Superalloy A-286 to Powder Injection Moulding (MIM) Process. In *Key Engineering Materials* (Vol. 651, pp. 824-829). Trans Tech Publications Ltd.

Ryan, G., Pandit, A., & Apatsidis, D. P. (2006). Fabrication methods of porous metals for use in orthopaedic applications. *Biomaterials*, *27*(13), 2651-2670.

Sarkar, R., Ghosal, P., Premkumar, M., Singh, A. K., Muraleedharan, K., Chakraborti, A & Sarma, B. (2008). Characterisation and sintering studies of mechanically milled nano tungsten powder. *Powder metallurgy*, *51*(2), 166-170.

Seeber, B. S. M., Gonzenbach, U. T., & Gauckler, L. J. (2013). Mechanical properties of highly porous alumina foams. *Journal of materials research*, *28*(17), 2281-2287.

Shah, F. A., Thomsen, P., & Palmquist, A. (2019). Osseointegration and current interpretations of the bone-implant interface. *Acta biomaterialia*, *84*, 1-15.

Shi, H., Zhou, Z., Li, W., Fan, Y., Li, Z., & Wei, J. (2021). Hydroxyapatite based materials for bone tissue engineering: A brief and comprehensive introduction. *Crystals*, *11*(2), 149.

Shih, C. C., Lin, S. J., Chung, K. H., Chen, Y. L., & Su, Y. Y. (2000). Increased corrosion resistance of stent materials by converting current surface film of polycrystalline oxide into amorphous oxide. *Journal of Biomedical Materials Research: An Official Journal of The Society for Biomaterials, The Japanese Society for Biomaterials, and The Australian Society for Biomaterials and the Korean Society for Biomaterials*, *52*(2), 323-332.

Shimizu, T., Matsuzaki, K., Nagai, H., & Kanetake, N. (2012). Production of high porosity metal foams using EPS beads as space holders. *Materials Science and Engineering: A*, *558*, 343-348.

Si, Y., Hu, J., Wang, X., Yang, H., Chen, Y., Shao, J., & Chen, H. (2016). Effect of carboxymethyl cellulose binder on the quality of biomass pellets. *Energy & Fuels*, *30*(7), 5799-5808.

Sidane, D., Khireddine, H., Bir, F., Yala, S., Montagne, A., & Chicot, D. (2017). Hydroxyapatite-TiO 2-SiO 2-coated 316L stainless steel for biomedical application. *Metallurgical and Materials Transactions A*, *48*(7), 3570-3582.

Silva, G., Baldissera, M. R., Trichês, E. D. S., & Cardoso, K. R. (2013). Preparation and characterization of stainless steel 316L/HA biocomposite. *Materials Research*, *16*(2), 304-309.

Sola, A., Bellucci, D., & Cannillo, V. (2016). Functionally graded materials for orthopedic applications–anupdate on designand manufacturing. *Biotechnology advances*, *34*(5), 504-531.

Studart, A. R., Gonzenbach, U. T., Tervoort, E., & Gauckler, L. J. (2006). Processing routes to macroporous ceramics: a review. *Journal of the American Ceramic Society*, *89*(6), 1771-1789.

Sun, Z., Fan, J., & Yuan, F. (2015). Three-dimensional porous silica ceramics with suspension in acrylamide/polyethylene glycol systems. *Ceramics International*,*28*(8), 859–864.

Szewczyk-Nykiel, A., & Nykiel, M. (2015).Analysis of the sintering process of 316l–Hydroxyapatite composite biomaterials. *Czasopismo Techniczne*.

Szewczyk-Nykiel, A., & Nykiel, M. (2010). Study of hydroxyapatite behaviour during sintering of 316L steel. *Archives of Foundry Engineering*, *10*(3).

tailored uniform pores: Prepared by inactive spheres. *Journal of the European*

Tange, M., Manonukul, A., & Srikudvien, P. (2015). The effects of organic template and thickening agent on structure and mechanical properties of titanium foam fabricated by replica impregnation method. *Materials Science and Engineering: A, 641*, 54-61.

Teo, J. C., Si-Hoe, K. M., Keh, J. E., & Teoh, S. H. (2006). Relationship between CT intensity, micro-architecture and mechanical properties of porcine vertebral cancellous bone. *Clinical biomechanics*, *21*(3), 235-244.

Thanh, D. T. M., Nam, P. T., Phuong, N. T., Van Anh, N., Hoang, T., & Dai Lam, T. (2013). Controlling the electrodeposition, morphology and structure of hydroxyapatite coating on 316L stainless steel. *Materials Science and Engineering: C*, *33*(4), 2037- 2045.

Thavornyutikarn, B., Tesavibul, P., Sitthiseripratip, K., Chatarapanich, N., Feltis, B., Wright, P. F., & Turney, T. W. (2017). Porous 45S5 Bioglass®-based scaffolds using stereolithography: Effect of partial pre-sintering on structural and mechanical properties of scaffolds. *Materials Science and Engineering: C*, *75*, 1281-1288.

Tiainen, H., Wiedmer, D., & Haugen, H. J. (2013). Processing of highly porous TiO2 bone scaffolds with improved compressive strength. *Journal of the European Ceramic Society*, *33*(1), 15-24.

Twigg, M. V., & Richardson, J. T. (2002). Theory and applications of ceramic foam catalysts. *Chemical Engineering Research and Design*, *80*(2), 183-189.

Upadhyaya, G. S. (2000). *Sintered metallic and ceramic materials: preparation, properties, and applications*. Wiley.

Vaccaro, A. R. (2002). The role of the osteoconductive scaffold in synthetic bone graft. *Orthopedics*, *25*(5), S571-S578.

Vallet-Regi, M., & González-Calbet, J. M. (2004). Calcium phosphates as substitution of bone tissues. *Progress in solid state chemistry*, *32*(1-2), 1-31.

Vivanco, J., Aiyangar, A., Araneda, A., & Ploeg, H. L. (2012). Mechanical characterization of injection-molded macro porous bioceramic bone scaffolds. *Journal of the mechanical behavior of biomedical materials*, *9*, 137-152.

Wakai, F., & Bordia, R. K. (2012). Microstructural evolution and anisotropic shrinkage in constrained sintering and sinter forging. *Journal of the American Ceramic Society*, *95*(8), 2389-2397.

Wang, X., Xu, S., Zhou, S., Xu, W., Leary, M., Choong, P& Xie, Y. M. (2016). Topological design and additive manufacturing of porous metals for bone scaffolds and orthopaedic implants: A review. *Biomaterials*, *83*, 127-141.

Weinand, W. R., Goncalves, F. F. R., & Lima, W. M. (2006). Effect of sintering temperature in physical-mechanical behaviour and in titanium-hydroxyapatite composite sinterability. In *Materials science forum* (Vol. 530, pp. 249-254). Trans Tech Publications Ltd.

Wilson, J. (2018). Metallic biomaterials: State of the art and new challenges. *Fundamental Biomaterials: Metals*, 1-33.

Wu, Y. C., Lee, T. M., Chiu, K. H., Shaw, S. Y., & Yang, C. Y. (2009). A comparative study of the physical and mechanical properties of three natural corals based on the criteria for bone–tissue engineering scaffolds. *Journal of Materials Science: Materials in Medicine*, *20*(6), 1273-1280.

Xie, F., He, X., Cao, S., & Qu, X. (2013). Structural and mechanical characteristics of porous 316L stainless steel fabricated by indirect selective laser sintering. *Journal of Materials Processing Technology*, *213*(6), 838-843.

Xie, F., He, X., Ji, X., Wu, M., He, X., & Qu, X. (2017). Structural characterisation and mechanical behaviour of porous Ti-7.5 Mo alloy fabricated by selective laser sintering for biomedical applications. *Materials Technology*, *32*(4), 219-224.

Yan, C., Hao, L., Hussein, A., Young, P., & Raymont, D. (2014). Advanced lightweight 316L stainless steel cellular lattice structures fabricated via selective laser melting. *Materials & Design*, *55*, 533-541.

Yang, D., Zhang, Y., Song, X., Chen, Y., Shen, Z., & Yang, C. (2016). Effects of sintering temperature and holding time on porosity and shrinkage of glass tubes. *Ceramics International*, *42*(5), 5906-5910.

Yao, X., Tan, S., Huang, Z., & Jiang, D. (2006). Effect of recoating slurry viscosity on the properties of reticulated porous silicon carbide ceramics. *Ceramics International*, *32*(2), 137–142.

Yu, X., Lu, Z., & Zhai, W. (2021). Enhancing the flow resistance and sound absorption of open-cell metallic foams by creating partially-open windows. *Acta Materialia*, *206*, 116666.

Zhang, L., He, Z. Y., Zhang, Y. Q., Jiang, Y. H., & Zhou, R. (2016). Rapidly sintering of interconnected porous Ti-HA biocomposite with high strength and enhanced bioactivity. *Materials Science and Engineering: C*, *67*, 104-114.

Zhao, Y. H., Wee, K. H., & Bai, R. (2010). Highly hydrophilic and low-protein-fouling polypropylene membrane prepared by surface modification with sulfobetaine-based zwitterionic polymer through a combined surface polymerization method. *Journal of Membrane Science*, *362*(1-2), 326-333.

APPENDIX A

LIST OF PUBLICATIONS

Ahmad, S., Rani, R. Y., Yusop, U. A., Muda, R., Rahman, H. A., Ismail, A., & Noor, F. M. (2022). EFFECT OF COMPOSITION AND SINTERING TEMPERATURES ON THE PROPERTIES OF STAINLESS STEEL (SS316L)-HYDROXYAPATITE (HAP) FOAM. *Malaysian Journal of Microscopy*, *18*(2), 164-173.

Rani, R. Y., & Noor, F. M. (2022). Producing Stainless Steel (SS16L) with Hydroxyapatite (HA) via Slurry Method. *Research Progress in Mechanical and Manufacturing Engineering*, *3*(1), 1097-1103.