ALKALINE TREATMENT OF 3D PRINTED

TI-AL-V ALLOY FOR BIOACTIVITY SURFACE MODIFICATION

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by

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DECLARATION

I hereby declare that I have conducted ,completed the research work and written the dissertation entitled 'Alkaline Treatment Of 3d Printed Ti-Al-V Alloy For Bioactivity Surface Modification'. I also declare that it has not previously submitted for the award of any degree and diploma or other similar title of this for any other examining body or University.

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LIST OF SYMBOLS

ϴ	Theta
α	Alpha
β	Beta
º	Degree
µ	Micro

LIST OF ABBREVIATIONS

3D	3 Dimensional
AFM	Atomic Fourier Microscopy
AFM	Atomic Force Microscope
AHT	After Heat Treatment
NaOH	Sodium Hydroxide
SBF	Simulated Body Fluid
SEM	Scanning Electronic Microscope
Ti	Titanium
Ti-40Nb	Titanium Niobium
Ti-Al-V	Titanium Aluminium Vanadium
USM	Universiti Sains Malaysia
XRD	X-ray Diffractometer

ABSTRAK

RAWATAN BERALKALI ALOI TI-AL-V CETAKAN 3D UNTUK PENGUBAHSUAIAN PERMUKAAN BIOAKTIVITI

Rawatan alkali aloi Ti6Al4V bercetak 3D untuk pengubahsuaian permukaan bioaktiviti telah disiasat. Aloi Ti6Al4V digunakan secara komersil dalam industri terutamanya dalam aplikasi bahan implan. Pada masa ini, dalam pengeluaran moden aloi Ti6Al4V, cetakan 3D iaitu kaedah Peleburan Laser Terpilih digunakan dalam fabrikasi sampel kerana keserasiannya dalam menghasilkan bentuk aloi titanium yang kompleks dan menunjukkan potensi besar dalam aplikasi bioperubatan. Dengan memfokuskan pada jenis rawatan permukaan, aktiviti osseointegrasi antara muka implan tulang dipertingkatkan. Rawatan alkali telah dilaksanakan dalam penyelidikan ini untuk menyediakan pengubahsuaian permukaan bioaktiviti. Sampel direndam dalam 10M NaOH pada suhu 60°C selama 24 jam. Rawatan Haba Selepas digunakan untuk melihat kesan suhu pemanasan ke atas sampel yang termasuk pemanasan pada 200°C, 400°C, 600°C dan 800°C. Difraksi X-Ray menunjukkan kehadiran lapisan titanat amorfus pada 200°C dan pembentukan rutil pada rawatan haba 600°C dan 800°C. Pemerhatian morfologi dilakukan menggunakan Mikroskopi Elektron Pengimbasan Pancaran Medan (FESEM) dan analisis unsur menunjukkan pemendapan lapisan titanat apabila haba dirawat dengan suhu tinggi. Kajian bioaktiviti dalam larutan hank selama 7 hari mengesan sejumlah kecil Ca pada permukaan aloi. Penyelidikan ini mencadangkan bahawa suhu yang lebih rendah semasa rendaman beralkali diperlukan untuk mengelakkan dehidrasi lapisan natrium titanat semasa rawatan haba selepas supaya lapisan natrium titanat yang tinggi boleh membentuk lapisan selera yang lebih tinggi pada aloi permukaan.

ABSTRACT

ALKALINE TREATMENT OF 3D PRINTED TI-AL-V ALLOY FOR BIOACTIVITY SURFACE MODIFICATION

Ti6Al4V alloy has low bioactivity and surface treatment could improve its bioactivity. However, Ti6Al4V alloy manufactured by 3D printing has very fine microstructure compared to conventional manufacturing method.Thus, the aim of this work is to investigate the feasibility of modifying the surface of 3D printing Ti6Al4V alloy using NaOH alkaline treatment. . 3D printed Ti6Al4V alloy manufactured by 3D Gens Sdn Bhd in disc shape were soaked in 10M sodium hydroxide (NaOH) at 60ºC for 24hrs. Post heat treatment was applied to observe heating temperature affect upon the alkaline treated alloy at 200ºC, 400ºC, 600ºC and 800ºC. The X-Ray diffraction shows the presence of amorphous titanate layer after immersion in NaOH . The titanate was observed at 200ºC with the formation of rutile TiO2 after heat treatment at 800ºC. Morphology observation under Field Emission Scanning Electron Microscopy (FESEM) and elemental analysis indicate the deposition of titanate layer when heat treated with high temperature. The bioactivity of sample alkaline-heat treated at 200°C was investigated through immersion in Hank's solution for 7 days trace 0.34wt% of Ca on alloy surfaces. The surface roughness of the sample after heat treatment was analysed using AFM where sample treated with 800ºC exhibit the highest surface roughness and alkali-heat treated at 200ºC has the lowest surface roughness. The wettability of the sample was tested by recording the contact angle of the sample with droplet of ultrasonic water where sample after alkaline treatment has the lowest value indicating it has the highest hydrophilic properties. The findings suggests that lower temperature after alkaline soaking is required to prevent phase transformation of sodium titanate layer during the post heat treatment so that high sodium titanate layer can form higher appetite layer on the surface alloy.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The purpose of this study is to evaluate alkaline treatment on 3D printed Ti6Al4V followed by post-heat treatment for bioactivity surface modification. Ti6Al4V alloy are widely use in the application of biomaterial implant due to its interest upon their good mechanical properties and biocompatibility. A variety of different approaches, such as autologous bone grafting, utilization of standard implants manufactured from traditional methods, like casting, forging, machining and powder metallurgy techniques etc., were the common techniques in medical implantation. However, in recent times, the application of these approaches has been minimized owing to their compelling drawbacks such as complicated operative methods, blood loss, and pain in the patient, etc. Traditional production of Ti6Al4V alloy procedures invariably result in significant material waste, high manufacturing costs, and lengthy lead times. Recently, 3D printed technique has been discovered able to encounter the problems occur upon the fabricated Ti6Al4V alloy. In principle, a material serving as an implant in the human body must ensure biocompatibility to the host tissue. Depending on the final medical device customization and mechanical profile desired, a variety of surface modification techniques can be adopted, which are explored more in the surface modification techniques section.

Liu et al. (2021) has studied surface treatment and bioinspired coating for 3D printed implants where the alkaline treatment was found as the surface modification technique to form titanate layer on the alloy surface which enabling the osteointegration properties. Many different parameters have been studied using alkaline treatment including soaking temperature and time of alloy in alkaline solution, concentration of alkaline solution and different type of alkaline solution used. Recently, the influence of alkaline treatment to the Ti6Al4V and hydroxyapatite coating was studied by Du et al. (2014). Investigation on soaking time in alkaline solution was done by Luo et al. (2020) where surface roughness of the 3D printed porous Ti6Al4V was obtained and Hanib et al. (2016) have studied the effect of temperature used for alkaline treatment to the Ti6Al4V. There is also research being done by Ying et al. (2015) upon different heat treatment temperature and heat temperature of soaking in alkaline solution and its affect upon cell adhesion.

Post heat treatment is essential, as the alloy surface after alkaline treatment is unstable. In isolation, alkali-heat treatment is considered to be a basic surface modification technique that can provide an initial bioactive porous structure. Furthermore, subsequent heat treatment appears to be an essential aspect of alkali-heat-based technique. By considering these beneficial, alkaline treatment as well as post heat treatment on the alkaline treated alloy are proposed on 3D printed Ti-Al-V alloy Heat treatment temperature, were varied to investigate microstructure and phase, bioactivity in Hank's solution and hydrophilicity of the treated surface alloy.

Even though a lot of research have been done for various parameter upon alkaline treatment on surface modification bioactivity, yet there is still less reports were written upon 3D printed Ti6Al4V alkaline treated. Research recently was done on alkaline treatment effect upon Ti6Al4V alloy which fabricate by different method such as powder methology or arc melting.

The present study was aimed to investigate the bioactivity properties affected by the heat treatment temperature upon 3D printed Ti6Al4V alloy.

1.2 Problem Statement

Currently, the 3D printing Ti6Al4V alloy is adopted in the industry due to its ability to manufacture the implant that is unique for each patient. However, due to low bioactivity reported on Ti6Al4V alloy, 3D printed commercial implant based on this alloy need surface modification to enabling the osteogenesist properties on the surface of the 3D alloy. However, Ti6Al4V alloy manufactured by 3D printing has very fine microstructure compared to conventional manufacturing method. Thus, feasibility of 3D printing Ti6Al4V could be influenced by chemical route surface treatment. Thus, the aim of this work is to investigate the feasibility of modifying the surface of 3D printing Ti6Al4V alloy using NaOH alkaline treatment. In this work surface modification to enabling the osteogenesist properties on the surface of the 3D alloy. In this work surface modification method proposed for this implant is by alkaline treatment as this method does not use expensive equipment and suits for complex shape implant. Alkaline treatment is implemented to produce topographical changes and introduction of the hydroxyl and carboxyl groups on the surface layers.

However, in most cases the grown titanate layer that could improve apatite formation is not stable in the living body as it has lack of mechanical integrity such as osteointegration between attachment of the material with the bone. Thus, research is required to investigate the feasibility of titanate formation on 3D printed Ti6Al4V alloy and the effect of alkaline treatment as well as post heat treatment in modifying alloy surface properties.

1.3 Objectives

1. To investigate the feasibility of modifying surface of 3D printed Ti6Al4V alloy based on surface morphology and microstructure.
2. To determine the effect of post heat treatment from 200 to 800°C to the alkaline treated 3D printed Ti6Al4V alloy based on hydrophilicity and surface morphology.
3. To study the bioactivity of the alkaline treated-heat treated alloy in simulated body fluid.

1.4 Scope of Study

In this work, NaOH alkaline treatment was conducted on a 3D printed Ti6Al4V alloy in order to enhance bioactivity of the alloy. 3D printed Ti6Al4V alloy adopting selective laser melting in the shape of disc shape was produced by 3D Gens Sdn Bhd , The alloy was immersed in NaOH with concentration folllow previous work done by Yimin et al. (2015). This work focuses upon heat treatment after the alkaline treatment process. Thus, the alkaline treated alloy was heated to elevated temperature, i.e. 200°C,400°C,600°C and 800°C. Surface structural and phases of the untreated surface sample, after alkaline treatment and after heat treatment was analysed using X-ray diffractometer (XRD).

Meanwhile, for the surface microstructure and detection of element exist on the surface of the sample was analysed using Field Emission Scanning Electronic FESEM Microscope which also attach with energy-dispersive electron probe X-ray analyzer (EDX). The bioactivity of the alloy was investigated in Hank solution to investigate the behaviour of the alloy upon simulated body fluid. Other osteogenesis properties was also being determined through analysing the surface roughness using Atomic Force Microscopy (AFM) and the wettability of the sample was analysed through contact angle test.

1.5 Thesis Outline

This thesis was organized into five chapter. The first chapter cover the research background, problem statement, objective and scope of research. In the second chapter is upon literature review consist of Ti6Al4V alloy, Fabrication method, Alkaline treatment and heat treatment. Chapter 3 explains the raw material used, fabrication method to produce the sample, experimental procedure, parameter conduct and the characterization. Next, in chapter 4 will cover upon result and discussion. Finally, the research and recommendation for future work is discuss in Chapter 5.

CHAPTER 2
LITERATURE REVIEW

2.1 Bioimplant material

Nowadays, accident or incident can occur in any places and circumstances which lead to serious injuries and need replacement on the broken body part. Thus, bioimplant has highly become demand in biomedical industry due to the biocompatibility properties between the bone and implant material. There are also other general criterion that need to be take into account before selecting any material for bone replacement applications which are as follows (Katti et al , 2004):

1. Have high biocompatible and does not provoke any toxic reaction in the biological system.
2. The material must possess almost as the same to the bone physical and mechanical properties.
3. The fabrication and processing of the selected material must be economically viable.
4. 4. High wear resistance in any circumstances.

Different materials have different properties which will determine either the selected material is said to be compatible with the existing tissue and mechanically compatible inside the human body. The metallic implant which are widely use in the application of hip arthritis, and total hip replacement (THR) due to their high mechanical properties as a bearing component in the human body. Orthopedic bioimplants must be chosen carefully in order to support fracture and healing over the long term. The intended use, suitability for manufacturing, and prospective market size are the main factors influencing the choice of a bioimplant. Metals and metal alloys are among the several types of biomaterials that are frequently utilised to create orthopaedic bioimplants due to their biocompatibility, low cost, abundance of resources, and suitable mechanical qualities, such as high tensile strength, which gives damaged bones strength ((Ahirwar et al., 2020). Metallic biomaterials are typically utilised for load-bearing applications and need to have enough fatigue strength to withstand the rigours of regular operation. Currently, titanium-based alloys (Ti-6Al-4V), cobalt chromium alloys (CoCrMo), 316L stainless steel, and several other metals including tantalum, gold, dental amalgams, and other "specialty" metals, are employed in biomedical applications. Due to its exceptional qualities, titanium is one of the most promising engineering materials, and interest in using titanium alloys for mechanical and tribological components in the biomedical industry is increasing quickly. The several metallic materials utilised in total hip joint replacement are listed in Table 1 below.(Santos, 2017) , there is also problem in the application of metal as implant for the hip joint part in long-term period. As time went by, metal ions are released due to wear hence, lead to negative effect to the patient body (Ghalme et al,2016).The mixed lubrication regime causes wear to occur in the articulation of artificial joints consistently. Millions of minute particles are generated by the action of an artificial hip joint and are rubbed off by cutting motions. These particles, which are entrapped within the joint capsule's tissues, could trigger unfavourable reactions to foreign bodies. The discharged particles are phagocytosed and "digested" by histocytes and giant cells, which produce granulomas or tissues that resemble granulomas. These interfere with the bone's natural remodelling process at the layer where the implant and bone meet, causing osteolysis. Therefore, the femoral head and cup's construction materials have a big impact on how well the device works. attempts have been made to lessen wear since the invention of endoprosthetics by employing a variety of different combinations of materials and surface treatments(Santos,2017)

2.2 Titanium Alloy

Titanium and its alloys represent the gold standard for orthopaedic and dental prosthetic devices, because of their good mechanical properties and biocompatibility. The biocompatibility of titanium is due to its low electrical conductivity, which aids in the electrochemical oxidation of titanium, resulting in the creation of a thin passive oxide layer (Quin et al,2014 year). The oxide layer, in turn, provides excellent corrosion resistance. As titanium has an oxide isoelectric point of 5–6 this protective passive layer can retained at pH values same as in the human body. Titanium and its oxides have a low ion production tendency and poor reactivity with macromolecules in aqueous conditions (Tengvall,et al.,2014). However, the mechanical properties and bioimplant properties of the titanium is also highly influenced by the titanium element, alloying element, fabrication technique, mechanical processing and chemical composition.

In general, pure titanium itself has a good corrosion resistance, low thermal density, low thermal elastic modulus, low density, moderate strength and high reactivity upon other element. Titanium alloy is unique as the crystal structure poses in the pure titanium alloy are different where it poses hexagonal closed pack structure (HCP) at low temperature while Body centered cubic BCC, as known as titanium at high temperature. It is highly resistant to corrosion that may be caused by human body fluids and won’t cause negative health reactions, as it can be manufactured into implants.

2.3 Alloying element

The crystal structure and phase of titanium alloy is highly affected by the alloying element and chemical composition. Pure titanium has a hexagonal closed packed (HCP) crystal structure which is also known as alpha, α, phase at room temperature. At high temperature, the pure titanium will exhibit a body-centered cubic crystal structure (BCC), as known as beta or β-phase, which is unstable. Thus, to stabilize the β-phase at room temperature, some elements need to be included into the pure titanium such as Nb, Ta, Zr, No, Pt or Sn. Titanium alloys, especially β-type alloys containing β-stabilizing elements, constitute a highly versatile category of metallic materials that have been under constant development for application in orthopaedics and dentistry. This type of alloy generally presents a high mechanical strength-to-weight ratio, excellent corrosion resistance and low elastic modulus. However, the phase that present after processing could varied due to the possibility of Ti alloy form onto either α, β, α+β and near α depending on the alloying element used.

Titanium alloys with the addition of Nb with the addition of Nb, Ta, Zr, Sn, Mo and V elements show a promising potential for biomedical applications. This is due to the ability of these elements in stabilizing the titanium body-centered cubic crystal structure (β phase) at ambient temperature. In so far as titanium alloys are concerned, the alloys that arise could be the future, in terms of orthopaedic uses.

2.3.1 Ti6Al4V

Nowadays, the current material that is commercially used into the titanium alloy is aluminium, Al, and vanadium which present as Ti6Al4V. This titanium alloy is categorized as alpha-beta (α-β) titanium alloys due to the existence of vanadium element as a stabilizer for ductile β-phase, providing hot workability of the alloy (Agripa,2018). The Ti6Al4V alloy is widely used in the biomedical replacement of damaged part in human body due to its mechanical compatibility, high mechanical strength and fatigue resistance, biological compatibility where the material able to contact with the body fluid and should be a toxic to cells (Alessandra et al., 2010).

However, after a several studies have been done, there are some concerning upon the biocompatibility of Al and V elements in the commercial Ti6Al4V alloy which is upon the toxicity of vanadium elements when it was exposed to high wear. The vanadium element was found to be toxic and can cause neurological disorders and Alzheimer's disease when it was placed too long in the body fluid. This phenomenon is called as cytotoxicity (Afonso et al, 2007). According to the research done by (Geutsen et al.), the cytotoxicity properties is only occur upon the Ti6Al4V due to the chemical reaction titanium alloy exhibiting cations released through corrosion and wear, in the solution which including Ti^{4+}, $Al^{3+}$and V^{5+} (5 cations, where the V^{5+}presenting high toxicity in long-term implantable. However, Ti6Al4V is still can be used in hip prosthesis as no toxic behavior is found in short-term application.

Figure 2.1 shows the microstructure of Ti-6Al-V under optical micrograph where consist of bright and dark region indicating the existence of Ti-α .Figure 2.2 shows the X-ray diffraction of Ti6Al4V alloy consist of alpha and beta phase which contribute to its compatibility in the implantation application.

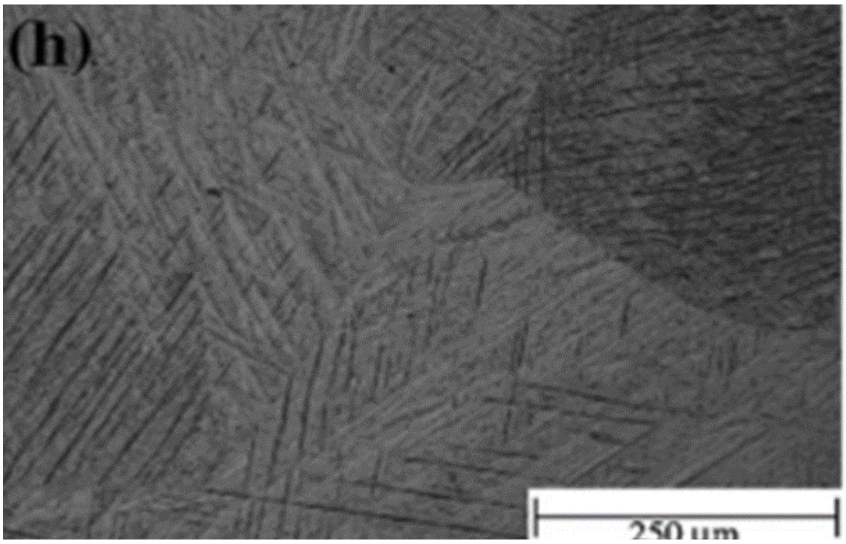

Figure 2.1 Microstructure of Ti6Al4V alloy under optical microscopy(Koike, 2011)

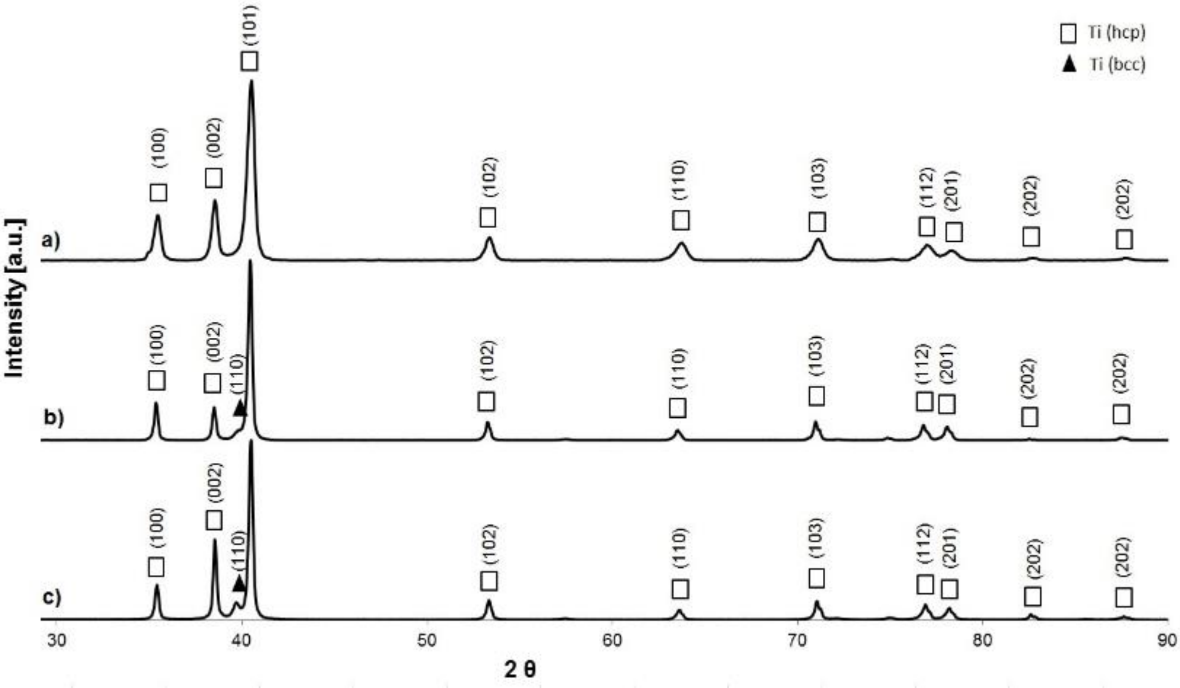

Figure 2.2 The XRD (X-ray diffraction) patterns for Ti-6Al-4V alloy obtained in the SLM (a), EBM (b)and heat-treated and annealed sheet (c) (Wysocki,2017)

2.3.2 Ti-40Nb

As the commercial titanium alloy Ti6Al4V alloy can be toxic in the long-term application, thus, research has been done towards another element which is niobium. The addition of Nb into the titanium can reduce the modulus of Ti alloy originated from the β and α phase (Chen et al, 2020). The Nb material has highly inert and has unreactive surface which is good for the biomaterial application. The surface properties of the Nb makes Nb as a good additional alloying element upon stabilizing the β-phase of the titanium alloy. The Nb element also shows a good stability of readily form and protective layer on Nb metal surface. Another advantage of Nb as the addition element towards the titanium alloy is due to no diffusion ion into the surrounding bone tissue which contribute to the no inflammatory occur towards bone tissue. The surface of Nb material also show high resistance to oxide film breakdown in physical solution.

Through the in-progress research, it is found that Nb element gives a bundle of advantage towards the implantation application. It is also found that Nb surface can react with oxide which leads to the formation of Nb_2O_5 with the combination in Ti alloy can give high corrosion resistance compared to the commercial Ti6Al4V. As the Ti-40Nb has a high corrosive resistance upon the oxide layer, thus the cytotoxicity occur in the application of Ti6Al4V application can be overcome by replacing the additional alloying element from Ti6Al4V to Ti-Nb .However, as the Ti6Al4V alloy is widely used in the industry, thus, the current effort is still focusing towards the adjustment upon current material Ti6Al4V instead of replacing the current material.

2.4 Method for Fabrication of Titanium Alloy

Titanium alloy can be produced either through conventional method or advanced fabrication method. The conventional method that is widely used in fabricating Titanium alloy including powder metallurgy and self-propagating high temperature synthesis. For advanced fabrication method are consist of Gas atomization, plasma atomization process, cold spray, 3d printing, electron beam melting and selective laser melting.

2.4.1 3D printed Ti6Al4V

Ti-6Al-V alloy is widely used in the bioimplant application due to its high compatibility and high corrosion rate resistant. In the current application, some of the implant part is too complex which the shape could not be achieve through conventional methodology process such as powder metallurgy or arc smelting. Thus, to overcome the problem upon the existing element in the commercial material used in the industry, Ti6AlV, in the titanium alloy, an advanced manufacturing process such as additive layer manufacturing or selective layer manufacturing has been proposed. (Sidambe & Oh, 2014) . It is also conceivable to construct more complicated porous structures with higher mechanical performance using modern manufacturing, potentially matching the modulus of elasticity of local bone. While advanced manufacturing's economic and engineering possibilities for the creation of musculoskeletal implants is evident, the impact on the materials' biocompatibility has received less attention. The ability of advanced powder manufacturing processes to produce components suited for biomedical implant applications has been evaluated, with a focus on surface treatments and porous structures.

One of the advanced manufacturing 3D printed technique used is by using selective laser melting, SLM , which was developed by EOS in Germany. Selective laser sintering (SLS) or selective laser melting are other terminology used to describe DMLS (SLM). A high-power optic laser with a power range of 200 W to 400 W is utilised in the DMLS system to fuse metal powder into a solid component based on a 3D CAD file. Components are manufactured using the additive approach from layer to layer, similar to the EBM system, with the layer thickness commonly being 20 m. Figure 2.3 depicts a schematic representation of the DMLS cycle's SLM form.

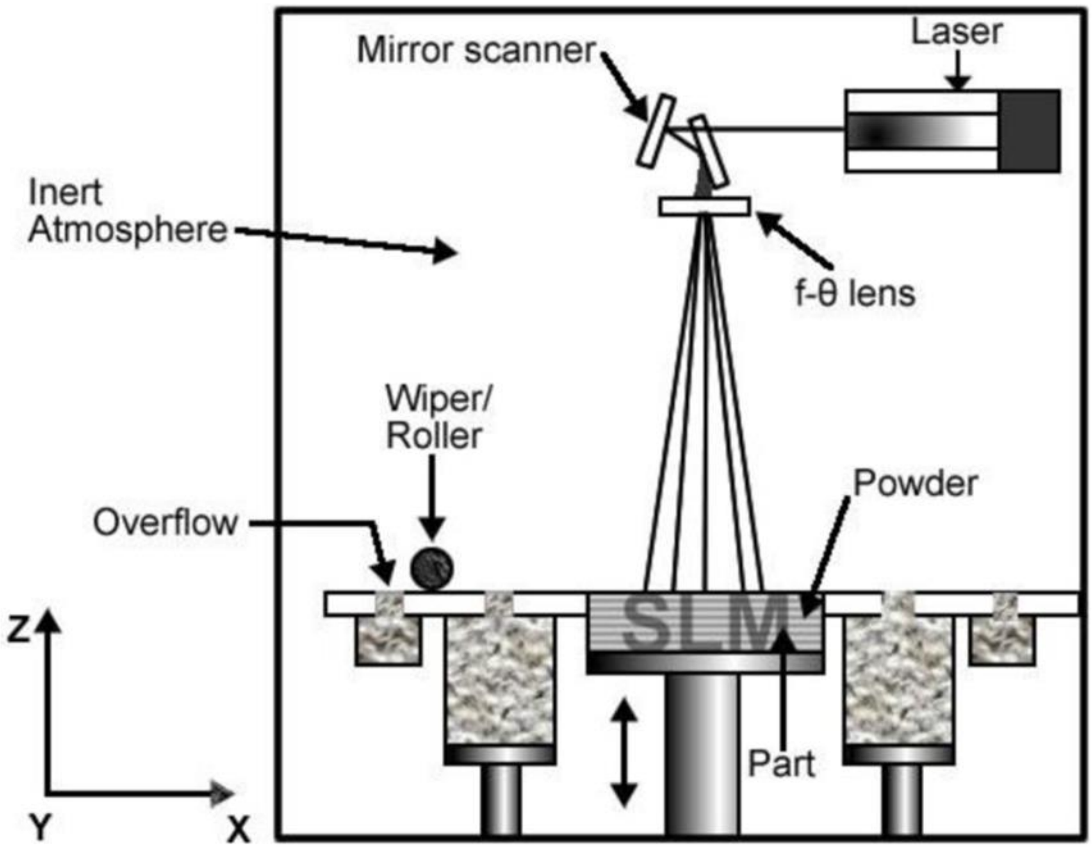

Figure 2.3 Depicts a schematic representation of the DMLS cycle's SLM form (Agripa & Botef, 2019)

As a result, the DMLS as known as SLM takes on the issues of producing biomedical implants with the desired surface finish without the requirement for post-processing such as polishing, as the EBM method does. Hollander et al.,year) described one of the experiments that were conducted to explore the suitability of the titanium DMLS for biomedical implant manufacturing. They presented findings that illustrated the impact of various surface characteristics on Ti-64 "bone replacements" created using SLM. The biocompatibility of the SLM Ti-64 material was investigated using primary human osteoblasts (HOB). The SLM surfaces were compared to a commercial Thermanox® control (Nalge Nunc Int., New York, NY, USA) and traditional bulk titanium. The results revealed that the grown cells were successful. The results demonstrated that grown cells adhered to and proliferated on SLM substrates, with alkaline phosphatase (AP) activity increasing after 7 days but decreasing after 14 day. The authors concluded that the increased metabolic activity of osteoblasts on SLM discs compared to controls could be related to the SLM material's larger surface area, which took longer for the cells to cover.

When using metallic biomaterials like Ti in implantology, it's critical to understand the role of various surface qualities when bone comes into contact with the implant. As a result, research has been conducted to better understand the early human bone response to Ti implants, with more recent studies focusing on innovative production processes like as DMLS. (Sidambe, 2014) reported on the early human bone response to a DMLS Ti6AlV4 implant surface after conducting an in vivo investigation in which a micro-implant was put into the anterior mandible of a patient during traditional jaw implant surgery. the micro implant and surrounding tissues were retrieved after two months of unloading healing, and the tissue structure was examined using microscopy. The peri-implant bone was shown to be in close contact with the implant's surface on histology. The average percentage of bone-to-implant contact was 69.51%. DMLS

Ti-64 is a promising alternative to traditional implant surface topographies, according to the authors.

The literature survey has revealed to a certain extent that DMLS of titanium can be adopted for the fabrication of custom orthopaedic implants. The results of *in vivo* tests showed that the DMLS scaffolds with unpolished and unmodified surfaces were able to support bone regeneration and that DMLS of titanium as an advanced manufacturing technology is a promising alternative to conventional implant surface topographies. On the other hand the survey has revealed that porous Ti DMLS scaffolds are biocompatible, and that pore width can influence growth around the pores and the resistance to compressive force.

Several papers have been published on the creation of a 3D imprinted implant utilising the selective laser melting (SLM) technology. And, to the best of the author's knowledge, this sort of implant has poor mechanical qualities on a micro/nano scale, particularly due to uncontrolled excess melted-metal deposits on the surface .

2.4.2 Fabrication of TiNb Alloy by Powder Metallurgy

Due to its high biocompatibility, porous architecture, suitable mechanical properties, etc., TiNb-based alloys have received a lot of attention in the medical field of orthopaedic applications. The literature reviews the current progress in fabrication techniques, porous structure, mechanical characteristics, corrosion resistance, bioactive hydroxyapatite surface modification, in vitro and in vivo biocompatibility of TiNb-based alloy.

Metal is widely used in the biomedical implant application due to its strength and ductility. However, the conventional metal used such as Ti6Al4V exhibit some limitation which is cytotoxicity some incompatible metallic elements, and mismatch of stiffness between the implant and surrounding bone tissue (Kunčická et al, 2017). Thus, ongoing research was done upon the new titanium alloy which introducing new elements such as Ti, Nb, Zr and Ta due to their excellent biocompatibility in terms of osseointegration, osteoinduction and cytocompatibility.

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It was reported by Yong Hua Li and Xiao Yang Shang that different fabrication method of TiNb alloy gives different result upon their biocompatibility and other mechanical properties. This occur due to different porous size obtain upon the fabrication of the titanium alloy.

When the sample was prepared through Polymeric Sponge Impregnation Process, the sample obtain has high open porosity and big pore size compared with other approaches. The demerits include limitation of the product shape, uncontrollability of product density, etc. ((X. Liu et al., 2005). Porous Ti–25 wt-%Nb alloy with porosity of 40~70% has been fabricated by PSIP from pure Ti and Nb powders. Porous Ti–50Nb–25at.-%Ta alloy scaffolds with porosity of 50~80% have been produced using PSIP from elemental powders.

Meanwhile, when the TiNb alloy was prepared using Selective Laser Melting, anet shape porous or compact parts were obtained. It is characterised by feasibility in preparing net shape parts with complex configuration and metastable phase from refractory metallic powders. But it is limited by high cost of equipment, low efficiency, complicated processes, etc. Porous Ti-40 wt-%Nb alloy with porosity of 17% has been produced by SLM approach from mechanical alloyed Ti–Nb powders.

Some researchers have performed in vitro and in vivo tests to evaluate the biocompatibility of TiNb-based alloys [Xu, et al,2015]. The in vitro studies including cell adhesion, cellproliferation, cell morphology, total protein content, mineralised bone-like nodule formation and alkaline. phosphatase activity tests indicated that porous sintered Ti–35Nb alloy and solid titanium had similar biocompatibility. The in vitro investigations indicated that MG-63 cells had excellent adhesion and proliferation ability on porous Ti–50Nb–25Ta alloy prepared by SHSP ((Ran et al., 2018)). Methylthiazol tetrazolium (MTT) assay results revealed that porous Ti–25Nb alloy fabricated by PSIP had no adverse reaction to cultured cells (Xu J,et al). The in vivo subcutaneous and tibial implantations of porous sintered Ti–1.6Nb–64Zr and Ti–5.5Nb–60Zr alloys on rats revealed that titanium alloy foam had excellent biocompatibility in terms of osteoinductive and osseointegrative abilities (Maya Aea ,et al).These investigations suggest that porous TiNb-based alloy is suitable to implant application owing to excellent biocompatibility.

2.5 Surface Treatment

The oxide layer (TiO_2) that is adhered to the implant's surface is responsible for its high biocompatibility of titanium. The electrostatic force created by the polarization of Ti alloy in bodily fluid is rather weak since the dielectric constant of TiO_2 is close to that of water. Therefore, the electrostatic force generated by the polarisation of Ti alloy in bodily fluid is not very strong. As a result, it would suppress the immune system's response to protein-based implants and limit the resulting rejection. Titanium, on the other hand, is a bioinert substance with a low surface activity. The bonding strength between the implant and human bones will be reduced when titanium is placed into the body because it will be coated in a layer of fibrous tissue that isolates it from the bone tissue . Therefore, in order to achieve long-term service, it is required to increase the surface activity of the Ti-base implants.

The implants have been treated using a variety of techniques, including physical (like plasma spraying) (Yu L.G et al.2008), mechanical (sandblasting) (Wenneberg et al,2019), and chemical or electrochemical routes (like alkali treatment) .The advantage of alkali treatment is that it can penetrate porous structures with acid and alkali solutions and change the surface of the structure's interior and exterior. The soaking of titanium alloy in alkali solution enabling the formation of titanate layer with Na^+ ion on the metal surface. The formation of sodium titanate on the titanium surface in the presence of HCl and NaOH would encourage bone mineralization through chemical reaction upon the Na^+ ion with oxide contain on the titanium surface layer.

A study to determine the percentage of metal components that are subjected to corrosion has done by Sailer et al. (2009) conducted a setback or a complication. It was reported that about half of the population was affected. Fracture was responsible for 24% of the total, while corrosion was responsible for the remaining 24%. Therefore, it is desirable to place a focus on early surface treatment of implants enhance the biological system's effective implantation.

Surface treatment and bioactive coating have both been investigated extensively for their tribological qualities in implants and are approved for usage in the orthopaedic profession. While 3D printing enables for the creation of porous architecture, tweaking surface qualities to achieve osseointegration with the bone is a difficulty, particularly with metallic implants where commonly used materials such as titanium alloy are bio inert (Lee et al., 2001) The release of harmful ions (Al and V) in titanium alloy offers a real threat to the biological system, hence a dense coating is required to prevent any ion leakage.

For optimizing rate of hydroxyapatite coating on the implant surface, pre-treatment of the metal is required to initiate an active surface. Many methods of pre-treatment on titanium surface before immersion into Simulated body fluid, SBF, solution has been widely studied, including sandblasting, alkali or acid treatment, heat treatment or in a combination of these three approaches. Nucleation of apatite is observed on alkali-heat treated metal after 4 weeks immersion in SBF which improved surface bioactivity with the formation of alkali titanate layer (Hanib et al., 2016). Chemical surface treatment changed Ti implant surface to form hydrogel layer (alkali titanate layer). The surface modification upon 3D printed Ti-Al-V alloy has been tested using various surface modification method including micro-arc oxidation

(MAO), laser surface texturing (LST), chemical etching, and alkali–heat treatment. each surface modification method have its pro and cons which are summarized in Table 1 (Junyi et al,2021).. They found that alkaline treatment decreasing in adhesive strength due to loss of surface structure. Thus, more research is appointed by considering the heat treatment upon temperature and time to encounter the limitation.

Table 2.1 Comparison of surface modification method with its advantage and limitation (J. Liu et al., 2021)

Method	Advantage	Limitation
Micro-arc oxidation	Homogenous oxide film layer, antibacterial and bone-forming cells capability	A few microcracks
Laser surface texturing	Swift and efficient process. Reduction in wear/friction and contamination. Superhydrophilicity surface and good mechanical fixation which prevent osteolysis	Tissue response and clinical trial vary on pattern dimension and material selection
Chemical etching	Remove unmelted powder residues in the 3D-printed part	Osseointegration capability only when paired with other methods

Alkali–heat treatment	Increase surface area for protein adsorption, induce HA nucleation sites, and good cytocompatibility	Decrease in adhesive strength due to loss of surface structure during alkali treatment

2.6 Alkaline Treatment and Its Mechanism

Alkaline treatment is one of the surface modification methods used due to the rapidity, environmentally friendly and has high efficiency compared to other surface modification method (Huang et al., 2021) .Through the research being done by Rastegari et al. (2019), it is found that the alkaline treatment can improve the wettability, able to form apatite, increasing the corrosion resistance and increase the biocompatibility of titanium alloy.

2.6.1 Mechanism of Reaction

The mechanism of reaction upon the titanium alloy surface with the alkaline treatment consist of few stages including the development of titanate layer, hydroxyl group attack to hydrated TiO_2 and the formation of alkali titanate hydrogel layer. Before the alkaline treatment, a passive oxide layers was exist on the surface of titanium alloy which can be view in Figure 2.4 As the titanium alloy was soaked into alkaline solution, NaOH, the titanium oxide layer partially dissolves with the alkaline solution and there will be ion changes on the metal urface upon OH ion and the Ti ion itself.

At high NaOH concentrations, general titanium dissolution occurs, and sodium titanate precipitation occurs. The general dissolution reaction of Ti in aqueous alkaline solution to form a titanate anion can be represented by equation (1)(2)(3)(4)(5) (Hazwani et al,2021):

$TiO_2 + NaOH \rightarrow HTiO3^- + Na^+$ (1)

$Ti + 3OH^- \rightarrow Ti(OH)_3^+ + 4e$ (2)

$2Ti(OH)3 + +2e \rightarrow 2TiO2 \cdot H2O + H2\uparrow$ (3)

$Ti(OH)3 + +OH- \ Ti(OH)4$ (4)

$TiO2 \cdot nH2O + OH- \ HTiO3 - \cdot nH2O$ (5)

The titanate anions produced on dissolution may react with Na+ cations in aqueous NaOH solution to produce sodium titanate. Equation 2 presents the general precipitation reaction of sodium titanate:

$2\ mNa^+ + [TinO2n + m]^{(2m)-} \rightarrow Na_2mTinO_2n+m$ (equation 4.2)

Sodium titanate formation was confirmed by XRD and Raman analysis. Figure 2a shows the and Figure 2b shows the surface Raman profiles of Ti metal control and treated samples. From Figure 2 it can be seen that sodium hydrogen titanate (Na_xH_2-xTi_3O_7) was formed on the metal surface by NaOH treatment (AT), and then was transformed into sodium titanate (Na2 Ti6 O13).

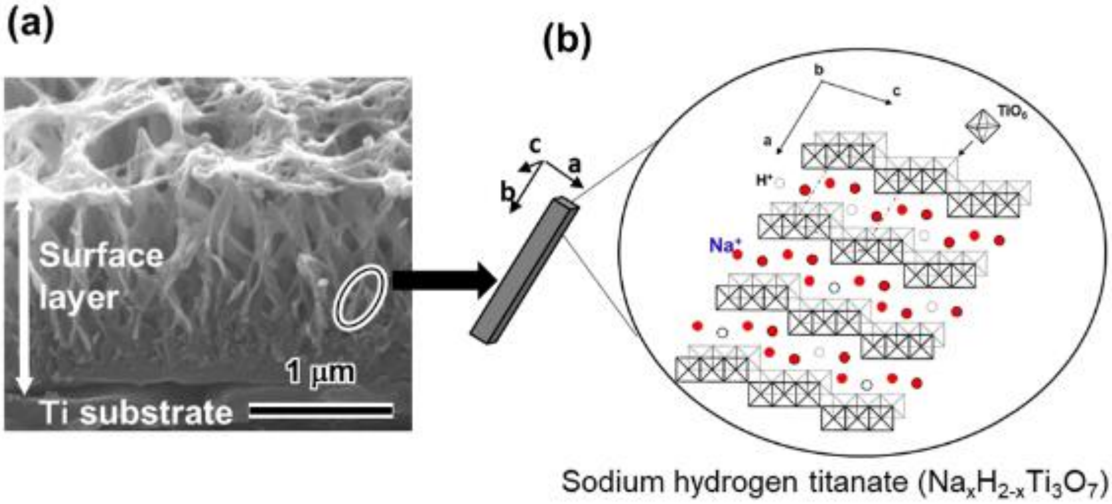

Figure 2.4 Cross section SEM image of Ti subjected to NaOH treatment (**b**) illustration of sodium hydrogen titanate structure. (Reproduced from (**a**) (Kim et al., 1999)

A research was done by ((Su et al., 2016)) shows the effect of using different temperature of immersion in 10M NaOH towards surface morphology, cell adhesion and bioactivity properties. They reported irregular crack occur upon alkaline treated at 40, 50 and 60°C (A40, A50 and A60, respectively). Meanwhile there was no crack occur on the metal surface which was subjected at 30°C (A30) where fine pores well interconnected with an average diameter of approximately 50-100nm.

The pore size increased bigger when higher temperature were applied during the immersion in the alkaline solution. Thus, it was found that 30°C was the most optimum temperature to be used in the immersion in alkaline NaOH solution. The comparison upon the immersion temperature performed in the alkaline solution can be observed in Figure 2.5.

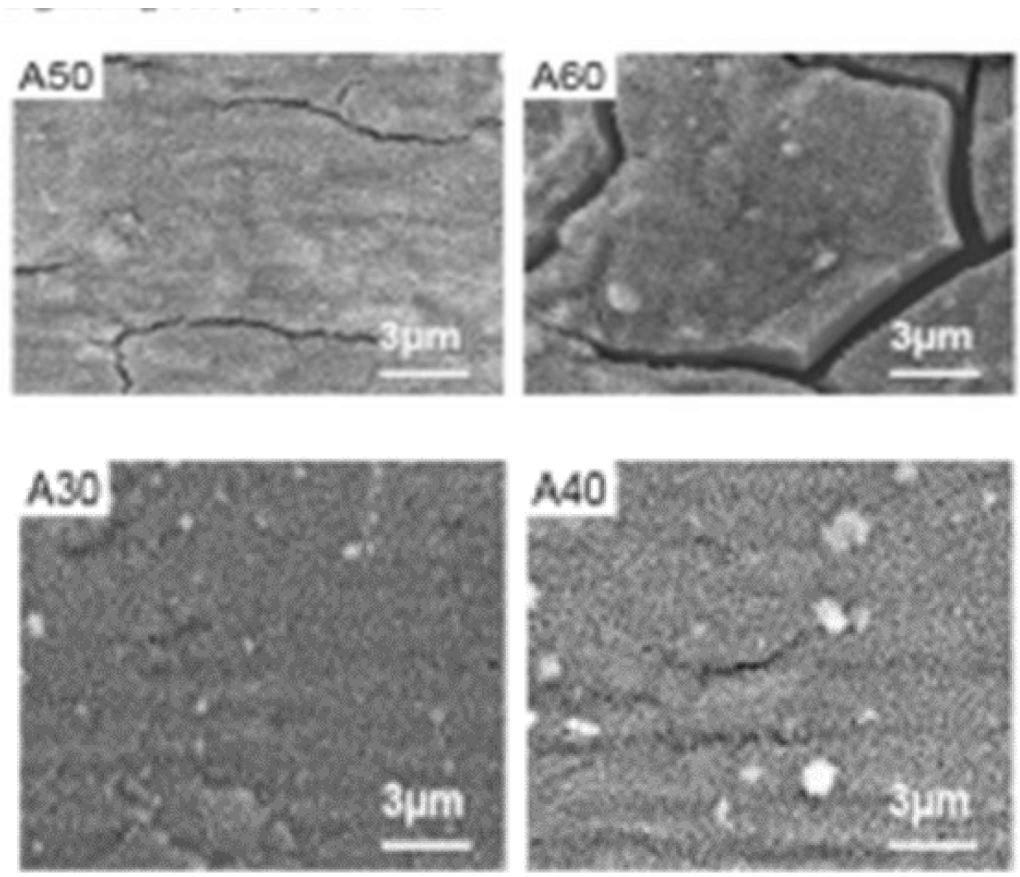

Figure 2.5 SEM photographs subjected to alkali treatments with 10-M NaOH solution at immersion temperature of 30,40,50, and 60°C(A30,A40,A50 and A60 respectively) (Su et al,2015)