Chapter 44
Laser Additive Manufacturing of Titanium-Based Implants: A Review

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ABSTRACT

Titanium and its alloys exhibit a unique combination of mechanical, physical properties and corrosion resistance behaviour which makes them desirable for aerospace, industrial, chemical, medical and energy industries. The selective addition of alloying elements to titanium enables a wide range of physical and mechanical properties to be obtained. Ti-based alloys are finding ever-increasing applications in biomaterials due to their excellent mechanical, physical and biological performance. Intense researches are being pursued in the development of new Ti-based alloys with bio-functionalization closer to human bone, owing to their excellent mechanical strength and resilience when compared to alternative biomaterials, such as polymers and ceramics. Several manufacturing techniques are capable of producing porous materials. There is a need to control pore size, shape, orientation and distribution. This work reviews the application of Ti-based alloys in the biomedical industry and also proposes laser additive manufacture process for the manufacture of medical implants.

1. INTRODUCTION

Metals and their alloys are widely used as biomedical materials. Metallic biomaterials like stainless steels, Co-Cr alloys, commercially pure titanium and its alloys are extensively used due to their excellent mechanical properties. However, metallic materials sometimes show toxicity and are fractured because of their corrosion and mechanical damages (Yuhua Li. et al, 2014; Kannatey-Asibu, 2009).

The family of titanium alloys offers a wide spectrum of strength and combinations of strength and fracture toughness. This permits optimized alloy selection which can be tailored for a critical component. The development must be performed on the basis of metallurgy and the resultant alloys must have a good balance between mechanical properties and corrosion resistance. Among metallic materials, titanium

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and its alloys are considered the most suitable materials for biomedical applications due to their superior properties. They satisfy the requirements of implantation materials better than other materials (Elias et al., 2008;Temenoff & Mikos, 2008).

Laser additive manufacturing is one of the processes for manufacture of titanium based alloys. The process has many variables that can influence the soundness and mechanical properties of the resulting part by affecting characteristics such as surface finish, porosity, residual stresses/cracking, microstructure, and texture. The variables include laser type, laser power and power distribution, laser spot size and shape, laser traverse speed, line spacing, layer thickness, deposition pattern, powder shape, size, and size distribution, powder feed rate, powder velocity, substrate temperature, substrate surface finish, substrate thickness, substrate microstructure and texture, and the size and shape of the deposit (Gu et al., 2012; Kobryn & Semiatin, 2001).

The composition of implant biomaterials must be carefully selected to avoid adverse reactions. Metals such as Ti, Zr, Nb, Mo, Ta, Sn are non-toxic and have good compatibility. β-type Ti-based alloys have high strength and low elastic modulus compared to pure titanium, hence they are used as a starting material for the improvement of mechanical properties of porous compacts. Although, fabrication of implants from materials with lower elastic modulus can reduce stress shielding effect, the modulus mismatch to bone is still substantial. To provide a way for living bone to attach itself permanently to an implant, an artificial bone should have a porous structure. Porous titanium implants demonstrate an important gain in promoting tissue in-growth and in the firm securing of an implant (Elias et al., 2008).

Porous materials in implants are increasingly attracting widespread interest of researchers and desirable by the biomedical industries. The mechanical properties of porous Ti-based alloys are dependent on porosity, pore morphology, pore size distribution and microstructure. There is a need to come up with a novel method of manufacture of the porous Ti based alloys with a keen control of pore size, shape, orientation and distribution. There is also need to develop analytical models to predict the structure-dependent mechanical performance of porous materials. Analytical models can calculate the overall material response under idealized conditions or simplified assumptions (Zhiqiang & Liou, 2013; Udomphol, 2007).

Materials used for biomedical applications cover a wide spectrum and must exhibit specific properties. An ideal implant should have mechanical properties close to natural bone and should bond well with human tissue. The most important property of materials used for fabricating implants is biocompatibility and corrosion resistance. There is need to develop new implants with low elastic modulus that mimic the architecture and also encourage bone to grow into the pores. A material with a porous structure is a desirable implant to meet the above mentioned requirements and also eliminate the problem of interfacial instability with the host tissue (Yuhua Li. et al, 2014; Kannatey-Asibu, 2009).

Titanium alloys are considered the most attractive metallic materials for biomedical applications. Despite the excellent properties of Titanium and its alloys, the addition of elements can also exert significant influences on mechanical properties. Mechanical strength may be increased by adding alloying elements or through heat treatments, which may lead to solid solution strengthening. If the elastic modulus decreases, the mechanical strength also decreases (Elias et al., 2008; Temenoff & Mikos, 2008; Gu et al., 2012; Kobryn & Semiatin, 2001; Zhiqiang & Liou, 2013; Udomphol, 2007).

The production technique utilized to manufacture porous material affects pore shape, size, distribution, and cell wall/edge structure, which in turn determines mechanical properties, i.e., yield strength and elastic modulus. There is therefore need to investigate the effects of the various process parameters on the manufacture process in order to control the process and hence achieve an efficient manufacturing process.

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