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Material processing of hydroxyapatite and titanium alloy (HA/Ti) composite as implant materials using powder metallurgy: A review

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ABSTRACT

The bio-active and biodegradable properties of hydroxyapatite (HA) make this material a preferred candidate for implants such as bone replacement in replacing natural tissues damaged by diseases and accidents. However, the low mechanical strength of HA hinders its application. Combining HA with a biocompatible material with a higher mechanical strength, such as a titanium (Ti) alloy, to form a composite has been of interest to researchers. A HA/Ti composite would possess characteristics essential to modern implant materials, such as bio-inertness, a low Young's modulus, and high biocompatibility. However, there are issues in the material processing, such as the rheological behavior, stress-shielding, diffusion mechanism and compatibility between the two phases. This paper reviews the HA and Ti alloy interactions under various conditions, *in vitro* and *in vivo* tests for HA/Ti composites, and common powder metallurgy processes for HA/Ti composites (e.g., pressing and sintering, isostatic pressing, plasma spraying, and metal injection molding).

1. Introduction

The rapid growth of the global population is leading to an increased demand for implants for bone dysfunction caused by diseases such as arthritis and cancer [1]. Such implants are necessary to repair or alter natural body tissues [2]. However, given the unique structures and mechanical properties of natural tissues such as bone tissue, repairing or changing them is challenging. Since the introduction of bioceramics as medical implants in the 1960s, metal implants such as titanium alloy, stainless steel, and cobalt–chromium alloys have been extensively used in medical applications [3]. In the early period of medical implant development, the only criteria for implant material suitability were appropriate physical properties and non-toxicity [4]. Today, the criteria include the physical properties of the bone implant material and its ability to promote the growth of body tissue [5]. Metal-based implants have a higher Young's modulus than bones, which leads to stress shielding. Metal implants also have poor biocompatibility, which is necessary to promote the growth of natural tissue. However, metal-based implants have the beneficial mechanical properties of strength and corrosion resistance. Hydroxyapatite (HA) is a bioceramic material with poor mechanical properties, especially for load-bearing applications. However, HA has a similar structure to bones and can promote the growth of natural tissues. Combining a titanium alloy with HA creates a new biomaterial with excellent mechanical and biological properties. Thus, research on this material and its preparation process has been conducted [6–10]. This paper aims to review the interaction between titanium alloys and HA as a medical implant composite. Common methods of combining HA and titanium are also discussed.

2. Criteria for biomaterials applications

In the early period of implant material development, a material was considered suitable to replace natural tissue when it had minimal or zero toxicity [11]. Later on, the ability to promote natural tissue growth was considered. Several studies have been conducted to achieve this goal in terms of the processing route, design and material modification [12–18]. Biomaterials for implants should not be cytotoxic. Cytotoxicity is caused by increased metallic ion content in the blood. Thus, biocompatibility itself can be translated simply as "do no harm" to the body and due to encourage healing [19]. The roughness of an implant surface is conducive to the bonding between implant materials and tissues [20]. Porous structures and rough surfaces are necessary for facilitating bone ingrowth and osteointegration [11,21–23]. Rough surfaces and porous structure able to control by its processing condition [24–29].

Stress shielding is a common problem of biomaterials [30,31]. This phenomenon arises when the Young's modulus of bones (Fig. 1) and the implant material are different, which causes bone resorption. Most biomaterials based on metals and ceramics have

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