

Handbook of Characterization of Metals and Alloys: Principles and Properties

VOLUME 2

Edited by Avery Logan



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Published by Auris Reference ltd. www.aurisreference.com

United Kingdom

Edition 2014

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ISBN: 978-1-78154-375-7

Printed in United Kingdom

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Preface

Metals and alloys are critical building blocks of many products in modern society. From nanomaterials to architectural structures, these materials have a huge range of uses and applications. High-purity metals and alloys find uses in automobiles, semiconductor devices, aircraft, sputter targets, evaporation sources, magnetic media, and many other products. Accurate and precise determination of their chemical composition ensures that end users have the right materials for their specific applications. For many applications the surface finish of the material can determine its lifetime and stability. This is particularly important in the biomedical field. Surface passivation can extend the lifetime of a biomedical implant, improve biocompatibility and reduce toxicity.

Characterization of Metals and Alloys provides an introduction to surface and interface analysis techniques for specialists and educated professional metallurgists or scientists. This book illustrates with case histories how characterization techniques can be used to determine important properties of metals and provides a systematic approach to the task of correlating structure and composition with properties. This is a useful reference book for practical engineers and scientists who want to learn what can be accomplished with modern analytical techniques, or who want troubleshooting advice on problems involving the structure/property relationships in metals and alloys. In the first chapter magnesium alloys have always been attractive to designers due to their low density, only two thirds that of aluminum alloys in the aerospace industry and therefore can be an innovation technology if used for low weight airframe structures. This has been a major factor in the widespread use of magnesium alloy castings and wrought products. In the chapter second and third chapter we discussed the quality of Mg alloys with high specific modulus and specific strength is the lightest in the structural materials. Their density is about 2/3 of aluminium alloys and 1/4 of steels. The weight of whole structural materials is decreased drastically owing to some components or parts produced by Mg alloys. Thus, Mg alloys are widely used in aerospace, weapons, automobile and other fields. In the forth chapter we discussed use of earth metals in medicine. In the fifth chapter we discussed about lightweight Mg alloys with excellent shock-absorption properties are being actively adopted for use in electronic information devices and automotive parts. In the sixth chapter

we discussed about the use of Mg alloys in welding. In the seventh, eight and nine chapters we discussed the use of different alloys in different fileds and research on them.

Editor

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Chapter 1

TITANIUM AND TITANIUM ALLOYS AS BIOMATERIALS

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INTRODUCTION

Bone and its several associated elements – cartilage, connective tissue, vascular elements and nervous components – act as a functional organ. They provide support and protection for soft tissues and act together with skeletal muscles to make body movements possible. Bones are relatively rigid structures and their shapes are closely related to their functions. Bone metabolism is mainly controlled by the endocrine, immune and neurovascular systems, and its metabolism and response to internal and external stimulations are still under assessment [1].

Long bones of the skeletal system are prone to injury, and internal or external fixation is a part of their treatment. Joint replacement is another major intervention where the bone is expected to host biomaterials. Response of the bone to biomaterial intervenes with the regeneration process. Materials implanted into the bone will, nevertheless, cause local and systemic biological responses even if they are known to be inert. Host responses with joint replacement and fixation materials will initiate an adaptive and reactive process

[2]. The field of biomaterials is on a continuous increase due to the high demand of an aging population as well as the increasing average weight of people. Biomaterials are artificial or natural materials that are used to restore or replace the loss or failure of a biological structure to recover its form and function in order to improve the quality and longevity of human life. Biomaterials are used in different parts of the human body as artificial valves in the heart, stents in blood vessels, replacement implants in shoulders, knees, hips, elbows, ears and dental structures [3] [4] [5]. They are also employed as cardiac simulators and for urinary and digestive tract reconstructions. Among all of them, the highest number of implants is for spinal, hip and knee replacements. It is estimated that by the end of 2030, the number of total hip replacements will rise by 174% (572,000 procedures) and total knee arthroplasties are projected to grow by 673% from the present rate (3.48 million procedures) [6]. This is due to the fact that human joints suffer from degenerative diseases such as osteoarthritis (inflammation in the bone joints), osteoporosis (weakening of the bones) and trauma leading to pain or loss in function. The degenerative diseases lead to degradation of the mechanical properties of the bone due to excessive loading or absence of normal biological self-healing process. Artificial biomaterials are the solutions to these problems and the surgical implantation of these artificial biomaterials of suitable shapes help restore the function of the otherwise functionally compromised structures. However, not only the replacement surgeries have increased, simultaneously the revision surgery of hip and knee implants have also increased. These revision surgeries which cause pain for the patient are very expensive and also their success rate is rather small. The target of present researches is developing implants that can serve for much longer period or until lifetime without failure or revision surgery [7]. Thus, development of appropriate material with high longevity, superior corrosion resistance in body environment, excellent combination of high strength and low Young's modulus, high fatigue and wear resistance, high ductibility, excellent biocompatibility and be without citotoxicity is highly essential [8] [9].

In general, metallic biomaterials are used for load bearing applications and must have sufficient fatigue strength to endure the rigors of daily activity. Ceramic biomaterials are generally used for their hardness and wear resistance for applications such as articulating surfaces in joints and in teeth as well as bone bonding surfaces in implants. Polymeric materials are usually used for their flexibility and stability, but have also been used for low friction articulating surfaces. Titanium is becoming one of the most promising engineering materials and the interest in the application of titanium alloys to mechanical and tribological components is growing rapidly in the biomedical field [10], due to their excellent properties.

This chapter is focused on the use of titanium and its alloys as biomaterials from a tribological point of view. The main limitation of these materials is their poor tribological behavior characterized by high friction coefficient and severe adhesive wear. A number of different surface modification techniques have been recently applied to titanium alloys in order to improve their tribological performance as well as osseointegration. This chapter includes the most recent developments carried out in the field of surface treatments on titanium with very promising results.

BIOMATERIAL PROPERTIES

The main property required of a biomaterial is that it does not illicit an adverse reaction when placed into services, that means to be a biocompatible material. As well, good mechanical properties, osseointegration, high corrosion resistance and excellent wear resistance are required.

Biocompatibility

The materials used as implants are expected to be highly non toxic and should not cause any inflammatory or allergic reactions in the human body. The success of the biomaterials is mainly dependent on the reaction of the human body to the implant, and this measures the biocompatibility of a material [11]. The two main factors that influence the biocompatibility of a material are the host response induced by the material and the materials degradation in the body environment (Figure 1). According to the tissue reaction phenomena, the biocompatibility of orthopedic implant materials was classified into three categories by Heimke [12], such as "biotolerant", showing distant osteogenesis (bone formation with indirect contact to the

material); "bioinert", showing contact osteogenesis (bone formation with direct contact to the material), and "bioactive", showing bonding osteogenesis (bone formation with chemical or biological bonding to the material).

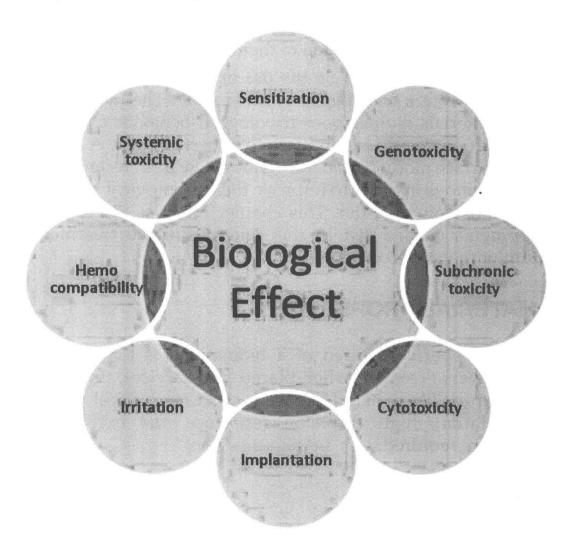


FIGURE 1. Biological effects of a biomaterial

When implants are exposed to human tissues and fluids, several reactions take place between the host and the implant material and these reactions dictate the acceptability of these materials by our system. The issues with regard to biocompatibility are (1) thrombosis, which involves blood coagulation and adhesion of blood platelets to biomaterial surface, and (2) the fibrous tissue encapsulation of biomaterials that are implanted in soft tissues.

Mechanical Properties

The most important mechanical properties that help to decide the type of material are hardness, tensile strength, Young's modulus and elongation. An implant fracture due to a mechanical failure is related to a biomechanical incompatibility. For this reason, it is expected that the material employed to replace the bone has similar mechanical properties to that of bone. The bone Young's modulus varies in a range of 4 to 30 GPa depending on the type of the bone and the direction of measurement [13] [14].

Osseointegration

The inability of an implant surface to integrate with the adjacent bone and other tissues due to micromotions, results in implant loosening [15]. Osseointegration (capacity for joining with bone and other tissue) is another important aspect of the use of metallic alloys in bone applications (Figure 2). A good integration of implant with the bone is essential to ensure the safety and efficacy of the implant over its useful life. It has been shown in previous studies [16], that enhancement of the bone response to implant surfaces can be achieved by increasing the roughness or by other surface treatments [17]. Although the precise molecular mechanisms are not well understood, it is clear that the chemical and physical properties of the surface play a major role in the implant – surface interactions through modulation of cell behavior, growth factor production and osteogenic gene expression [18] [19] [20].

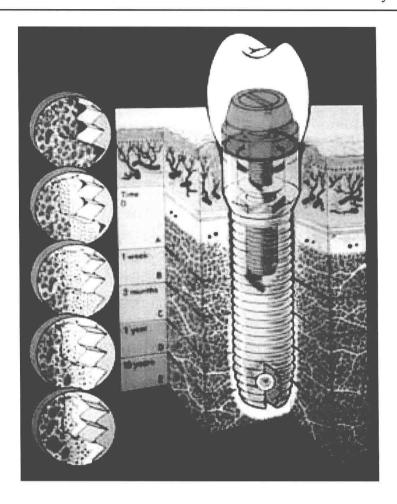


FIGURE 2. Schematic drawing of the principles of osseointegration [21]

Furthermore, it is known that even if initial implant stability is achieved, the bone may retreat from or be isolated from the implant because of different reasons or situations listed below:

Reaction of the implant with a foreign body as debris from implant component degradation or wear, or to toxic emissions from the implant [22]

- 1. Damage or lesion to the bone through mechanical trauma surgery
- 2. Imposition of abnormal or unphysiological conditions on the bone, such as fluid pressures or motion against implant components
- 3. Alteration to the mechanical signals encouraging bone densification; strain reductions or stress-shielding of replaced or adjacent bone.

High Corrosion Resistance

All metallic implants electrochemically corrode to some extent. This is disadvantageous for two main reasons: (1) the process of degradation reduces the structural integrity and (2) degradation products may react unfavorably with the host. Metallic implant degradation results from both electrochemical dissolution and wear, but most frequently occurs through a synergistic combination of the two [23] [24]. Electrochemical corrosion process includes both generalized dissolution uniformly affecting the entire surface and localized areas of a component.

Metal implant corrosion is controlled by (1) the extent of the thermodynamic driving forces which cause corrosion (oxidation/reduction reactions) and (2) physical barriers which limit the kinetics of corrosion. In practice these two parameters that mediate the corrosion of orthopedic biomaterials can be broken down into a number of variables: geometric variables (e.g., taper geometry in modular component hip prostheses), metallurgical variables (e.g., surface micro-structure, oxide structure and composition), mechanical variables (e.g., stress and/or relative motion) and solution variables (e.g., pH, solution proteins and enzymes) [25].

The corrosion resistance of a surgically implanted alloy is an essential characteristic since the metal alloys are in contact with a very aggressive media such as the body fluid due to the presence of chloride ions and proteins. In the corrosion process, the metallic components of the alloy are oxidized to their ionic forms and dissolved oxygen is reduced to hydroxide ions.

The corrosion characteristics of an alloy are greatly influenced by the passive film formed on the surface of the alloy and the presence of the alloying elements.

Wear Resistance

Wear always occurs in the articulation of artificial joints as a result of the mixed lubrication regime. The movement of an artificial hip joint produces billions of microscopic particles that are rubbed off cutting motions. These particles are trapped inside the tissues of the joint capsule and may lead to unwanted foreign body reactions. Histocytes and giant cells phagocytose and "digest" the released particles and form granulomas or granuloma-like tissues. At the boundary layer between the implant and bone, these interfere with the transformation process of the bone leading to osteolysis. Hence, the materials used to make the femoral head and cup play a significant role in the device performance. Since the advent of endoprosthetics, attempts have been made to reduce wear by using a variety of different combinations of materials and surface treatments.

Nowadays, the materials used for biomedical applications are mainly metallic materials such as 316L stainless steel, cobalt chromium alloys (CoCrMo), titanium-based alloys (Ti-6Al-4V) and miscellaneous others (including tantalum, gold, dental amalgams and other "specialty" metals). Titanium alloys are fast emerging as the first choice for majority of applications due to the combination of their outstanding characteristics such as high strength, low density, high immunity to corrosion, complete inertness to body environment, enhanced compatibility, low Young's modulus and high capacity to join with bone or other tissues. Their lower Young's modulus, superior biocompatibility and better corrosion resistance in comparison with conventional stainless steels and cobalt-based alloys, make them an ideal choice for bio-applications [26]. Because of the mentioned desirable properties, titanium and titanium alloys are widely used as hard tissue replacements in artificial bones, joints and dental implants.

TITANIUM AND TITANIUM ALLOYS

The elemental metal titanium was first discovered in England by William Gregor in 1790, but in 1795 Klaproth gave it the name of titanium. Combination of low density, high strength to weight ratio, good biocompatibility and improved corrosion resistance with good plasticity and mechanical properties determines the application of titanium and its alloys in such industries as aviation, automotive, power and shipbuilding industries or architecture as well as medicine and sports equipment.

Increased use of titanium and its alloys as biomaterials comes from their superior biocompatibility and excellent corrosion