Chapter 1

Introduction

1.1 Introduction

Nowadays, the increasing road accidents and general degradation of physio-mechanical properties of the bones have raised the demand for replacement of organs and bones with the artificial components. Cases of musculoskeletal related diseases such as osteoarthritis, rheumatoid, arthritis, and osteonecrosis are increasing each year. Joint replacement is a medical surgery procedure to alleviate pain and disability in those suffering from musculoskeletal disease. Therefore, the need of novel implant biomaterials for soft and hard tissues is continuously increasing. The lack of proper choice of biomaterial results in to the failure of implant which leads the patient towards revision surgery [1]. Joint replacement revision surgery is a surgery procedure that is performed after the primary surgery due to (i) implant loosening, (ii) infections, and (iii) pain.

Revision surgery is usually more expensive and is occasionally more complex than the primary joint replacement surgery. Implant loosening is a condition in which the bone implants become mechanically instable and accounts for 70% of the cases for revision surgery. The major reason lies due to stress shielding effect caused by high young's modulus of selected material. Therefore, great effort has been made to develop suitable implant materials with zero-rate revision surgery [2]. In continuation of that efforts, the most common and suitable biomaterials found in the area of bone tissue engineering are titanium and titanium alloys.

The current thesis deals with the study of titanium based various metal ceramic composite which may be potentially used for the load bearing bio implants. In this work, titanium and their alloys matrix are reinforced with the bioactive ceramics. Therefore some details of Titanium, their alloys, and biomaterial like bioceramics are needed to be discussed which are given bellow.

1.1.1 Titanium

Titanium is the fourth most abundant structural metal after aluminum, iron, and magnesium. Ilmenite ($FeTiO3$) and rutile ($TiO2$) are the most important mineral sources for Ti metal [3]. It is termed as a wonder and glamour metal as well as metal of promise by many scientists and orthopedic doctors. Extraction of titanium from its ores was not developed on a commercial scale until the Kroll's process was developed in 1950. Today, a large number of titanium and titanium alloys are used in various applications like chemical and petrochemical industries as well as other consumer goods such as cameras, aerospace, medical, watches, and sports equipment. However, one of the largest users of titanium is still the medical industry, where titanium alloys are used as a bio-implant.

Due to its properties such as resistance to corrosion, inertness, its capacity to adsorb proteins readily onto its surface, and low cytotoxicity, titanium has been considered as a very good biocompatible material for surgical implant for years. It is found applicable in orthopedic, maxillofacial, oral surgery and cardiovascular surgery [4-7].

Initial development of titanium alloys during the past few decades came from the aerospace industries [8]. There was a critical need for new substances with greater strength: weight ratios at high temperatures.

It has a number of features that distinguish it from the other light metals [9].

1. At 882.5 °C, titanium undergoes an allotropic transformation from a low temperature, hexagonal close-packed structure called alpha phase to a body-centered cubic structure beta phase that remains stable up to the melting point.

2. Titanium is a transition metal with an incomplete shell in its electronic structure which enables it to form solid solutions with most substitional elements having a size factor within 20%.

3. Titanium and its alloys react with several interstitial elements including the gases oxygen, nitrogen and hydrogen, and such reactions may occur at temperatures well below the respective melting points [10].

4. In its reactions with other elements, titanium may form solid solutions and compounds with metallic covalent or ionic bonding [9].

Titanium appears to be a favorable choice in the area of biomedical applications as it may be used in place of 316L SS and Co-Cr alloys on account of having less elastic modulus, better biocompatibility and corrosion resistance.

Alloying of titanium is dominated by the ability of elements to stabilize either of the alpha or beta phases. This behavior, in turn, is related to the number of bonding electrons, i.e. the group number, of the element concerned [11].

The properties of titanium alloys are determined primarily by the morphology, volume fraction and individual properties of the two phases so it is desirable to examine the general principles that are involved even though they relate mainly to the alpha or beta group.

In the recent literatures, it has been found that currently Ti-6Al-4V alloy is being used in orthopedic implant due to its comparable greater compressive and tensile strength, yield strength, and high resistance to corrosion in biological environments [12]. Yet although these have all greatly improved the quality of life with their introduction, these implants still have numerous issue i.e in Ti-6Al-4V alloy like high Young's modulus as compared to cortical bones i.e., 5 GPa and 110 GPa for bone and dense titanium, respectively (13 LeGeros and Craig, 1993) and with the long term use, Al and V may cause allergic reaction and neurological disorders like Alzheimer's disease [14]. High cost is also one of the constraint for economical point of view.

1.1.2 Bio ceramic

With the discovery of transforming clay into ceramic pottery give rise to an agrarian society and an enormous improvement in the quality and length of life. Further, another revolution occurred in the use of ceramics during the past four decades to improve the quality of life.

This revolution is the innovative use of specially designed ceramics for the repair, reconstruction and replacement of diseased or damaged parts of the human body. Ceramics used for this purpose are termed bioceramics''[15].

The field of bioceramics contains the single crystal and polycrystalline alumina, zirconia, hydroxyapatite, bioactive glasses, bioactive glass-ceramics. Several special ceramics and glasses have been designed and developed in the midcentury which is to be use in the health care such as eyeglasses, diagnostic instruments, chemical wares, thermometers, tissue culture flasks, fiber optics for endoscopy and carriers for enzymes & antibodies [16].

Bio ceramics are also used to fill space while the natural repair processes restore functions. In other situations, the ceramic is used as a coating on a substrate, or as a secondary phase in a composite which combine the characteristics of both into a new material with enhanced mechanical and biochemical properties. Among the richest class of bio-ceramic, some composition of glasses based on borate, silicate, and amorphous phosphate structures are also bio-active.

These glasses are composed of calcium and phosphates, which are present in a proportion that is similar to the bone hydroxyapatite . Bioglass is a soda – lime – phosphosilicate (Na2 O–CaO–P2 O5 •SiO2) glass that reacts in the physiological environment [17]. When these glasses are present in an aqueous solution of body, it reacts with it. As a result of this reaction, a change in the structure and chemical composition of bioactive glass occurs which causes its dissolution and the layer of hydroxyapatite is formed on the glass surface which has a similar composition to the natural bone mineral. Collagen fibrils from host bone are thought to interact, via cellular processes, with the fine topography of the HCA layer, creating a strong bond with the bioactive glass. Bioactive glasses have different families and each family has a different composition. The series of bioactive glasses containing various compositions have been studied by Prof. Hench and their research group and established their relations in triangular form as shown in figure [18].

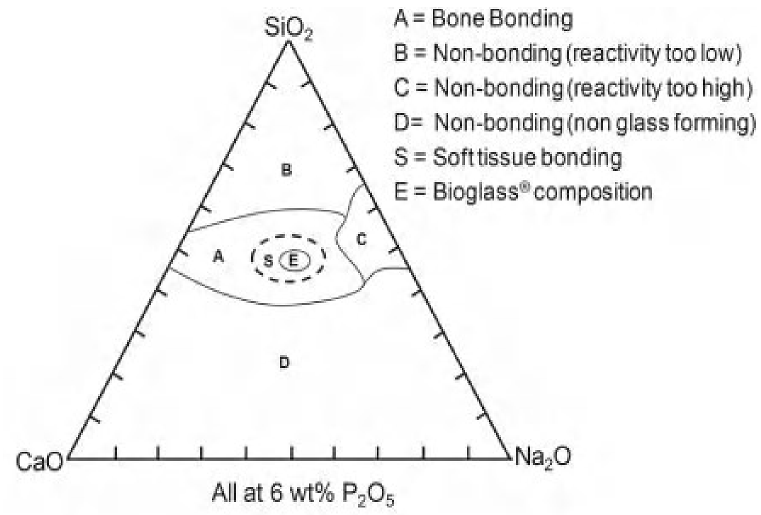

Figure 1. Bioactivity map of compositions in the SiO_2–Na_2O–CaO system (6 wt% of P_2O_5) showing regions of bioactive response

Although the bioactive glasses show the good compatibility and bioactivity, they cannot be used alone in the hard tissue replacement because of lack of sufficient mechanical properties.

1.2 Objective

With the above discussion, there are following four major problems in the currently available bio-implant in the market.

1. Mismatch of modulus because of high elastic modulus of implant.

2. Lack of bioactivity in currently using implants.

3. Lack of adherences of surface coating.

4. Some of alloying elements in widely used ti alloy are proven toxic in long clinical trials.

The aim of the present work is to develop the appropriate composite which will meet out the above requirements. So the composites of newly developed Ti alloys with some bioactive glasses have been developed with the aim to club the mechanical properties of metal alloy with biological properties of glasses and to find out the effect of reinforcing bioactive glasses on composite behavior.

References

1. Elena P. Ivanova, Kateryna Bazaka, Russell J. Crawford, 5 - Metallic biomaterials: types and advanced applications, New Functional Biomaterials for Medicine and Healthcare, Woodhead Publishing, *2014, Pages 121-147*.

2. C.B Johansson et al., "Quantitative Comparison of Machined Commercially Pure Ti and Ti-6Al-4V Implant in Rabbit," J. Oral Maxillofac. Implants, *13 (1998), p.315.*

5. Sukotjo C, Lima-Neto TJ, Santiago Júnior JF, Faverani LP, Miloro M. Is There a Role for Absorbable Metals in Surgery? A Systematic Review and Meta-Analysis of Mg/Mg Alloy Based Implants. *Materials (Basel)*. *2020; 13(18):3914*.

6. Pacifici L, DE Angelis F, Orefici A, Cielo A. Metals used in maxillofacial surgery. *Oral Implantol (Rome)*. *2017; 9 (Suppl 1/2016 to N 4/2016):107-111*.

7. A Titanium Arch Bar for Maxillomandibular Fixation in Oral and Maxillofacial Surgery *VOLUME 64, ISSUE 6, P989-992, JUNE 01, 2006*

8. Introduction to aerospace materials,Introduction to Aerospace Materials, *Woodhead Publishing, 2012, Pages 1-14,*

10. Gunarajulu Renganathan, Narasimhaswamy Tanneru, Suguna Lakshmi Madurai, 10 - Orthopedical and biomedical applications of titanium and zirconium metalsFundamental Biomaterials: Metals, *Woodhead Publishing, 2018, Pages 211-241, ISBN 9780081022054*

11.C.B Johansson et al., "Quantitative Comparison of Machined Commercially Pure Ti and Ti-6Al-4V Implant in Rabbit," *J. Oral Maxillofac. Implants, 13 (1998), p.315.*

12. Özcan, Mutlu, and Christoph Hämmerle. 2012. "Titanium as a Reconstruction and Implant Material in Dentistry: Advantagrtes and Pitfalls" *Materials 5, no. 9: 1528-1545*

13. Hanawa, Takao. “Titanium-Tissue Interface Reaction and Its Control With Surface Treatment.” *Frontiers in bioengineering and biotechnology vol. 7 170. 17 Jul. 2019.*

14. Introduction to biomaterials and implantable device design, Editor(s): Elena P. Ivanova, Kateryna Bazaka, Russell J. Crawford, New Functional Biomaterials for Medicine and Healthcare, *Woodhead Publishing, 2014, Pages 1-31, ISBN 9781782422655.*

15. Yamamuro T. (2004) Bioceramics. In: Poitout D.G. (eds) Biomechanics and Biomaterials in Orthopedics. *Springer, London.*

16. Chevalier, L. Gremillard, Ceramics for medical applications: A picture for the next 20 years, *Journal of the European Ceramic Society, Volume 29, Issue 7, 2009, Pages 1245-1255.*

17. Liane Bingel et.al “Influence of dissolution medium pH on ion release and apatite formation of Bioglasss 45S5” *Materials Letters 143 (2015) 279–282.*

18 Hench LL and Wilsn J,An introduction to Bioceramics, World Scientific Publishing CO, London-Singapore, 1993,