Chapter 1

INTRODUCTION

Titanium and its alloys are utilized extensively in a wide variety of vital applications, ranging from the aerospace industry to the production of power and marine components and medical implants. Titanium is used in various medical applications, including load-bearing orthopedic implants, dental screws, abutments, and other dental components. Commercially pure titanium (CP-Ti) and Ti-6Al-4V are the two types of titanium alloys used in producing these medical devices. Today's implant business uses these metals frequently due to their vast application and popularity. These alloys are so popular because the bone around them tends to combine with the material in the body. Titanium also possesses excellent wear resistance, high specific strength, strong corrosion resistance, low density, and high biocompatibility. In addition, titanium has exceptional mechanical properties. Titanium's low density makes it possible for cells to proliferate inside the implant, which in turn helps to strengthen the relationship between the natural cells in the surrounding area and the artificial implant. This phenomenon of implant integration to natural cells is termed "osseointegration," which was first described by Branemark et al.

Numerous studies on CP-Ti and Ti-6Al-4V have shown a variety of advantageous properties, but there are still a number of problems that need to be addressed. The high Young's modulus of CP-Ti and Ti-6Al-4V (100-110 GPa), in comparison to the human cortical bone (up to 30 GPa), generates the stress-shielding effect near the joint, which ultimately leads to the loosening of joints and the early failure of the material. The primary materials used in biomedical implants are constantly in contact with the surrounding body fluid. For example, the dental implant is permanently submerged in saliva, and the screws used in hip and knee implants are in contact with human blood plasma. These fluids are also responsible for the gradual chemical deterioration of the surface of the implant as time passes. Although titanium and its alloys have been shown to have superior anticorrosion properties compared to cobalt-chromium and stainless steel, the passive layer that confronts the surface attack causes problems when it deteriorates with the fluid in the surrounding environment, besides the several advantages of Ti-6Al-4V over the CP-Ti in terms of lower young's modulus, high corrosion resistance, and suitable mechanical properties, aluminium and vanadium cause Alzheimer's disease and neurological disorders in the patient. Even though implants improve patients' quality of life and provide them with replacement of teeth bone and hard tissues, these implants have been linked to bone loss, inflammation of soft tissue, and other problems that cannot be reversed in patients (as a result of stress-shielding and bacterial colonization). There is currently no definite treatment available for the disease known as "peri-implantitis," which is the leading cause of implant failure caused by bacteria. In patients with dental implants, this disease causes gingiva inflammation, followed by bone loss. Diabetes, alcoholism, and smoking have all been identified as contributing factors to the progression of peri-implantitis. Bacterial infections caused by indwelling medical devices are common and challenging to treat due to the requirement of continuous antibiotic treatment and expensive surgical procedures, both of which can impose significant financial burdens on patients. Both the CP-Ti and Ti-6Al-4V do not have this inherent property to save the surroundings from bacterial infection. Several studies have shown that Staphylococcus aureus (S. aureus) and Escherichia coli (E. coli) bacteria can grow near the edge of a dental implant, which can cause etching and swelling and eventually loosen the implant.

To get the solution to these issues with CP-Ti and Ti-6Al-4V, research is going on to develop Al and V-free titanium. Titanium is a dimorphic allotrope, meaning that it can take on two different shapes depending on the crystallographic orientation. Titanium's metallurgy is predominately determined by the crystallographic transformation that takes place in the pure form of the element when it is heated to a temperature of 882 °C. Below this temperature, pure titanium takes on a structure known as alpha phase (α), which is characterized by hexagonal close packing. Above this temperature, the structure takes on a body-centered cubic form and is known as the beta phase (β). The fundamental effect that occurs as a result of alloying additions being made to titanium is a change in the temperature at which the transformation takes place, as well as the production of a two-phase field that contains both alpha and beta phases. Alloying biocompatible elements in titanium through different processing routes is a common way to develop new titanium alloy with attractive properties to it as a biomedical implant. Many studies have been presented in order to produce new Ti-based alloys with non-allergic and non-toxic components that are single-phase and have a low elastic modulus. This is being done in an effort to address the shortcomings that have been mentioned. For this reason, lower elastic modulus and high corrosion resistance Ti-based alloys that comprise non-toxic and non-allergic elements, including Mo, Nb, Zr, and Ta, have attracted interest as more competitive choices for biomedical materials. These alloys have a lower elastic modulus. These elements are added to the titanium to control the phase transformation or to stabilize the alpha and beta phases. Generally, the beta phase of titanium shows good mechanical properties than the alpha phase to use as a biomedical implant. The current biomedical research community is trying to develop a new biocompatible titanium alloy that can replace the CP-Ti and Ti6Al-4V.

The crystallographic phase of titanium is the reason for its controlled physical and chemical properties. The alpha phase shows better corrosion resistance, and the beta phase is responsible for suitable mechanical properties to use as a medical implant. An excellent example of the combined alpha and beta phase of titanium is Ti-6Al-4V. The V stabilizes the beta phase while the Al alpha phase of titanium. As discussed earlier, the Ti-6Al-4V also causes bacterial infection surrounding the joint. The commonly known metal ions (Cu^{2+}, Ag^{+}, and Zn^{++}) have been designated as antibacterial agents when alloyed with titanium. Out of these three elements, it was speculated that copper ions were primarily responsible for the antibacterial activity. There has been extensive research has been done on improving the antibacterial property of CP-Ti and Ti-6Al-4V by alloying copper during synthesis. Copper generally stabilizes the alpha phase of titanium and forms a new intermetallic compound, Ti_2Cu, which is responsible for the antibacterial properties and excellent corrosion resistance of titanium alloy.

The literature survey shows powder metallurgy is the least explored route in developing antibacterial titanium alloys. The development of alloys through the powder metallurgy process is a promising technique over the melting that can be used to control the porosity of the alloy. Because porosity is the primary critical factor in achieving better osseointegration between an implant and the patient's natural cells. The maximum utilization of raw materials is only possible by the use of this technique. There are many techniques that involve the processing of alloys by powder, i.e., spark plasma sintering, microwave sintering, tube furnace sintering, and conventional muffle furnace sintering. Although spark plasma sintering is the best technique to develop alloy, its higher cost always disappoints the implant industry. Titanium is a very classical material for use as an implant due to the fact that it possesses superior physical and chemical properties; however, processing titanium is also an extremely challenging task. Research is currently being conducted to develop low-cost binary and ternary titanium alloys for biomedical applications.

The current research aims to produce a unique titanium alloy by the powder metallurgy approach that possesses superior mechanical qualities, outstanding corrosion and wear resistance, and a beneficial antibacterial property. Conventional sintering in a muffle furnace was used to develop the four alloys, which were designated as Ti-5Cu, Ti-5Cu-5Nb, Ti-5Cu-10Nb, and Ti-5Cu-15Nb. After the sintering process, the formed phases are analyzed with XRD. The optical microscope and scanning electron microscopy techniques are employed to examine the microstructure. Density and porosity are factors considered when determining the alloys' physical properties. The Vicker hardness and compression test have been performed for the mechanical properties of developed alloys. Also, the corrosion resistance of the alloys is evaluated using the potentiodynamic polarisation method while the materials are present in simulated body fluid. In the reciprocating wear test, zirconia balls are used to evaluate the friction and wear response of the sintered alloys. In addition, the test for antibacterial efficacy is conducted using S. aureus and E. coli bacteria. Furthermore, the cell culture, proliferation, and viability test of the alloy are carried out using MG-63 animal cells to examine the growth of cells on the alloys. The conclusion reached as a result of this investigation will legitimately apply to developing a new biomedical implant by substituting CP-Ti and Ti-6Al-4V, the materials most commonly used these days.