Chapter 7

CONCLUSIONS AND FUTURE SCOPE

The present investigation is an approach to developing titanium-based alloys and their characterization to use for biomedical applications. Four different titanium alloys of copper and niobium named Ti-5Cu (S1), Ti-5Cu-5Nb (S2), Ti-5Cu-10Nb (S3), and Ti-5Cu-15Nb (S4) are developed by powder metallurgy route. This chapter of the thesis discusses the conclusions based on the results and discussion obtained from the different analyses, such as phase structure, microstructural analysis, physical and mechanical properties, corrosion and wear behavior, cytocompatibility, and antibacterial behavior of the developed alloys. The major conclusions of the present study are given as follows:

1. The binary Ti-5Cu, and ternary Ti-5Cu-5Nb, Ti-5Cu-10Nb, and Ti-5Cu-15Nb alloys were successfully synthesized by powder metallurgy technique. Fairly uniform distribution of both the binary and tertiary alloying elements are observed in their respective metallographic investigation.
2. X-ray diffraction (XRD), High-resolution scanning electron microscopy (HR-SEM), and Energy dispersive analysis of X-ray (EDAX) of the synthesized alloys confirms that alloys contain α-Ti, Ti_2Cu, and β-Ti.
3. With increasing niobium percentage in the ternary alloys, the volume fraction of the beta phase of titanium increases accordingly. The respective crystalline size and lattice strain of both the powder and developed alloys confirms that the sintering temperature (900 °C) is adequate for the proper sintering of the alloys.
4. The primary major aim of the study was to obtain both the alpha and beta phases of titanium in the developed alloys, which was successfully achieved in this investigation.

5. The density of the samples decreases with increasing the niobium percentage in the Ti-5Cu. The maximum density showed by Ti-5Cu, while the minimum by Ti-5Cu-10Nb. There is approximately 10% porosity achieved for the sample Ti-5Cu-15Nb. The porosity of the biomedical implant improves the osseointegration. The cells surrounding the implant easily make the proper integration with the implant having porosity.
6. The Vickers micro-hardness of the synthesized alloys also shows the variation with increasing the niobium percentage in the Ti-5Cu. Ti-5Cu-5Nb shows the maximum hardness, while Ti-5Cu-15Nb minimum. However, the hardness of the developed alloys is significantly better than the CP-Ti and Ti-6-Al-4V. The hardness of the biomedical implant permits better load-bearing capacity and bears the surface degradation by the external rubbing bone around the implant.
7. The compression test result of the developed alloys shows that the niobium plays the main key role in achieving the compressive strength of the alloys. Addition of only 5 wt. % Nb in Ti-5Cu enhances the compressive strength approximately by ≈ 60%, while adding 10 wt. % Nb to Ti-5Cu increases the compressive strength by about ≈ 20%. Furthermore, the addition of 15 wt. % Nb to Ti-5Cu decreases the compressive strength by approximately ≈ 6%. It shows that further addition of more Nb to Ti-5Cu would definitely decrease the compressive strength.
8. The developed titanium alloys are tested for their corrosion strength in simulated body fluid (pH=7.3-7.4) by electrochemical technique (open circuit potential, electrochemical impedance spectroscopy, and potentiodynamic polarization). The open circuit potential result shows that Ti-5Cu-15Nb is more unstable in the corrosive medium, while Ti-5Cu and Ti-5Cu-10Nb show the approximate same potential against

the SBF solution. Out of all four alloys, Ti-5Cu-10Nb shows better potential against the SBF.

9. The EIS test from the Bode plot and Nyquist plot of the alloys indicates that Ti-5Cu, Ti-5Cu-5Nb, and Ti-5Cu-10Nb have highly capacitive behaviour and formation of a highly stable oxide passive layer on the surface of the alloy in the solution.
10. From the bode plot in Fig. 5.2, the spectra profiles for Ti-5Cu and Ti-5Cu-5Nb almost touched. This behaviour indicates that the corrosion behaviour of these two alloys would not change even in lower pH solutions. However, the profile spectra of Ti-5Cu-15Nb are different and come in the lower phase angle. This indicates the less protective passive layer on the surface of the Ti-5Cu-15Nb.
11. The potentiodynamic polarization graph of anodic and cathodic slope using Tafel plot was used for the calculation of polarization parameters like corrosion potential (E_{corr}), corrosion current density (i_{corr}), breakdown potential, passive current density (i_{pp}), and re-passivation current density. The electrochemical technique of corrosion measurement shows that the corrosion rate of any metallic sample is directly proportional to the corrosion current density. Ti-5Cu-10Nb has lower corrosion current density than Ti-5Cu, Ti-5Cu-5Nb, and Ti-5Cu-15Nb, while Ti-5Cu-15Nb shows higher corrosion current density.
12. The corrosion resistance against the simulated body fluid of Ti-5Cu-10Nb is maximum while the minimum of Ti-5Cu-15Nb. The addition of 10 wt. % Nb enhances the corrosion resistance of the binary Ti-5Cu. It can depict from the result that the addition of further Nb to Ti-5Cu would decrease the corrosion resistance of the binary Ti-5Cu alloy.

13. The SEM and XPS analyses confirmed the electrochemical results, revealing that the passive layer is composed of TiO_2, Nb_2O_5, and CuO. And Ti-5Cu-10Nb is the most corrosion-resistant alloy in SBF.
14. The wear resistance of all four developed alloys is measured using the reciprocating ball-on-disk bio-tribometer against the zirconia ball at three different 10 N, 15 N, and 20 N in the same SBF solution. The coefficient of friction, wear volume, wear rate, and wear mechanism are compared with different loading conditions.
15. At 10 N load, in reciprocating condition shows that Ti-5Cu-5Nb attains minimum cof, while Ti-5Cu-10Nb maximum cof. Consequently, Ti-5Cu-10Nb attains a maximum and Ti-5Cu minimum wear rate. The SEM and EDS result shows that the worn surface contains Ti, Cu, and Nb oxide. The adhesion and abrasion wear mechanism was the leading cause of the surface degradation of the alloys.
16. At 15 N load, in reciprocating condition shows that Ti-5Cu-5Nb attains minimum cof, while Ti-5Cu-10Nb maximum cof. Consequently, Ti-5Cu-10Nb attains maximum and Ti-5Cu minimum wear rate. SEM and EDS result shows that the worn surface contains an oxide of Ti, Cu, and Nb. The adhesion, abrasion, oxidation, and delamination wear mechanism were the leading cause of the surface degradation of the alloys.
17. At 20 N load, in reciprocating condition shows that Ti-5Cu-5Nb attains minimum cof, while Ti-5Cu-15Nb maximum cof. Consequently, Ti-5Cu-15Nb attains maximum and Ti-5Cu minimum wear rate. SEM and EDS result shows that the worn surface contains an oxide of Ti, Cu, and Nb. The adhesion, abrasion, oxidation, and delamination wear mechanism were the leading cause of the surface degradation of the alloys.
18. With increasing 5 wt. % Nb to Ti-5Cu decreases the cof value at all three-loading conditions, while the addition of more Nb to Ti-5Cu increases the cof. Additionally, the wear rate and wear volume of the developed alloys increases with the addition of Nb to

Ti-5Cu. The point of contact of the hard zirconia ball on the surface of developed alloys causes the maximum Hertzian contact pressure, which results in maximum wear rate and wear volume.

19. The antibacterial properties of the developed alloys were studied by the plate count method. The result of the antibacterial test of all four alloys shows that the presence of copper in the alloys prevents the accumulation of both S. aureus. and E. coli. bacteria compared to the control (CP-Ti) and negative sample. The presence of Nb in Ti-5Cu-5Nb, Ti-5Cu-10Nb, and Ti-5Cu-15 Nb did not deteriorate the antibacterial property of Ti-5Cu.
20. The cell adhesion, proliferation, and viability of all four developed alloys are studied with MG-63 (human bone osteosarcoma) cells for 3. 5, and 7 days. The morphology of the accumulation of the cells after 3 days of culture on the developed alloys shows that the addition of Nb increases the bioactivity and cytocompatibility of the binary Ti-5Cu alloy.

Future Scope of the present investigation:

The development of novel metallic implants is need of the present biomedical industry. The increasing population and infrastructure lead to the increment of accidents. The replacement of the natural bone with an artificially developed implant became necessary for the proper functioning of the human body. The recent use of SS 316L, CP-Ti, and Ti-6Al-4V causes many problems in the human body in long-run applications. The present study is a normal approach for getting novel titanium alloys using copper and niobium. The results of the present investigation show that all four Ti-5Cu, Ti-5Cu-5Nb, Ti-5Cu-10Nb, and Ti-5Cu-15Nb could be used for biomedical applications after future study:

1. In the present investigation, varying weight percentages of Nb were alloyed to study the effect of Nb on Ti-5Cu. Further, we can investigate the effect of increasing wt. %

of copper to the alloys for microstructural, mechanical, corrosion, wear, and cytocompatibility properties of the alloys.

2. The mathematical simulation of the mechanical, corrosion, and wear behaviour of the developed alloys can be studied for investigation of properties.
3. The in-vivo study of the presently developed alloys can also be investigated for further confirmation and changes of properties with living cells and tissues.
4. The corrosion and wear resistance of the developed alloys can also be investigated by changing the pH value of the simulated body fluid solution.
5. The elastic modulus of the developed alloys can also be investigated by tensile test.