Chapter 8

MAJOR CONCLUSIONS

The present study designs and develops three novel HEAs for biomedical applications. The selected HEAs, i.e., Ti-$Co_{0.35}$-$Cr_{0.35}$-Nb-Zr, Ti-Nb-Ta-Cr-$Co_{0.2}$, and Ti-Nb-Ta-$Fe_{0.35}$-$Co_{0.35}$ (at. %) have been synthesized using mechanical alloying followed by spark plasma/muffle furnace sintering. This chapter makes a list of the major conclusions based on the results and discussion of the different analyses, such as microstructure, phase stability, mechanical and physical properties, cytocompatibility, corrosion, and wear behaviour of the developed HEAs. The major conclusions of the present study are given as follows:

1. The semi-empirical thermodynamic parameters (such as $\triangle S_{mix}$, δ, $\triangle H_{mix}$, and Ω) for the selected composition of the developed HEAs were found to be within the range for solid solution formation. The calculated VEC values of the developed HEAs suggest a high probability of the BCC phase.

2. Ti-$Co_{0.35}$-$Cr_{0.35}$-Nb-Zr HEA powder resulted in the single-phase BCC structure (a = 3.309 ± 0.03 Å) with minor undissolved Zr after 50 h of alloying.

3. Ti-Nb-Ta-Cr-$Co_{0.2}$ HEA powder up to 50 h of MA resulted in two distinct BCC phases, i.e. BCC1 (a = 3.307 ± 0.005 Å) and BCC2 (a = 2.882 ± 0.003 Å).

4. Ti-Nb-Ta-$Fe_{0.35}$-$Co_{0.35}$ HEA powder resulted in a monophasic BCC structure (3.305 ± 0.007 Å) after 50 h of alloying.

5. Differential scanning calorimetry thermogram of 50 h alloyed powders reveals a phase transformation. For Ti-$Co_{0.35}$-$Cr_{0.35}$-Nb-Zr HEA it is at ~821 °C, for Ti-Nb-Ta-Cr-$Co_{0.2}$ HEA it is ~862 °C and for Ti-Nb-Ta-$Fe_{0.35}$-$Co_{0.35}$ HEA it is ~812 °C. Thus,

it transformed into BCC and HCP phases after sintering at 950 and 1000 °C for better densification and strength.

6. Muffle furnace sintered sample shows high porosity (~12 %), whereas SPSed samples showed lesser porosity (~3 %). The lesser porosity is attributed to the ionization of the particles by localized sparking during the SPS processes.

7. The hardness and compressive strength of the sintered HEAs are higher than those of conventional implant materials due to the solid-solution strengthening effect during the alloying process.

8. The lower Young's modulus of the developed HEAs may be helpful in mitigating the effect of stress shielding.

9. The developed HEAs show high corrosion resistance and lower corrosion rate than the Ti-6Al-4V alloy in SBF. The oxide layers present on the surface act as a barrier, protecting the material from corrosion and thus making it more corrosion-resistant. Among all the three HEAs, Ti-Nb-Ta-Cr-$Co_{0.2}$ exhibits the highest corrosion resistance and lowest corrosion rate.

10. Double protective layers were formed on the surface during corrosion in SBF. The inner barrier layer is stronger than the outer porous layer.

11. The corroded surface of the HEAs reveals nano-sized pits with smaller in numbers, whereas Ti-6Al-4V shows larger pits with more significant in numbers, suggesting a pitting corrosion mechanism.

12. With an increase in load, the friction coefficient of the wear samples decreases while the wear volume and rate increases in the presence of SBF.

13. Ti-6Al-4V exhibited the minimum coefficient of friction but showed the maximum wear volume. In addition to the friction coefficient, the hardness of the sample is crucial for wear resistance.

14. The developed HEAs show a lower wear rate than the Ti-6Al-4V alloy. Among all the three HEAs, Ti-Nb-Ta-Cr-$Co_{0.2}$ exhibits the minimum wear rate.

15. The adhesion, oxidation, abrasion, delamination, and wear debris mechanisms are the leading causes of the surface degradation of the present HEAs.

16. Cells on sintered HEAs revealed better spreading than those on cp-Ti after 2, 4, and 6 days of culturing.

17. The optical density values for sintered HEA and cp-Ti reveal a trend of initial increase and subsequently decreasing with an extended incubation period, due to limited nutrients and space. Initial increasing trend of optical density indicates the cell's adaptation to the surroundings.

18. The cell viability greater than 90 % after 2, 4, and 6 days of incubation, reveals the non-toxicity of the developed HEAs.

19. Based on the structural, mechanical, corrosion, wear, and cytocompatibility properties it may be suggested that the developed HEAs can potentially be used as hard tissue replacements.