ABSTRACT

The ever-increasing demands for better efficiency and enhanced mechanical performance act as the drive for continuous research in the aerospace industry for appropriate materials. In this regard, Titanium alloys have gained significant attention for their exceptionally high specific strength, improved fatigue, creep as well as corrosion resistances, etc. A β-grade alloy, Ti-5Al-5V-5Mo-3Cr (Ti-5553), possessing adequate strength, ductility and toughness is an ideal candidate for landing gear and heavy structural components of aircraft. For successful utilisation of the alloy and for enhancing its performance further, it is crucial to develop a thorough insight on the processing-structure-property correlation for this alloy. In the present work, Ti-5553 alloy is produced by vacuum arc re-melting process. Microstructural characterization reveals the presence of very coarse β grains with morphologies varying from columnar to equiaxed at the edge to the center of the as-cast Ti-5553 pancake. To modify the microstructure and mechanical performance, two distinct thermomechanical processing schedules (*TMP-I* and *TMP-II*) are applied to as-cast Ti-5553 alloy pancakes. While *TMP-I* applies 40% thickness reduction via forging, *TMP-II* employs rolling with 20% thickness reduction, the rest of the steps for respective *TMP*s, remaining same. Typical bimodal microstructures with nearly similar sizes, distributions, and morphologies for the primary α_p grains and colonies of secondary α_s and β are generated in Ti-5553 alloy, subjected to either *TMP-I* or *TMP-II*. Interestingly, improved localized hardness values with respect to as-cast alloy are obtained for bimodal microstructure generated through either of the *TMP* schedules, *TMP-II* being more economic approach. Nevertheless, indentation size effect is noted to be nominally lower for the rolled alloy (*TMP-II*), thereby proving its suitability for large-scale application. Global behavior assessed through tensile tests also shows that bimodal microstructures obtained through *TMP-I* or *TMP-II*, yield higher strengths, toughness and ductility, as compared to the respective as-cast counterparts. The study therefore identifies *TMP-II* as the optimized and economically favorable processing schedule for Ti-5553 alloy to generate the targeted bimodal microstructure, offering the best combination of properties. The significant benefit of this approach thrives on rolling the alloy for only half the extent of that used for forging.

To progress a step forward, room temperature small-scale creep behavior of as-cast and optimally *TMP*ed (i.e. *TMP-II*) Ti-5553 alloys is investigated using nanoindentation technique. The effect of maximum load on different creep parameters is analyzed and correlated with the corresponding microstructures. It is noted that as the applied load levels vary from 10 mN to

100 mN, creep displacement of *TMP*ed Ti-5553 alloy is lower by ~ 20-64 % respectively, than that for the as-cast one. This is reflected in attaining significant reduction in the minimum creep strain rate from a value of 10^{-4} s^{-1} for as-cast to 10^{-5} s^{-1} for *TMP*ed Ti-5553 alloy.

Additionally, a systematic investigation is pursued to generate insights about the microstructural evolution and corresponding modification in local and global mechanical performance for as-cast Ti-5553 alloy, subjected to different extents of cold rolling. The thickness reduction is varied from 5% up to a maximum of 20%. It is observed that different deformation mechanisms get activated in the Ti-5553 alloy with increase in the thickness reduction. While the alloy subjected to the lowest degree of thickness reduction, deforms mainly via slip, that with the highest degree of rolling deforms through formation of parallel slip lines, zigzag slip lines, and deformation bands. Overall, activation of specific twins such as $\{332\} \langle 113 \rangle_{\beta}$ along the closed packed direction of the *β* matrix is noted for the optimally cold rolled alloys. Most interestingly, occurrence of stress-induced martensitic phase is also confirmed for all the cold rolled alloys with its volume percentage being directly proportional to the degree of deformation. This cold rolling imparted microstructural modifications also positively influence the local and global mechanical performance of Ti-5553 alloy. Highest values of hardness and compressive yield strength are noted for the Ti-5553 alloy, cold rolled up to the highest extent. A correlation between the hardness and strength of the alloy is also drawn.

Nevertheless, to expand the utilisation of Ti-5553 alloy in the chemical, marine and also aerospace industries, where the alloy needs to survive the harsh environments, it is essential to understand its corrosion resistance beyond its fundamental mechanical attributes. Accordingly, potentiodynamic polarization and electrochemical impedance spectroscopy tests along with post-corrosion investigations are performed on the as-cast and optimally *TMP*ed Ti-5553 alloys having coarse equiaxed β grains and bimodal microstructure, respectively, at *RT* and 50 °C. The polarization curves obtained for the as-cast and *TMP*ed Ti-5553 alloys at *RT* condition display similar shapes, suggesting the occurrence of specific electrochemical reactions. As-cast Ti-5553 alloy does not show a prominent breakdown of passive film during potentiodynamic polarization at *RT*. In contrast, the passive film on the *TMP*ed Ti-5553 alloy at *RT* is observed to break but re-heal and maintain steady re-passivation behavior due to degradation and reformation of the oxide film. However, as the solution temperature increases to 50 °C, the *TMP*ed Ti-5553 alloy exhibits passive film breakdown behavior, leading to a significant increase in the current density. This phenomenon is attributed to the presence of both *α* and *β* phases in the bimodal structure, where *α/β* interfaces act as galvanic coupling sites, enhancing

selective dissolution of the α phase. Nevertheless, unlike the mechanical properties, *TMP*ed alloy exhibits poor corrosion resistance as compared to the as-cast Ti-5553 alloy. Hence, this study suggests that it is crucial to tailor the microstructure according to the specific application demands in different industries. For instance, in the aerospace sector, for structural applications, where mechanical performance of the alloy is pivotal, the *TMP*ed or cold-rolled Ti-5553 alloy with bimodal or martensitic microstructure, respectively, could prove to be an optimal selection. On the other hand, single β-phase Ti-5553 as-cast alloy must be preferred in chemical and marine industries or even for specific aerospace applications, where corrosion resistance is of paramount importance. Overall, these findings depict the importance of tailored microstructure based on precise industrial requirements, emphasizing the intricate interplay between microstructure, phase contents, and desired performance characteristics.

Keywords: *Thermomechanical processing*; *Ti-5553 alloy*; *Bimodal microstructure*; *creep resistance*; *stress-induced martensite transformation*; *potentiodynamic polarization*; *electrochemical impedance spectroscopy*.