Characterization of fully lamellar Ti6Al-4V alloy

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Abstract. The high mechanical strength of the lamellar Ti6Al-4V extruded rod was characterized. The grain morphology of the extruded Ti-6Al-4V rod was investigated by optical microscopy. The microstructure of Ti-6Al-4V alloy consists of very fine α lamella of approximately 2.5 µm in thickness and β lamella with 1 µm thickness. Besides, a numerical model has been presented that reproduces the morphology of the lamellar colonies. In particular, the representative volume element with 512 elements, 4096 elements and, 32768 elements are studied with the C3D8 linear element. Experimental and numerical comparisons of the lamellae morphology have been presented.

1. Introduction
Titanium and its alloys are used in the automotive industry due to its high strength to weight ratio. Because of its high corrosion resistance, a good weldability and the possibility to alter the mechanical properties, the Ti64 alloys are most commonly used [1], [2]. Titanium has a hexagonal close-packed (hcp) crystal structure at room temperature, which is termed as α phase. At temperature 883°C, hcp structure has been transformed to a body-centered cubic (bcc) crystal structure, called beta phase [2], [3]. The (α+β) titanium alloy at room temperature consists of hcp α phase and body-centered cubic β phase. The transformation of α phase into β phase can be observed with increase in temperature of about 995°C. Hence the whole microstructure consists of the high temperature β phase. With the increase in temperature, α phase transforms into β phase at 995°C. By slow cooling from the β phase (starting from above β transus temperature) the lamellar microstructures can be obtained [4], [5]. The titanium alloys with lamellar microstructure consists of α colonies with different crystal orientations. The lamellae of α inside each colony will have the same crystal orientation [4].

In general, micro structural features such as lamellae orientation, lamellae thickness, colony size and the orientation of colonies with respect to loading direction will influence the mechanical properties. In the present work, the material characterization has been performed by choosing experiments (micro structural investigations) and numerical studies for lamellar Ti-6Al-4V alloy. Numerical modelling is a powerful tool for examining the deformation behaviour at local and global level. In order to represent the lamellar microstructure and to capture the important phenomena that a material undergoes during external loading, a multiscale description is required (figure 1). At micro level, the deformation mechanism (plasticity effects from dislocation slip) of lamellae can be modelled by the crystal plasticity material model. The effective global deformation behaviour of the material can be modelled by numerical homogenization at meso and macro level. In Titanium and its alloys, inelastic deformation depended on the orientation of each grain/lamellae etc. Because of low symmetry, the hcp materials show complex modes of deformation. In the current work, experimental
investigations of lamellar microstructure has been presented and the lamellar morphology inside the grain has been modelled using finite element simulations.

2. Microstructural characterisation
In the current work, Ti-6Al-4V has been received in the billet form with a chemical composition Ti-6.1Al-3.86V (in mass %). The samples are cut from the billet and they are metallographically prepared for the microstructure investigations [6]. The specimens were mounted in an epoxy resin, ground, polished and etched to reveal dual-phase lamellar microstructure. Surface prepared samples are visualized in the optical microscopy for the microstructure analysis. The grain morphology and the lamellae thickness are investigated quantitatively using the ImageJ software [7].

3. Finite element model
The numerical finite element model has been implemented with three-dimensional geometry using 8 node linear brick elements (C3D8). At integration point, the Titanium single crystal material model has been implemented for a single grain. The dislocation slip is considered as the basic deformation mechanism for permanent deformation. More information about the crystal plasticity model has been given in [8, 9, 10]. The finite element simulations have been performed for single grain with randomly oriented lamellae. Numerical simulations are performed for 512 elements, 4096 elements and 32768 elements. The mesh convergence has been observed for 32768 elements.

4. Results and discussion
It is observed that the initial structure of extruded Ti-6Al-4V rod consists of fully lamellar microstructure. A mean colony size of approximately 60 µm was obtained. It is observed that the colonies are randomly oriented in the radial direction, while in the extrusion direction the colonies are aligned parallel to the extrusion direction. Figure 2 presents the microstructure of Ti-6Al-4V obtained in the radial direction. The lamellar microstructure composed of α lamellae with an average lamella thickness of ~2.5 µm and thin β lamellae with an average thickness of ~1 µm. Similarly, figure 3 represents the microstructure of Ti-6Al-4V alloy in the extrusion direction. Alpha (α) lamella is the lighter phase and the beta (β) lamella is the darker phase.
Figure 2: (A and B) Typical optical image of lamellar structure Ti-6Al-4V alloy in radial direction.

Figure 3: (A and B) Optical micrographs of the lamellar structure of Ti-6Al-4V alloy in the extrusion direction.

In the case of finite element model, the measured lamella thickness of α and β phase has been implemented inside the grain. The α/β interface normal has been generated inside the grain with a random orientation. The distance vector has been measured between the Voronoi point and the integration point. The distance vector has been projected on the interface normal to compute the thickness of the lamellae. Using the thickness measurement, the alternating layers of α and β phases have been constructed [9]. Finite element simulation results are presented for 32768 linear elements. The bi-lamellar microstructure of Ti-6Al-4V with random orientation is shown in figure 4.
5. Summary and outlook
The characterisation of lamellar microstructure has been presented for Ti-6Al-4V. The experimental investigations reveal that the colonies are randomly oriented in the radial direction while in the extrusion direction the colonies are aligned parallel to the extrusion direction. It is observed that the microstructure consists of coarser $\alpha$ lamellae ($\sim 2.5 \ \mu m$) and fine $\beta$ lamellae ($\sim 1 \ \mu m$). The lamellar morphology for a single grain has been reproduced using finite element simulations. The mesh convergence has been observed with 32768 elements.

To investigate the effect of lamellar morphology on polycrystalline Ti-6Al-4V alloy, experimental and numerical studies of mechanical stress-strain behaviour will be performed to study the interaction between the lamellae and grain with the goal to identify texture evolution.

6. References

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