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Texture studies of hot compressed near alpha titanium alloy (IMI 834) at 1000°C with different strain rates

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Abstract. IMI 834 Titanium alloy is a near alpha (hcp) titanium alloy used for high temperature applications with the service temperature up to 600^{0}C. Generally, this alloy is widely used in gas turbine engine applications such as low pressure compressor discs. For these applications, good fatigue and creep properties are required, which have been noticed better in a bimodal microstructure, containing 15-20% volume fraction of primary alpha grains (α_p) and remaining bcc beta (β) grains transformed secondary alpha laths (α_s). The bimodal microstructure is achieved during processing of IMI 834 in the high temperature α+β region. The major issue of bimodal IMI 834 during utilization is its poor dwell fatigue life time caused by textured macrozones. Textured macrozone is the spatial accumulation of similar oriented grains in the microstructure generated during hot processing in the high temperature α+β region. Textured macrozone can be mitigated by controlling the hot deformation with certain strain rate under stable plastic conditions having β grains undergoing dynamic recrystallization. Hence, a comprehensive study is required to understand the deformation behavior of α and β grains at different strain rates in that region. Hot compression tests up to 50% strain of the samples are performed with five different strain rates i.e. 10^{-3} s^{-1}, 10^{-2} s^{-1}, 10^{-1} s^{-1}, 1 s^{-1} and 10 s^{-1} at 1000^{0}C using Gleeble 3800. The resultant bimodal microstructure and the texture studies of primary alpha grains (α_p) and secondary alpha laths (α_s) are carried out using scanning electron microscopy (SEM)-electron back scattered diffraction (EBSD) method.

1. Introduction

IMI 834 Ti alloy with bimodal microstructure is suggested having better creep and fatigue properties [1] for service temperature up to 600^{0}C. Bimodal microstructure consists of equiaxed primary alpha (α_p) grains and secondary alpha laths (α_s) which are transformed from high temperature β grains upon cooling. Such a microstructure is only possible with an appropriate thermomechanical treatment in the α+β field followed by cooling. The final properties of the products are mainly dependent on the microstructure and texture evolution during plastic deformation at higher temperature. But there is limited literature available on the crystallographic texture evolution during hot deformation.

Therefore the present study concentrates on the evolution of microstructure and texture during hot compression tests of IMI 834 near alpha titanium alloy at 1000^{0}C at five different strain rates such as 10^{-3} s^{-1}, 10^{-2} s^{-1}, 10^{-1} s^{-1}, 1 s^{-1} and 10 s^{-1}. The microtexture have been investigated by using electron backscattered diffraction (EBSD) in a field emission scanning electron microscope. EBSD micro texture analysis through studies of orientations and misorientations of grain boundaries is a more powerful method to investigate the microstructure evolution of deformed materials [2] and to understand the deformation mechanisms [3-4]. The aim of the present study is to separate the primary alpha grains (α_p) from secondary alpha (α_s) laths in the orientation map for analyzing the deformation texture in primary alpha grains by using TSL software.

2. Experimental details

IMI 834 Ti alloy, was received as pancake (250 mm diameter, 12 mm height) from DMRL, Hyderabad. The pancake was cut into cylinders of 10 mm diameter and 12 mm height to maintain an aspect ratio of 1.2 by electrodischarge machining. These cylinders are chamfered to avoid folding during initial stage of testing. Hot compression tests were performed to in a Gleeble 3800 testing maschine. Thermo mechanical simulator at IIT Roorkee at a deformation temperature of 1000^0C with different strain rates such as 10^{-3} s^{-1}, 10^{-2} s^{-1}, 10^{-1} s^{-1}, 1 s^{-1} and 10 s^{-1} with their flow stress-strain captured during the test. Heating rate is maintained at 5^0C/s with further holding time of 5 min at the deformation temperature of 1000^0C during hot compression tests. After reaching 50% reduction in height of the specimens, the deformed samples are rapidly quenched by water spraying facility in Gleeble 3800. For microstructure characterization, the hot compressed specimens are cut parallel to the compression axis. In order to achieve the surface quality required for EBSD examinations, electro polishing is performed at 18 V and 5^0C in an electrolytic solution consisting of 600 ml methanol, 300 ml butyl alcohol and 100 ml perchloric acid. The prepared samples are probed with a FEG-SEM (Carl-Zeiss, Model number: Supra 40) operating at 20 kV and equipped with an EBSD orientation imaging system. Microstructures are taken at the center of the compression specimen with step size of 0.4 µm. The collected data are analyzed by using TSL (Tex Sem Laboratory) –OIM software.

3. Results and discussion

The orientation (EBSD) map of the separated primary alpha grains in the as-received material IMI 834 Ti alloy is shown in Fig. 1 (a). It should be noted that the as-received material consists of equiaxed primary alpha grains and secondary alpha laths. Both primary alpha and secondary alpha colonies having same crystal structure (hcp) but the morphology of primary alpha grains is equiaxed and secondary alpha grains is lath type. Primary alpha grains and secondary alpha grains were distinguished by using grain mode option in OIM analysis software. The largest grains observed in the inverse pole figure map (IPF) are primary alpha (α_p) and all small grains are associated with secondary alpha (α_s) lamellae.

The volume fraction of primary alpha grains observed in as-received sample is 45%. The average grain size of the equiaxed primary alpha grain size (α_p) is 20 µm, calculated by using grain size intercept length method. After 50% deformation at 1000°c with strain rates of 10^{-3} s^{-1}, 10^{-2} s^{-1}, 10^{-1} s^{-1}, 1 s^{-1} and 10 s^{-1} the observed orientation maps displayed deformed and fragmented primary alpha grains; as shown in Fig. 1. (b-f). The volume fraction and grain size of primary alpha grains in Fig. 1 (b-f) are 6.5% with 6.6 µm, 17.4 % with 8 µm, 26.2% with 10.7 µm, 19.5% with 8.4 µm and 27.6% with 8.3 µm respectively.

The pole figures and inverse pole figures of primary alpha grains in as received IMI 834 Ti alloy and hot deformed specimens are given in Fig 2. (a-f). A strong basal texture in the as-received material perpendicular to the CD-RD plane is noticed. In case of deformation conditions texture varies significantly with strain rate.

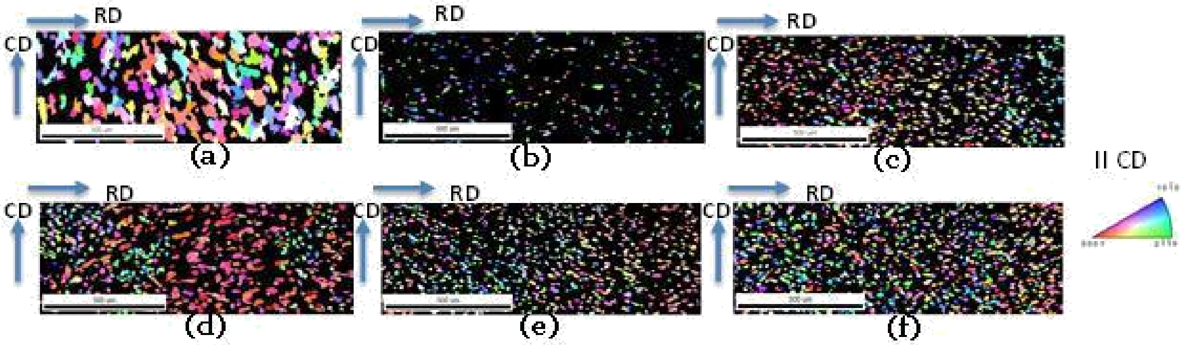


Figure 1 EBSD Orientation maps of primary alpha grains: (a) as-received IMI 834 Ti alloy hot compressed at 1000^0c with (b) 10^{-3} s^{-1} strain rate (c) 10^{-2} s^{-1} strain rate (d) 10^{-1} s^{-1} strain rate (e) 1 s^{-1} strain rate and (f) 10 s^{-1} strain rate.

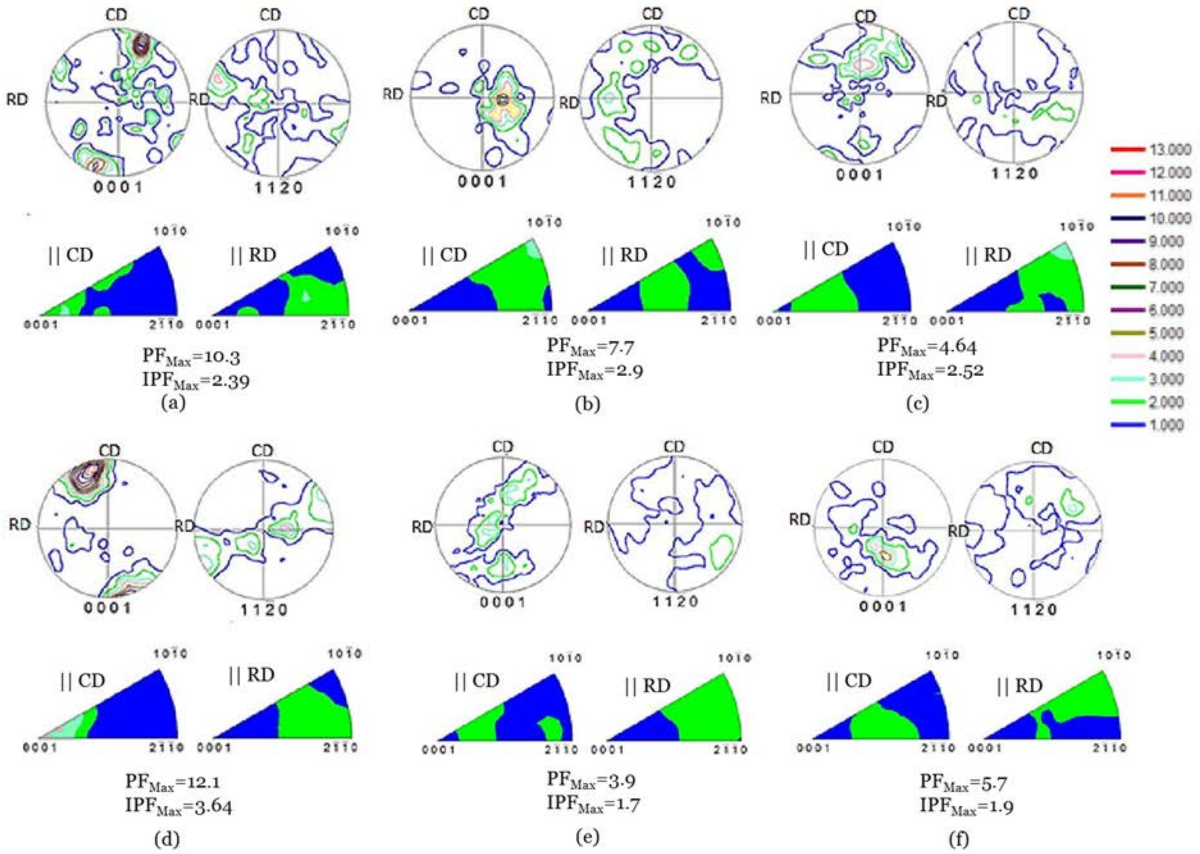


Figure 2 Pole figures and Inverse Pole figures of as-received and deformed samples: (a) as-received IMI 834 Ti alloy (b) 10^{-3} s^{-1} strain rate (c) 10^{-2} s^{-1} strain rate (d) 10^{-1} s^{-1} strain rate (e) 1 s^{-1} strain rate (f) 10 s^{-1} strain rate.

Figure 3 shows the Kernel average misorientation profile of the as-received and after hot deformation of IMI 834 titanium alloy. It clearly reveals that with increased strain rate the dislocations generate more misorientation inside the grains which ultimately aid in fragmentation of the α_p grains. Fig 4. shows number fraction of Schmid factor of various possible hcp slip systems in as-received and deformed specimens. The basal slip remains nearly similar in all strain rates. In as-received material, pyramidal and first order pyramidal slip systems are more favorable. At low strain rate (10^{-3} s^{-1}), prismatic and pyramidal slip systems are more active. Strain rate 10^{-1} s^{-1} showed higher first and second order pyramidal slip systems. Different strain rates showed different slip systems which ultimately resulted into various α_p textures.

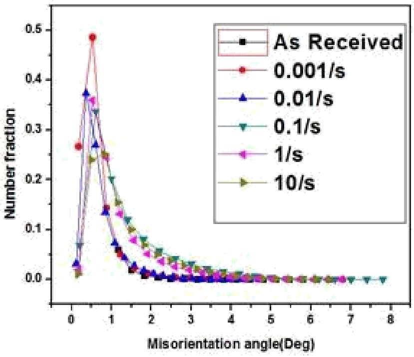
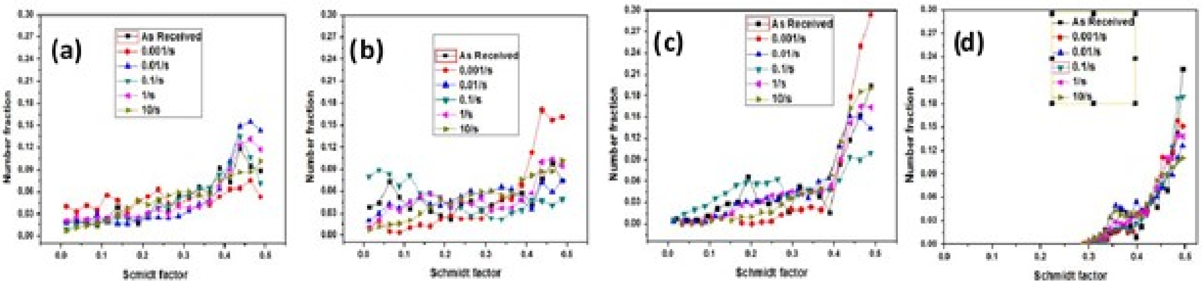


Figure 3 Kernel average misorientation profile of as-received and deformed IMI 834 Ti alloy.



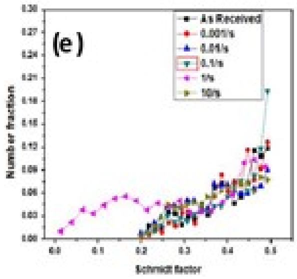


Figure.4 Number fraction of Schmidt factor of hcp slip systems before and after deformation: (a) basal slip {0001}<11-20> (b) prismatic slip {-1100}<11-20> (c) pyramidal slip {-1101}<11-20> (d) first order pyramidal slip {10-1-1}<11-23> and (e) second order pyramidal slip {11-2-2}<11-23>.

4. Conclusion

Volume fraction of primary alpha grains increases with increasing strain rate during hot deformation followed by water quenching. No twinning was observed in primary alpha grains after deformation but more fragmentation of primary alpha grains. The variety of textures during hot deformation at different strain rates suggests the activation of different slip systems which is confirmed from Schmid factor profiles of hcp slip systems.

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