Texture Evolution of Ti6Al4V during Cold Deformation

Gajanan Kulkarni, Vijay Hiwarkar, and Rajkumar Singh

***Abstract*—This research studies the effect of cold deformation on the texture evolution of Ti6Al4V alloy. To study this, Alloy is deformed at room temperature with low strain rate of 0.01 s-1 and increase in 5% stage of deformation. Flow curve and texture evolution were correlated with each other at each stage of deformation. Texture evolution was measured at each stage of deformation with the help of Electron Back-Scattered Diffraction (EBSD) technique. Grain fragmentation affects the texture pattern and texture intensity. EBSD mapping confirms the strong basal texture evolution and the effect of grain fragmentation on basal texture intensity during increasing deformation.**

***Index Terms*—Ti-6Al-4V, cold deformation, electron backscattered diffraction (EBSD), texture.**

I. Introduction

At room temperature, Titanium is the low stacking fault energy material with hexagonal close pack structure (HCP) [1]. Ti6Al4V is an alpha beta alloy, where Al acts as alpha stabilizer and V acts as beta stabilizer. Improved properties such as high strength to weight ratio, good fatigue properties and excellent corrosion resistance have made Ti6Al4V a leader in the manufacturing of aerospace components [2]. Strain rate and temperature affect the deformation behavior of Ti6Al4V [3]. At room temperature, volume fraction of alpha phase is more which influence the deformation behavior of Ti6Al4V [4]. Plastic deformation of alpha phase affects the texture evolution at room temperature [5]. In Ti6Al4V alloy, the plastic deformation mainly takes place by slip and twin activity [6]. Twinning promotes the plastic deformation of commercially pure titanium [7]. In Ti6Al4V, Twinning decreases with increasing high solute content and presence of Ti3Al precipitates [8], [9].

The texture formation during plastic deformation is mainly depends upon the processing route [10], [11] Alloying element such as hydrogen affect the deformation behavior of Ti6Al4V [12]. Grain size also affects the occurrence of deformation twinning [13]. It has been also observed that, textures are correlated with plasticity and flow stress behavior of material during deformation in hexagonal material, like titanium, where the basal texture causes the fracture [14]. S. Panda *et al.* observed during the tensile deformation of three (0°,45°,90°) different orientation samples that, strong basal texture causes high flow stress and low plasticity and weak basal texture shows low flow stress and high plasticity [15]. It is also found that, the increase in grain fragmentation also results in to change in texture behavior [16].

In the present study, the texture evolution of Ti6Al4V alloy during cold deformation process was investigated. Furthermore, effect of grain fragmentation on texture evolution was studied.

II. Experimental Procedure

In this study, Ø8 mm × 12 mm specimens were machined from Annealed Ti-6Al-4V bar. Sample machining direction was parallel to rolling direction. Chemical content of as received material is listed in Table. I. The cold compression test was done on servo hydraulics MTS machine 0.01 s-1 strain-rates. The samples were deformed with 5% deformation degree. Electrolyte containing 90% of methanol and 10% perchloric acid was used for polishing in EBSD technique. The electro-polishing was done at voltage of 26V for 10sec. The scanned area for EBSD was 300μm^2 and step size of 0.3μm.

TABLE I: Chemical Composition of the as Received Sample in wt%

Chemical elements	Al	V	Fe	O	C	N	Ti
Wt%	6.4	4	0.16	0.18	0.02	0.01	Balance

III. Result and Discussion

A. Stress Strain Curve

True stress strain curve was plotted during the cold deformation of the Ti6Al4V alloy. True stress strain curves and IPF map of as received material are shown in Fig. 1. The samples were cold deformed with 0.01 s-1 strain rate up to 30% deformation. It was observed that, as the deformation increases the flow stress increases. EBSD mapping shows that, as received sample of Ti6Al4V with average grain size is 10μ contains 86% of alpha phase and 14% beta phase. According to dislocation theory, as the plastic deformation increases the dislocations density increases, which results in flow stress increases with increase in deformation. At slower strain rate and at early stage of deformation, as the dislocation density is less. They can easily glide slip planes and does not get hindered by obstacles [17]. After progressive deformation, due to rapid multiplication of the dislocations flow stress increases [18].

B. Texture Evolution

Detailed EBSD mapping was undertaken in order to identify the microstructural features contributing to the

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significant changes taking place during compression testing. The EBSD maps of the as received and deformed samples are shown in Fig. 2. It was observed that, the darker regions increase with increasing deformation. Due to small grain size and presence of Aluminum, twins are not observed in the microstructure [19].

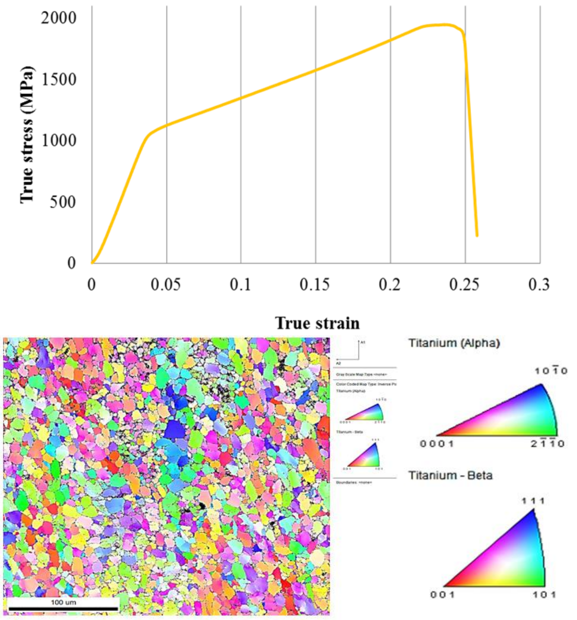


Fig. 1. a) Flow curve b) IPF map of Ti6Al4V alloy.

Kernel average misorientation (KAM) is defined as the average misorientation of the particular point with all its neighbors having maximum misorientation up to 5° [20]. Effect of plastic deformation on the KAM of the Ti6Al4V as received and deformed samples is shown in Fig. 3a) and Fig. 3b). KAM generally signifies the dislocation density distribution, strain introduction and stored energy inside the grain during processing [21]. It was observed that, as the deformation increases KAM increases. Increase in deformation results in volume fraction of grains having 5° misorientation angle. At 25% deformation, higher KAM results in higher volume fraction of grains are oriented to 5°misorintation angle. It signifies that, highest deformation is taking place at 25 % deformation. Average KAM value increases with increase in deformation. GOS (Grain orientation spread) indicates the misorientation between this average orientation and the orientation of each individual measurement point within the grain. GOS results are shown in Fig. 3c. GOS results follow same pattern as that of KAM results.

Effect of plastic deformation on the grain size and average grain size of the Ti6Al4V as received and deformed samples is shown in Fig. 3d). Grain size data was obtained from EBSD. It was observed that, average grain size and grain size reduces with increasing deformation. Volume fraction of small size grains increases with increase in deformation. At 25% deformation, high volume fractions of smaller grains are observed. It indicates that, grain refinement increases with increasing strain. As the twins were not observed in Microstructure, these results are only speculated in terms of dislocation activity in low stacking fault energy material. The process involves emission of partial dislocations from α/β interface. With increasing strain, these partial dislocations forms planar network by cross slip. The planar dislocation arrays separate the individual grains in to sub grains [22].

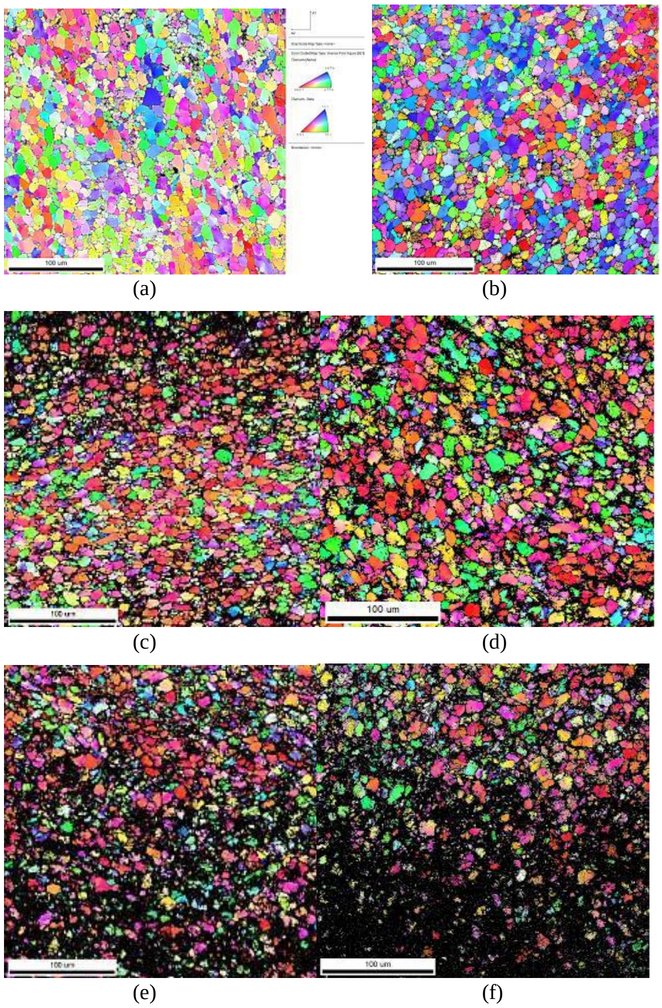
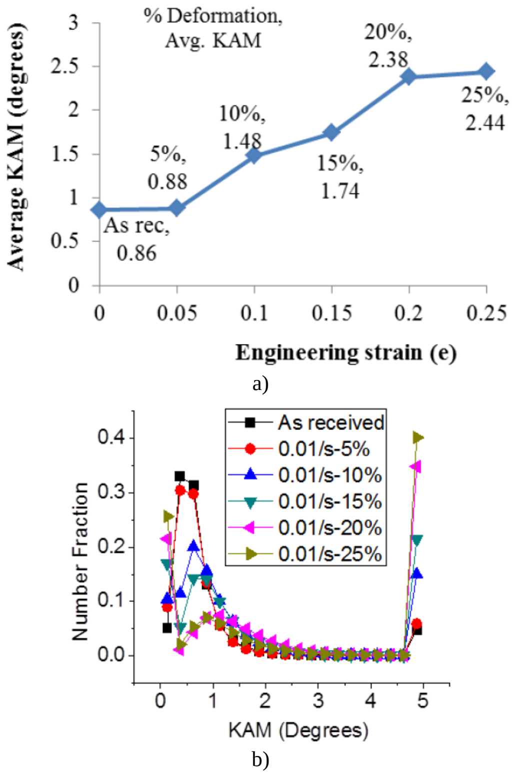
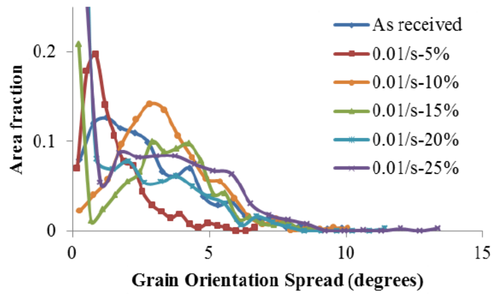
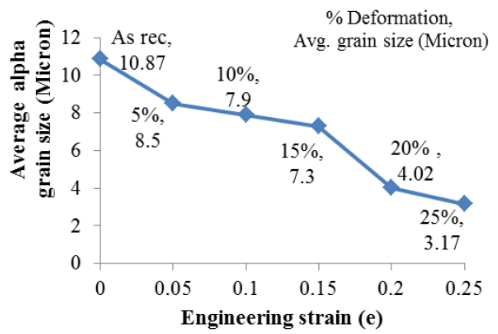


Fig. 2. EBSD (Inverse pole figure) maps of the as received and deformed samples, a) As received sample b) 5% deformed c) 10% deformed d) 15% deformed e) 20% deformed f) 25% deformed.





c)



d)

Fig. 3. a) Avg. KAM, b) KAM, c), GOS, d) Avg. grain size of deformed specimen.

Texture was correlated with flow stress and plasticity of the material during plastic deformation [23]. Effect of plastic deformation on the texture evolution of Ti6Al4V is shown in Fig. 4. Texture evolution was represented by IPF (Inverse Pole figures) showing the grain orientation distribution in the processed sample. This grain orientation distribution was measured by texture intensity. Effect of plastic deformation on the texture intensity is shown in Fig. 9. It was detected that, there was significant change in deformation texture with increase in deformation. During the deformation of Ti6Al4V with 0.01/s strain rate, the texture plays an important role. It was observed that, the texture intensity increases with increase in deformation. At 15% deformation, strong basal texture was observed. After 15% deformation, material exhibit weak basal texture. Texture intensity decreases. The grain fragmentation results in decrease of basal texture intensity. Grain fragmentation causes to change the grain orientation [24].

Rolling direction and deformation direction is in the longitudinal direction of the sample. At the early stage of deformation, complex texture was observed. As received sample of the Ti6Al4V, mainly shows the complex texture with intensity of 1.7. At 5% deformation, as deformation increases strain in the grains also increases which causes to rotate the grains in other direction to accommodate the plastic strain. This results in to texture change from complex texture to <10-10> with increase in intensity of 2.1. In earlier literature; it was observed that, the strong basal texture was observed with increase in deformation .At 10% deformation, texture intensity increases from 2.1 to 2.4 and the texture direction changes from <10-10> to <0001> direction and <2110> direction. <0001> is the basal texture. At 15% deformation, texture intensity reaches to peak intensity value of 3.1, which indicate that there is high strain in the grain. At 15% deformation, texture shift was observed in two directions. This change leads in to the building of maximum plastic strain in the grain. After progressive deformation, grain fragmentation was observed (Fig. 3d). Due to grain fragmentation, texture intensity decreases from 3.1 to 2.3 and basal texture was observed. When the texture was correlated with flow curve it was observed that, at 20% deformation flat curve was observed. This can be speculated in terms of the strain that, strain building in the grain decrease with deformation and there are chances of crack initiation in the sample due to localized deformation.

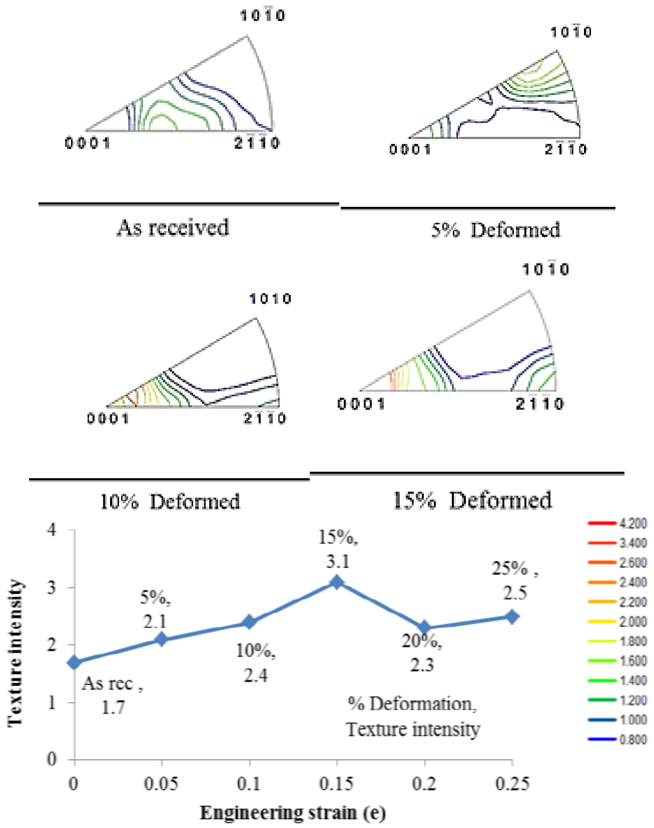


Fig. 4. Texture evolution and Texture intensity at each stage of deformation with 0.01/s strain rate.

IV. Conclusion

Effect of Cold deformation on Ti6Al4V with very slow strain rate of 0.01s-1 was studied and investigated. Electron backscatter diffraction (EBSD) Technique was used for the analysis of material deformation behavior and texture evolution. Flow stress increases with increase in deformation. Grain fragmentation was observed at higher strain. Cold deformation of Ti6Al4V results in Basal texture evolution. With increasing deformation up to 15% strain, the basal texture intensity increases. After that the grain fragmentation results in decrease in basal texture intensity.

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FUTURE WORK

In the future, more simulation works need to be carried out in order to understand the cold deformation behavior of Ti6Al4V deeper:

(1) Dislocation density during cold working of Ti6Al4V will be analyzed by TEM study

(2) To study the effect of dislocation gliding on different crystallographic plane for cold deformation.

(3) In order to predict the texture evolution of Ti6Al4V during cold deformation processes, FEM and Simulation has to be carried out.

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