Micro/Nanomechanics Mapping of Deformation Pattern of Lamellar of TiAl

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Summary

Detailed deformation pattern of lamella TiAl tension and bending specimens with and without a crack were measured by the micro/nanomechanics technique called SIEM (Speckle Interferometry with Electron Microscopy). The material had colonies (grains) of various sizes and mismatched lamellar orientations. We find that grain boundaries have higher stiffness than the interior region of the grains and they tend to deflect cracks. Multiple crack orientations along the lamella direction are developed from a single crack. These are the preferred propagation directions.

Introduction

Lamellar titanium-aluminum alloys have high stiffness, high density-normalized strength, and high fatigue resistance for temperature up to 1000℃ [1]. Thus it is an ideal material for high performance turbine engines [2]. The mechanical properties of the material are function of the grain size, lamella orientation, etc. There exist computational models based on crystal plasticity representing the material behavior under load. However there seems to be a lack of experimental verification of these models. Since the grains are micro sized with mismatched lamellar orientations, an experimental mechanics tool that is capable of full field measurement at a micro/nano scales is needed for the validation measurements. In this paper we introduce the SIEM (Speckle Interferometry with Electron Microscopy) [3][4] technique to map the full field deformation of TiAl specimens under uniaxial tension and bending with and without a crack. Deformation maps in terms of displacement and strain contours were obtained.

The Experimental Tool

The micro/nano experimental mechanics tool that we adopted for the task is called SIEM (Speckle Interferometry with Electron Microscopy). The basic principle of SIEM is described in the following.

A speckle pattern consisting of micro or nano sized random particles is first deposited onto the specimen surface which is to be loaded inside the chamber of a SEM (Scanning

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Electron Microscope). Load is applied to the specimen with the speckles following the deformation. The speckle patterns are digitally recorded sequentially and compared using a specially designed algorithm called CASI [5] as schematically shown in Fig. 1.

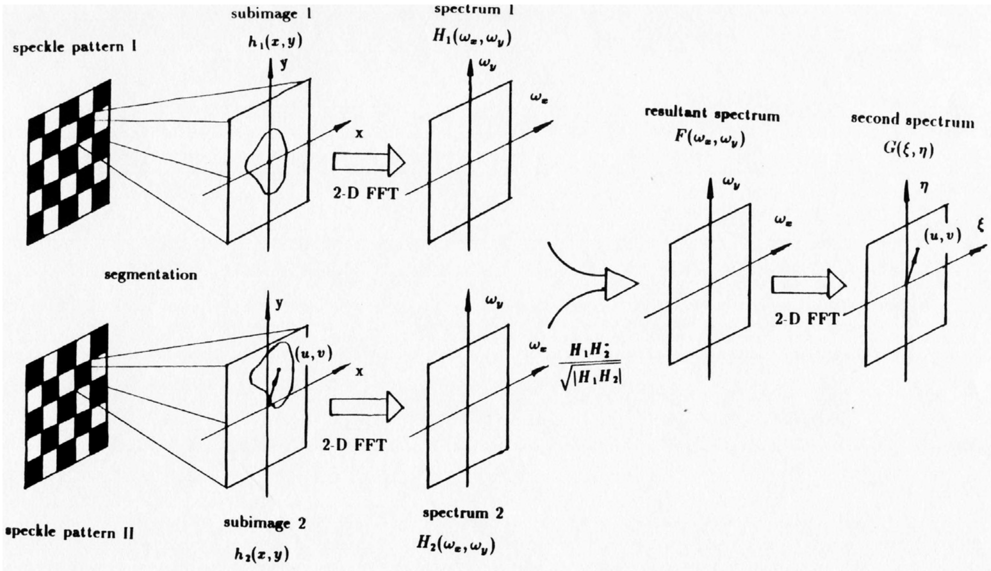
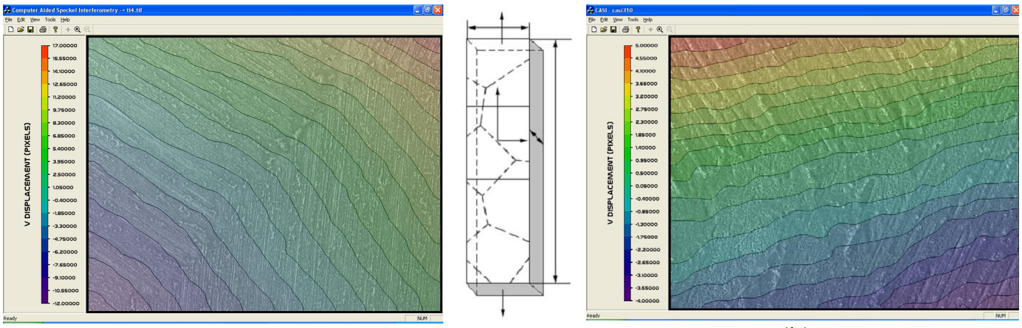


Fig. 1 Schematic of CASI for calculating displacement vectors

A pair of speckle patterns are divided into corresponding subimages of 32x32 pixels, for example, and processed using the CASI algorithm. The result is a distribution of displacement vectors (or displacement contours). Appropriate displacement strain relations are used for the calculation of the strain tensor distribution.

Deformation Map of Specimens Under Uniaxial Tension

Fig. 2 is the deformation pattern (v-displacement contours) of a simple coupon specimen under uniaxial tension. Fig. 2(a) shows the displacement contours bending along the boundary of two grains and Fig. 2(b) indicates that the grain boundary is stiffer than that of the interior region of the grains as evidenced by the fact that the contour spacings are coarser (the normal strain ε_{yy} is inversely proportional to the contour spacing).



(a) (b)

Fig. 2. v-field displacement contours of TiAl specimen under uniaxial tension

Another example of uniaxial tension is shown in Fig. 3 where the vertical displacement contours clearly indicate the existence of inter-colony shear at the grain boundary.

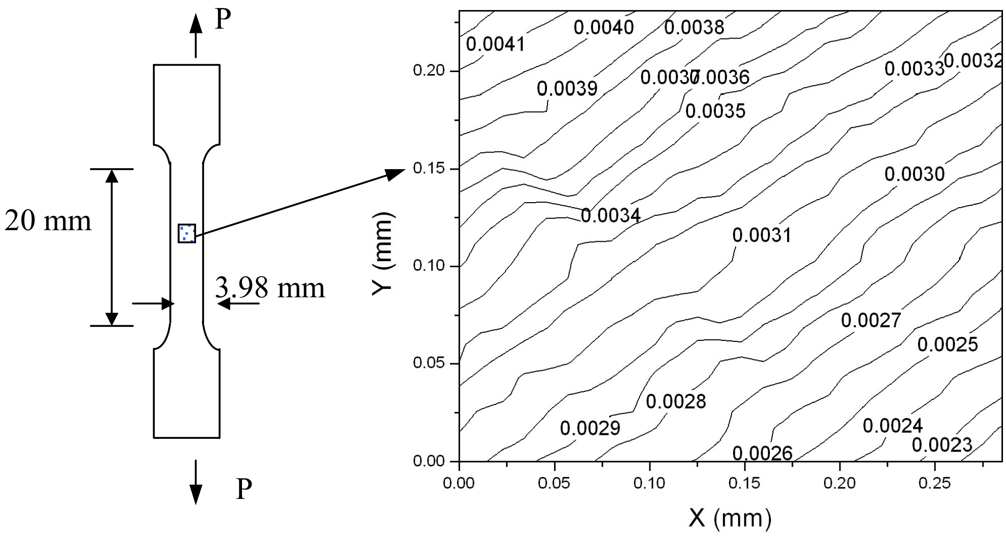
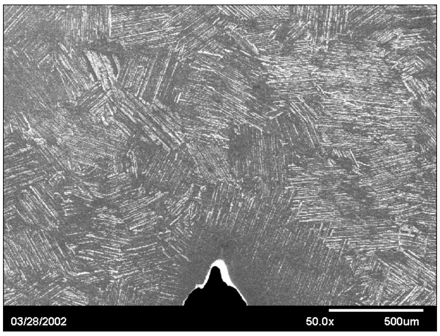


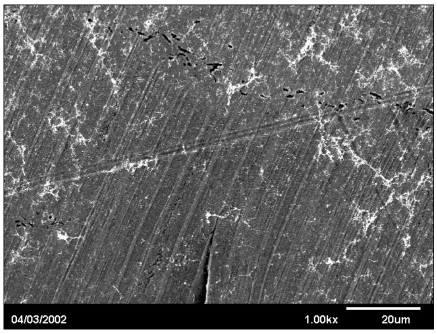
Fig. 3 v displacement field of a uniaxial loaded γ-TiAl specimen with a far field stress σ=310MPa. Each contour represents a 0.1 μm displacement increment. Displacement contours indicate the existence of inter-colony shear.

Deformation of TiAl Specimens with Cracks

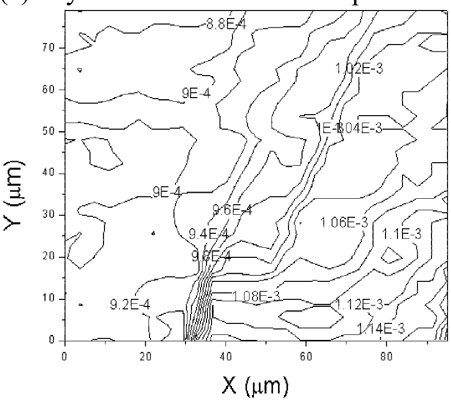
Fig. 4 shows the deformation pattern of a TiAl specimen with an edge notch under 3-point bending load. Fig. 4(a) depicts the various grains with mismatched lamella orientations. A fatigue crack was created at the notch tip as shown in Fig. 4(b). Under load the deformation pattern in terms of displacement contours are shown in Fig. 4(c) and 4(d) and the contours of opening strain ε_{xx} are exhibited in Fig. 4(e).



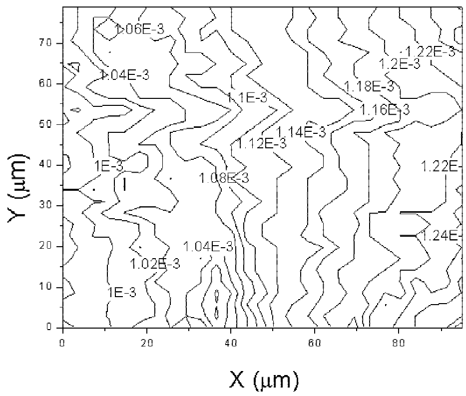
(a) Crystal orientations of the specimen



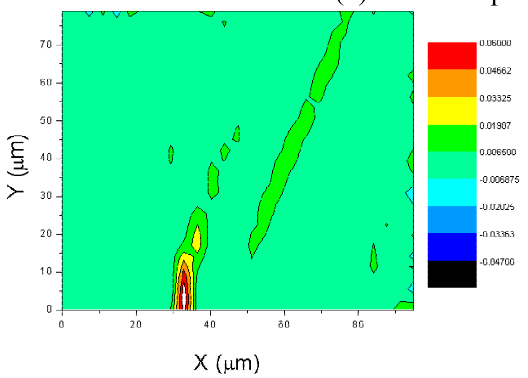
(b) Detailed view of the fatigue tip



(c) u-field displacement contour



(d) v-field displacement contour



(e) Horizontal strain field ε_{xx}

Fig. 4 A TiAl specimen with an edge crack under 3-point bending load

Another example is given in Fig. 5 where the picture depicts the deformation patterns of a late stage propagation of a single edge crack under steadily increasing uniaxial load. As can be inferred from the strain pattern shown in Fig. 4(d), multiple cracks would be created along the lamella orientation if the load were further increased and the picture shown in Fig. 5 is such a result. When the crack reaches the boundary of another grain that has a different lamellar orientation, it tends to be defected and then propagates along the new grain orientation as depicted in the figure.

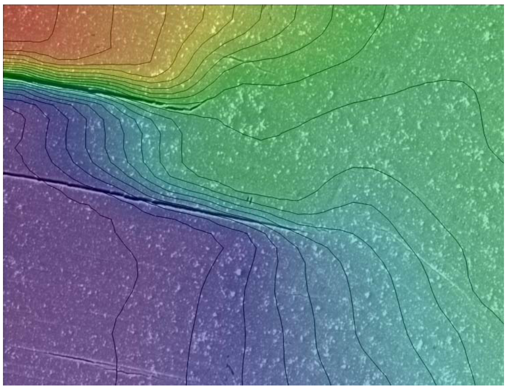


Fig. 5 vertical displacement contours indicating the deflection of the direction of crack propagation

Conclusion

We have successfully applied the micro/nano experimental mechanics technique SIEM to mapping the deformation pattern of TiAl specimens under tension/bending. Under uniaxial tension the deformation pattern is highly nonuniform. Displacement contours tend to bend along the grain boundaries. And there is evidence of inter-colony shear. When there is a single crack present, multiple cracks are generated along the lamella orientation as the load increases. The cracks tend to be deflected along the grain boundary. After crossing the boundary, the cracks resume propagation along the lamellar orientation of the new grains.

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