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AFM / SEM Backscattered Imaging of Slip Bands in Titanium

S. Okerstrom

Medtronic Inc., 7000 Central Ave. NE, Minneapolis, MN 55432

Fatigue crack initiation in titanium as a function of surface damage accumulation was the subject of this study. Titanium is commonly found in implantable medical devices. However, mechanical heart valve housings require a highly fatigue resistant grade of titanium. This demanding application is filled by grade 4 titanium. Grade 4 has higher concentrations of iron and oxygen than grades 1 – 3, which substantially increases the strength of the material. Pulsatile blood flow from each heartbeat causes a pyrolytic carbon coated disc to contact the valve housing support members seventy-two times per minute or about 38 million times per year. This makes the housing a candidate for high-cycle fatigue loading. A mechanical heart valve is pictured in Figure 1.

A model developed by Gerberich et al in 1998[1] determines the number of cycles to fatigue crack initiation (N_i), through measurements of surface plasticity in conjunction with the material's properties. The model was tested with respect to grade 4 titanium. It should also be noted that up to 0.5% iron is allowed in grade 4 of which 0.05% is soluble in the titanium. This creates a local saturated phase of about 10% iron. The iron rich areas are a potential concern as sites for crack initiation and propagation. The iron rich phase appears as white stringers in the SEM backscattered image in Figure 2.

Three protocols were used to fatigue grade 4 titanium test specimens in compression / tension, cantilever beam and pure bending regimes. The surfaces were examined periodically using scanning electron microscopy (SEM) secondary and backscattered electron imaging and atomic force microscopy (AFM) for slip band appearance. Backscattered electron imaging's deeper sample penetration highlighted slip band information not visible in secondary electron imaging. Areas of interest could later be found in the AFM to acquire quantitative slip band height and width measurements as shown in Figure 3.

Correlation of AFM slip band space and height measurements to the power log damage accumulation model [1] produced a reasonable fit. Thus, the model also appears applicable to grade 4 titanium. In addition, after examining the fatigue fractured samples near the fracture area and in the fracture face, the cracks do not start in the iron rich areas, nor do they affect propagation of the cracks. Therefore, the iron rich phase produced by iron saturation had no effect on crack initiation or propagation. [2]

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[1] Gerberich, W. W., Harvey, S.E., Kramer, D. E., and Hoehn, J. W., *Acta mater*, 1998, **46** (14), 5007

[2] Okerstrom, S. J., Masters Thesis, University of Minnesota, May 2000.

FIG. 1. Prosthetic Heart Valve

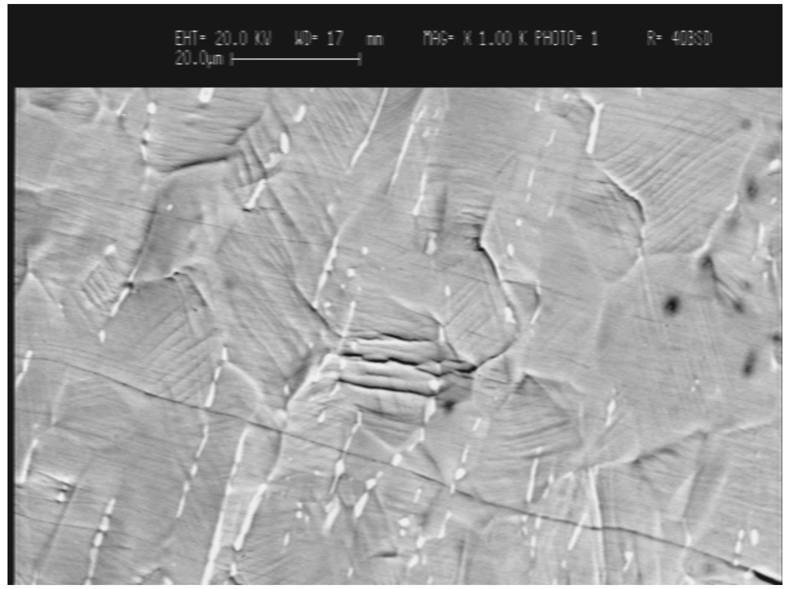

FIG. 2. SEM backscattered image of slip bands and iron saturation (white stringers) on a grade 4 titanium fatigue specimen surface.

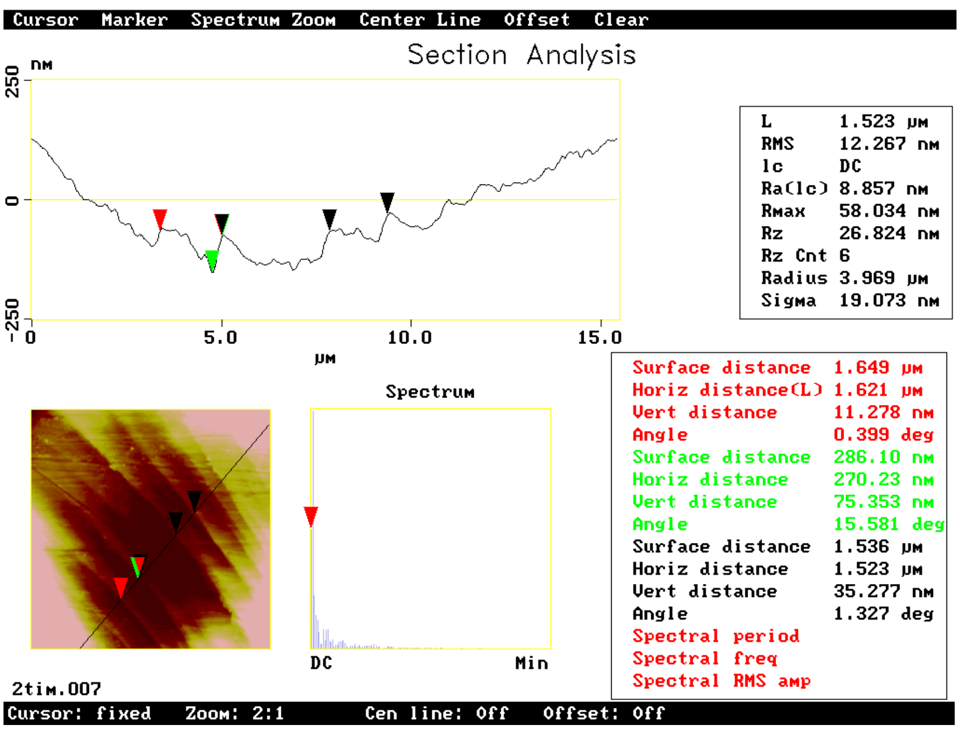

FIG. 3. AFM image of slip bands and cross-sectional view with height and width measurements on surface of grade 4 titanium fatigue specimen.

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