Fatigue Fracture of a Ti-6Al-4V Rod

Like people, materials can get tired under repeated stress. Even if the stress is much lower than the tensile strength of the material, material failure can still occur. This kind of failure is known as fatigue and it is one of the most common failure mechanisms in materials. Generally, fatigue is broken up into three stages: crack initiation, crack propagation, and final static failure.

This analysis describes the fatigue fracture of a rod composed of Ti-6Al-4V, a material widely used in medical implants due to its excellent biocompatibility. Figure 1 is an image of the fracture surface of the Ti-6Al-4V rod. On the outer surface of the rod there is a rough Ti-V coating which is likely present to improve bone integration. The cross section of the fracture surface includes three different regions corresponding to the three stages of fatigue failure. The crack initiated at the surface of the rod and then slowly propagated to cover approximately two-thirds of the cross section. When the crack reached a critical size, final static failure occurred. As the crack grew closer to the edge, the fracture mode changed from a plane-strain mode (mode I) to a plane-stress mode (mode II), resulting in the formation of shear lips.

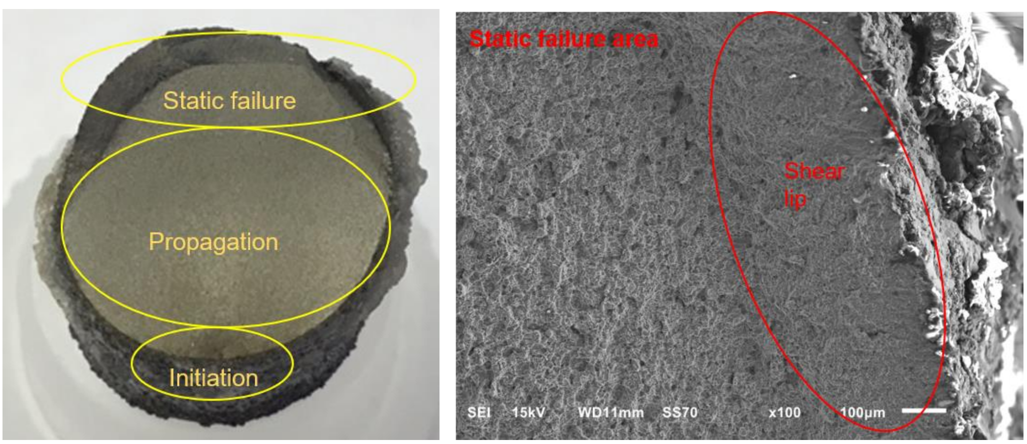

Figure 1. (Left) The fracture surface images of the Ti-6Al-4V rod, (right) shear lip in the static failure area.

SEM images of the Ti-6Al-4V rod at the crack initiation site are shown in Figure 2. As indicated by the chevron marks that point to the origin of fracture in the 100X images, the crack did indeed originate from the surface of the rod. The Ti-V coating at the initiation area was thinner than it was in non-initiation areas. In this area, the coating was broken up into small particles oriented perpendicular to the coating. Due to the relatively weak bonding between the coating and the substrate, cracks formed at the interface and then grew along the coating. The relatively thin coating in the initiation area was possibly due to pitting corrosion or a preexisting defect in the coating.

Address: 10025 Valley View Road, Ste 150, Eden Prairie, MN 55344, U.S.A.
Tel: +1 (952) 941-2199, Fax: +1 (952) 746-8086, Email: natlab@ebatco.com
www.ebatco.com

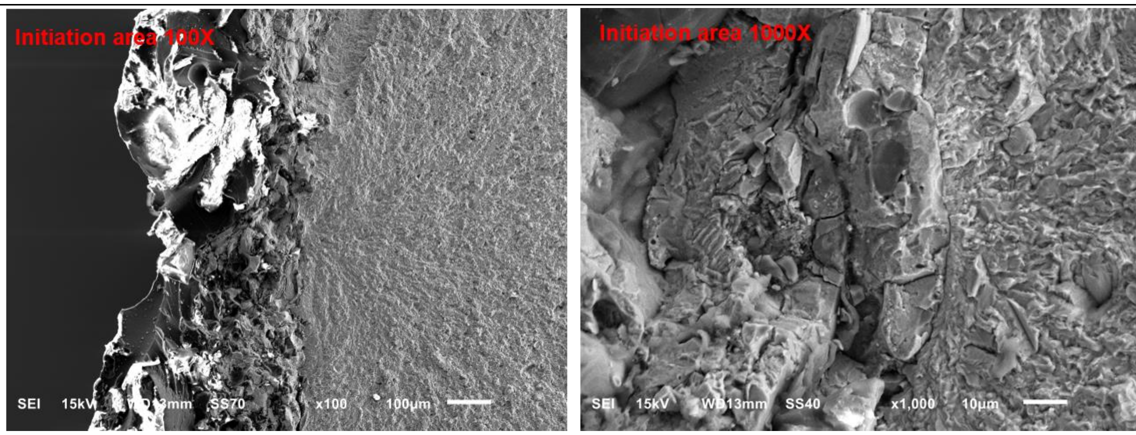

Figure 2. SEM images at fatigue crack initiation area, (left) 100X, (right) 1000X.

Figure 3 compares the microstructure of the Ti-6Al-4V rod in the crack propagation and static failure areas. In the propagation area, striations were found, or ridges showing the progression of the crack front after each successive loading cycle (red circles, Figure 3). In the static failure area, the surface was rough with dimple microstructures, which is typical of ductile fracture. Shear lips, at roughly 45^{o} angles, were also formed at the edge similar to what was shown in Figure 1.

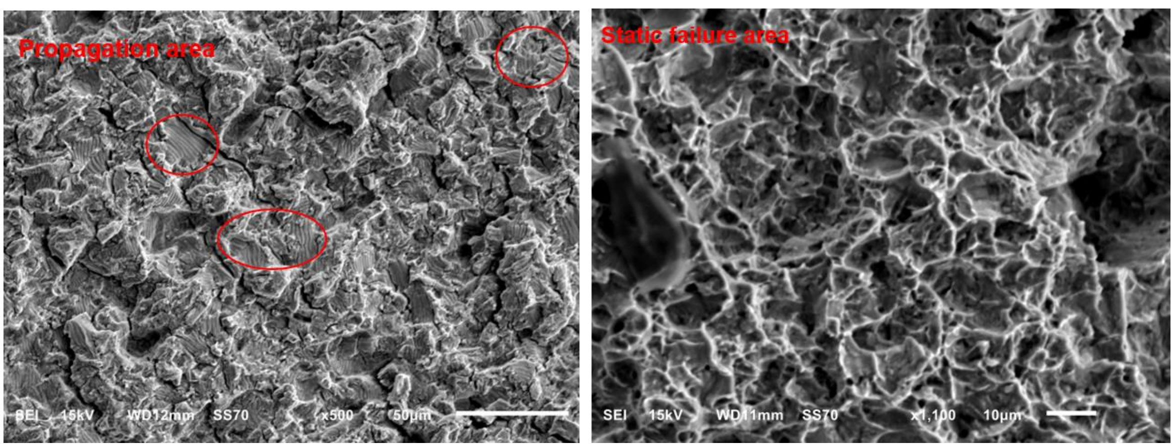

Figure 3. Microstructure of the fatigue fracture surface of Ti-6V-4Al in propagation (left) and static (right) failure areas.

Based on the microstructural analysis, the fracture surface of the Ti-6Al-4V rod had a typical fatigue fracture morphology. The crack initiated at the surface from a thin spot on the coating layer. Typical striation patterns formed in the crack propagation area, and the static failure area had a ductile failure morphology.