Low-Cycle Fatigue Failure of Steel Wire

Failure analysis is of utmost importance in many industrial applications, such as semiconductor, packaging, transportation, manufacturing and biomedical devices. Knowing how and why a material failed is essential to ensuring a product's reliability. Scanning Electron Microscopy (SEM) is one of the most powerful tools in failure analysis. By revealing the information about the microstructure at the fracture surface, one can derive lots of information about the failure mechanisms.

Material failure below its yield stress limit is often called fatigue failure. It occurs when the sample undergoes cyclic loading. Local microscopic cracks may develop at a certain stress threshold below its yield strength. Over a period of time, these cracks propagate, coalescence and eventually cause a fracture. A typical metal fatigue failure develops in three stages: crack initiation, crack propagation and final fracture. Each stage has its own characteristic morphology. The crack initiation site is located at the most stress-concentrated areas. The crack propagation shows typical striation lines, perpendicular to the direction of crack propagation and formed by each loading cycle. The final fracture area is the rapid fracture region, which typically shows a rough fracture surface. A dependable design against fatigue-failure requires thorough understanding on the failure mechanisms and knowledge in structural engineering, mechanical engineering, and materials science and engineering.

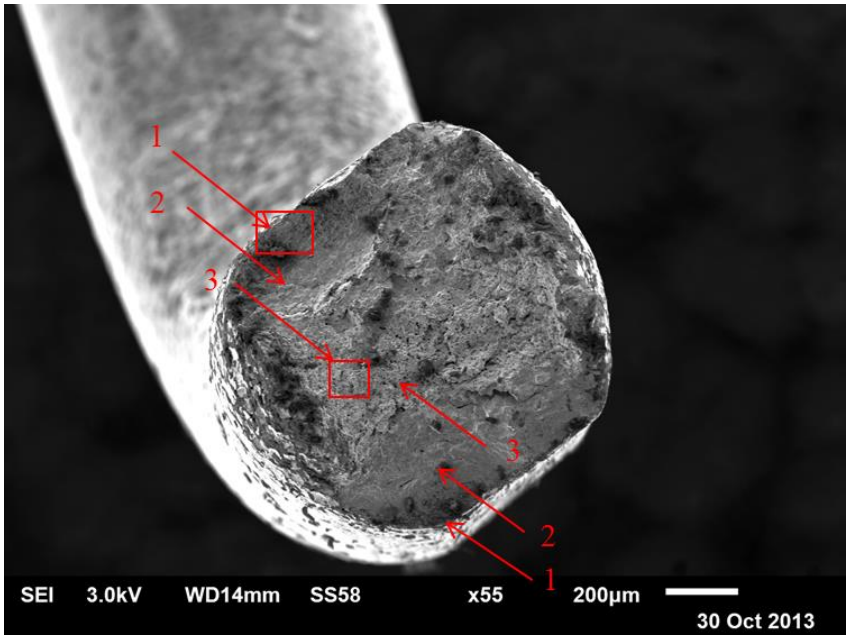

Figure 1. Scanning Electron Microscopy (SEM) image of an fractured steel wire.

Figure 1 illustrates an SEM image obtained by Ebatco NAT Lab's JEOL 6610LV for fracture failure analysis of a steel wire failed under cyclic loading. Bending of the wire back and forth has caused both sides of the wire to undergo compression and tension forces, and the final wire rupture. Arrows marked with 1, 2 and 3 indicate the typical three stages of fatigue failure. Arrows marked with 1 indicate crack initiation regions. Arrows marked with 2 indicate crack propagation regions. Arrows marked with 3 are the final fracture regions.

Figure 2 presents higher magnification images of the red rectangles shown in Figure 1. The image below at left shows the area close to the crack initiation region. In this image, the striations as typical fatigue characteristics caused by crack propagation can be easily seen. The image below at right illustrates typical dimple structures from ductile fracture in the final fracture region. The dimples are formed due to high local plastic deformation at final rupture of the wire.

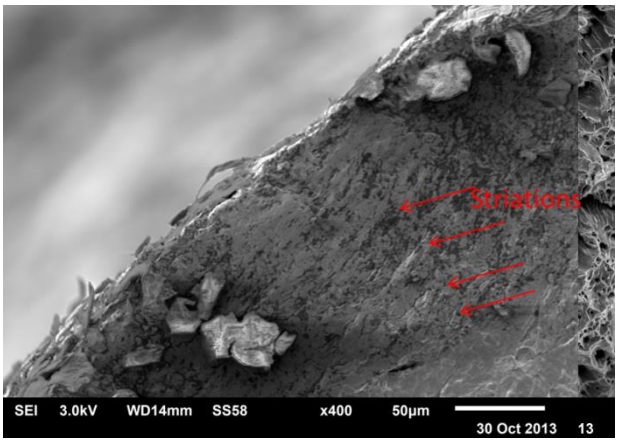

Figure 2. Enlarged fracture areas from Figure 1; left image, rectangular 1; right image, rectangular 3.