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A VIEW FROM THE PENTHOUSE: USEFUL INFORMATION FOR THE WORLD OF BOILERS

FATIGUE, THERMAL FATIGUE, CORROSION FATIGUE

Fatigue may be defined as the response of a material to a variable stress or strain. The most obvious would be a rotating shaft in a pump or a fan. For steel, no failure would be expected below some stress level. This minimum stress is sometimes called the "endurance limit." Failures occur when the operational stress exceeds the endurance limit, usually because of stress-intensification factors: such things as a change in shaft diameter, a key-way, a cut thread, or external damage. Failures occur at or near ambient temperatures.

Thermal fatigue occurs at elevated temperatures where the reaction of oxygen and steel form iron oxide. Under a variable stress or strain, failures are said to be caused by thermal fatigue. Similarly, in a corrosive environment, a variable stress or strain leads to failure in a condition known as corrosion fatigue. Under ambient conditions, the concept of an endurance limit leads to a safe design stress, under high-temperature or corrosive conditions, no similar endurance limit exists. Thus, under these adverse conditions, failure can be expected regardless of the stress.

All three of these fatigue-fracture modes have some similar characteristics, in that all are brittle failures. By brittle is meant limited or slight macroscopic change in the thickness of the component at the point of failure. The failure often appears "suddenly", with no warning of any problem.

Figure 1 shows the failure of a shaft from a coal pulverizer. Fatigue failures have characteristic "clam-shell" markings that point back to or surround the origin. There may be more than one fracture-initiation site, as evidenced by steps in the perimeter of the shaft.

Figure 1.

Cracks that initiate from the multiple surface origins join in a single crack until the cross-sectional area of sound metal is too small for the applied stress, and failure occurs by tensile overload. On a microscopic scale the fracture surface contains striations that develop one per cycle.

Within the boiler environment, corrosion fatigue can occur on the waterside of a tube, usually at an attachment weld. In cross section, corrosion-fatigue cracks are transgranular and somewhat bulbous in cross section, as shown in Figure 2. The corrosive environment attacks the fresh surface developed by the fatigue-crack growth, leaving behind the shape shown in Figure 2.

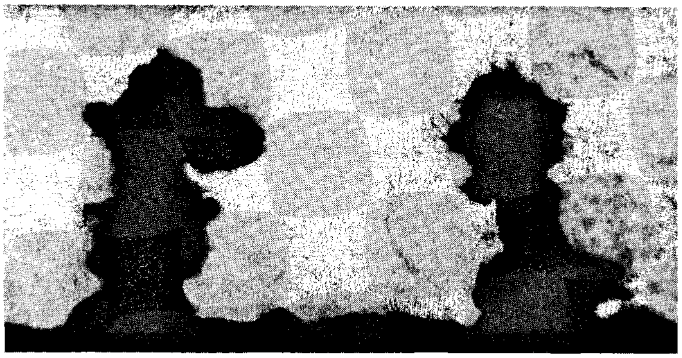

Figure 2.

Coal-ash corrosion of waterwalls or superheaters leads to a circumferential grooving. In superheaters the appearance is sometimes called "alligator hide". This too is a corrosion fatigue. A liquid phase forms from the ash on the surface of the tube. That liquid can support only a small amount of fuel ash. When the thickness is too great, the slag is shed from the tube at the liquid layer. The insulating effect is lost, and the tube temperature rises. This temperature cycling as the ash layer forms and sheds leads to a fatigue strain within the tube as it expands and contracts with the change in surface temperature. This fatigue, in connection with the corrosivity of the liquid ash species, leads to corrosion-fatigue cracks. In cross section they appear as dagger-like penetrations into the tube surface as shown in Figure 3.

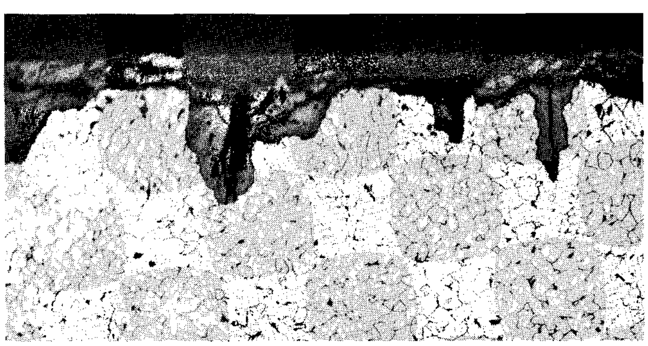

Figure 3.

Thermal-fatigue cracks occur in boilers at superheater header connections and refractory-retaining lugs. For example, differences in expansion between the roof tubes and a superheater outlet header cause a bending of the superheater tubes, which, in turn, leads to thermal-fatigue cracks at the weld. Refractory-retaining lugs are also alternately heated and cooled as ash or refractory forms and erodes. In cross section these thermal-fatigue cracks are, again, transgranular and dagger-like in appearance, as shown in Figure 4.

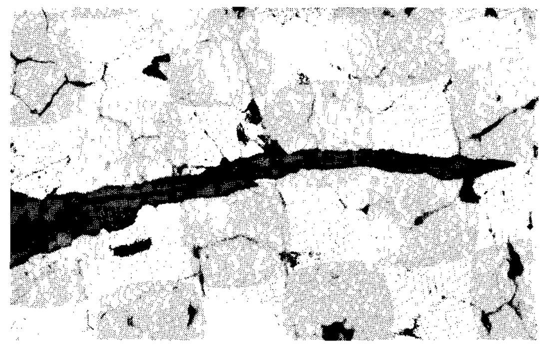

Figure 4.

Figure 4 is from a refractory-retaining lug.

In review, the differences between fatigue, corrosion-fatigue, and thermal fatigue are one of atmosphere or environment only. Fatigue occurs under ambient temperature conditions, thermal fatigue occurs at elevated temperatures where iron oxide is essentially the only corrosion product, and corrosion fatigue occurs in corrosive environments. All have variable stress or strain applied as part of the failure mechanism.

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