Four basic types of fracture mechanisms: Part II

Intergranular fracture and fatigue fracture surfaces among mechanisms of failure that are observed in actual parts.

In the previous article, we discussed the fracture surfaces that are apparent for ductile or overload type fractures, and the fractures that occur with brittle cleavage fracture. In this article, we will discuss intergranular fracture, as well as fatigue fracture surfaces.

INTERGRANULAR FRACTURE OR DECOHESIVE RUPTURE

In intergranular fracture (Figure 1), there is decohesion at the grain boundaries. The fracture surface often has the appearance of “rock candy” and there is little bulk plastic deformation. This type of fracture is usually related to either environmental or specific microstructures.

Grain boundaries in most engineering materials are stronger than a single grain of material (assuming properly processed). The grain boundaries interrupt the lattice of individual grains and provide for increased strength by pinning dislocation movement. Fine grain materials have more surface area than do larger grained materials, so more dislocations are pinned, increasing ductility and strength.

Grain boundaries are also locations where voids and crystal faults gather. They are also an easy path for diffusion. Impurities often segregate to grain boundaries. Failure along grain boundaries can occur by either environmental or by specific microstructures where precipitation has occurred.

Intergranular fractures can be divided into two different categories — those that have a dimpled intergranular fracture and those that have a brittle intergranular fracture. In dimpled intergranular fracture, microvoid coalescence occurs on the grain boundaries. In brittle intergranular fracture, the grain boundaries show no evidence of microvoid coalescence but show a more “rock candy” type of fracture [1].

In dimpled intergranular fracture, the grain boundaries have a low ductility. Often this is due to the formation of microvoids at precipitates decorating the grain boundaries. It can also occur in aluminum alloys where significant precipitate free zones (PFZ) have occurred. The grain boundaries in this case are nearly pure aluminum and are weaker (and more ductile) than the interior of the grains. This is most common in 7XXX (Al-Mg-Zn) alloys [2].

Brittle intergranular cracking is usually associated with grain boundary strengthening. It is easily recognized because of its highly faceted appearance. Causes can include brittle second phase particles at grain boundaries, segregation of impurities to grain boundaries, or environmentally induced embrittlement [3].

In either brittle or ductile intergranular fracture, the mode of fracture is readily apparent. However, the mechanism or cause of fracture is not so readily deduced.

The causes of intergranular fracture are usually associated with improper processing or a specific environment that weakens the grain boundaries. Generally, the causes of intergranular fracture are:

- Grain boundary precipitates.
- Segregation of impurities to grain boundaries by thermal processing.
- Elevated temperatures and stress (creep).
- Environmentally attack or weakening of the grain boundaries (usually specific systems).

Examples of causes of intergranular fracture are listed in Table 1.

FATIGUE-INDUCED FRACTURE

Parts are subjected to varying stresses during service. These stresses are often in the form of repeated or cyclic loading. After enough
applications of load or stress, the components fail at stresses significantly less than their yield strength. Fatigue is a measure of the decrease in resistance to repeated stresses.

Fatigue failures are brittle appearing, with no gross deformation. The fracture surface is usually normal to the main principal tensile stress. Fatigue failures are recognized by the appearance of a smooth rubbed type of surface, generally in a semicircular pattern. The progress of the fracture (and crack propagation) is generally suggested by beach marks. The initiation site of fatigue failures is generally at some sort of stress concentration site or stress riser.

Three factors are necessary for fatigue to occur. First, the stress must be high enough that a crack is initiated. Second, the variation in the stress application must be large enough that the crack can propagate. Third, the number of stress applications must be sufficient enough that the crack can initiate. Second, the variation in the stress application must be large enough that the crack can initiate.

Figure 2: Schematic representation of the mechanism of fatigue intrusions and extrusions after [5].

Figure 3: Fatigue striations evident in a 7XXX aluminum. Each striation represents one stress cycle.

CONCLUSION

In this article, a brief description of intergranular fracture and fatigue has been discussed. This article is not intended to be a thorough examination of these modes of failure, but to introduce the reader to the different mechanisms of failure that are observed in actual parts.

Should you have any questions regarding this article, or have suggestions for further articles, please contact the editor or myself.

REFERENCES