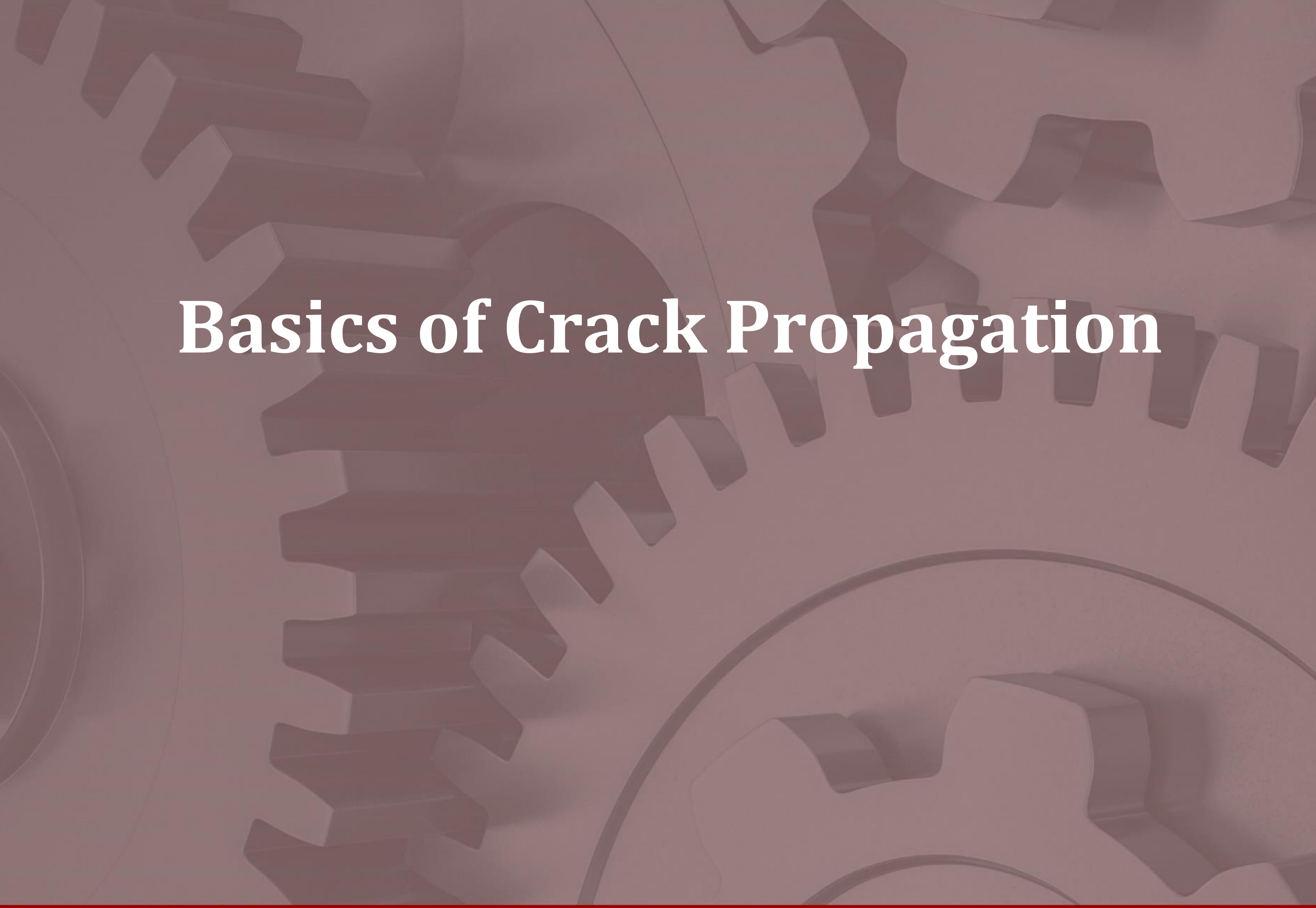

Basics of Crack Propagation

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Basics of Crack Propagation

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1 Preliminary Considerations

Engineers are often faced with analyzing component failures caused by pre-existing cracks or with designs where components include features that can be conducive to cracks (and thus lead to subsequent failure under certain service regimes), such as sharp corners, channels, etc. This course introduces the Engineers to the Crack Propagation Theory and provides a few specific practical examples related to solving related problems.

Cracks are material faults that are either already existing in a Component before service or that develop during the component's life, potentially leading to its failure. Their very existence weakens the component, and as a result, often its useful life is reduced. For the vast majority of the designs, the Cracks are not an intended feature – they fully develop during the component's manufacturing or after the component has been placed in service. For this reason, a lot of the Crack propagation analysis is related to forensic analysis, where the engineer tries to answer questions like "did a Crack originated/caused the failure?", "what service parameters can the Cracked component continue to withstand?", or "how long can the component continue its service with a given Crack?".

The Crack Propagation Theory has been developed for several decades now and is based on many theoretical considerations supported and enhanced by physical experiments. The development of the theory was energized by several product failures that were well-publicized in the media, notably in the shipbuilding industry and aircraft industry. In the subsequent years, this theory has been validated and refined by further experiments and applications to real-world cases. A correct understanding of this theory gives the engineer the ability to predict the failure of a component with a known defect (within reasonable parameters) or to prescribe the maximum size of a defect in a component such that it can still be used safely.

Equipped with the knowledge presented in this course, the engineer can do several things:

- Design for an acceptable flaw size (Crack) for the known service regime of a component (estimated stress levels)
- Estimate the safe regime (e.g., stress levels) generated by a known material flaw (Crack of a given size and shape)
- Estimate the stress levels/load regime experienced by a failed structure/component before failure

It is well understood that for a Cracked Component under steady load conditions, the crack continues to open as the loads increase. Moreover, experiments have shown that cracked components subjected to cyclic loads show that the Cracks advance a minute amount with each load cycle until the component finally fails.

The following material presents the basics of Crack propagation in homogeneous and isotropic ductile materials, such as metals, etc., under steady-state loading conditions.

2 Definitions

The "Crack" represents an abrupt opening in a material, such as material discontinuity, a sharp convex feature, etc. The crack can be intentional (as is the case of the specimens for tests, or sometimes even the design intent, like a mechanical fuse) or unintentional (e.g., material defects). Engineers can encounter a significant number of such cases where a component develops a Crack during service.

The "Crack Face" is the side of the crack. Ideally, it is a perfect plane, although, in practice, it is an irregular surface. A Crack has 2 faces.

The "Crack Tip" is the point at which the Crack faces meet, viewed plane normal to the Crack Faces. At a microscopic level, the point is proven to be a curve, or, even more accurately, a curved surface.

The "Material" represents the material that the component containing a crack is made of.

3 Background Information

Cracks in materials can appear due to several factors, such as:

- inherent material discontinuities (at the level of material micro-structure: grain orientation, vacations, etc.)
- fatigue (high cycle or low cycle)
- because of manufacturing techniques (incorrect welding processes or incompatible with the desired application, rough or fast material removal processes, incompatible material additive processes, etc.)
- inherent geometrical features (such as threads, sharp corners, channels, low radius fillets, etc.)

In general, Cracks are V-type material faults in an otherwise locally homogeneous material. As the angle at the Crack tip is often very small, significant stress concentrations develop at the Crack tip during service. This causes the material at the Crack tip to reach its plastic region. If the local stresses are high enough, the material ruptures and exposes new material to elevated stresses, this becoming the mechanism under which the Crack tip advances. This phenomenon continues if the unfavorable stress conditions continue to exist until there is not enough material to bear the stresses and the component breaks.

Research has shown that the Cracks travel in two modes in the material's crystalline structure. The easier way for a Crack to propagate is along the granular boundaries (inter-granular cleavage). When this is not possible (e.g., the cohesion between the material grains is stronger than the cohesion of the grains themselves), the energy that opens a Crack is forcing it thru a material grain by splitting the atomic bonds within the grain material.

A few decades ago, George R. Irwin identified several modes of Crack opening[i], based on the way the crack Faces move with respect to each other: Type I, Type II, and Type III. They are presented in detail in the following material.

3.1 Type I Cracks: Opening Mode

This is the most common type of crack. As the stresses increase, the Crack Faces are moving away from each other, quasi-symmetrically with respect to the plane normal to the direction of the stresses. Figure 1 shows this type of crack, with the symmetric forces applied to the component.

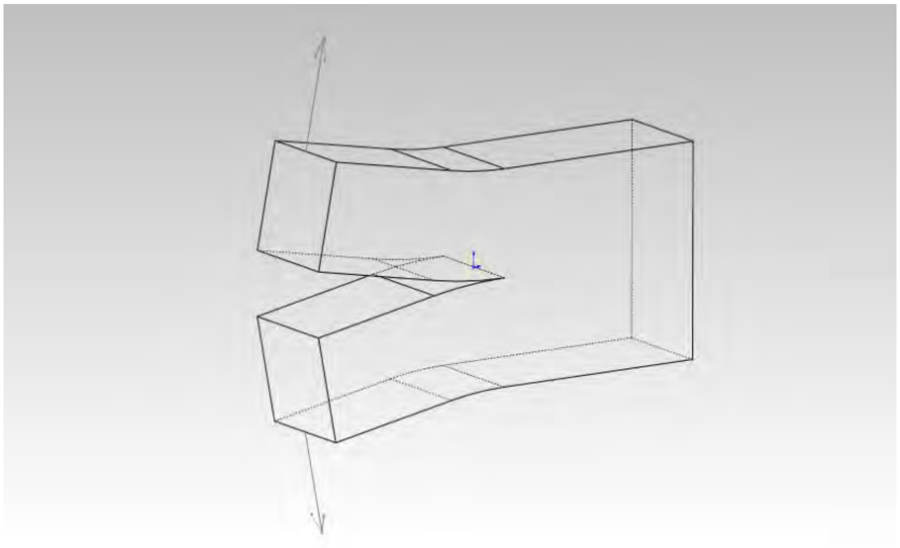

Figure 1: Typical type I Crack "Opening mode"

An example of this case is a beam under bending stresses, with a Crack on the outbound fiber.

3.2 Type II Cracks: Sliding Mode (In-Plane Shear)

In this mode, the Crack surfaces are sliding on the same plane, which is in the direction of the applied stresses. Although the Crack surfaces may begin being equal, as the stresses develop, one surface grows, and the other is shrinking. The initial geometrical symmetry is lost as the applied stresses increase. Figure 2 shows this type of crack, again, considering symmetric forces applied to the component.

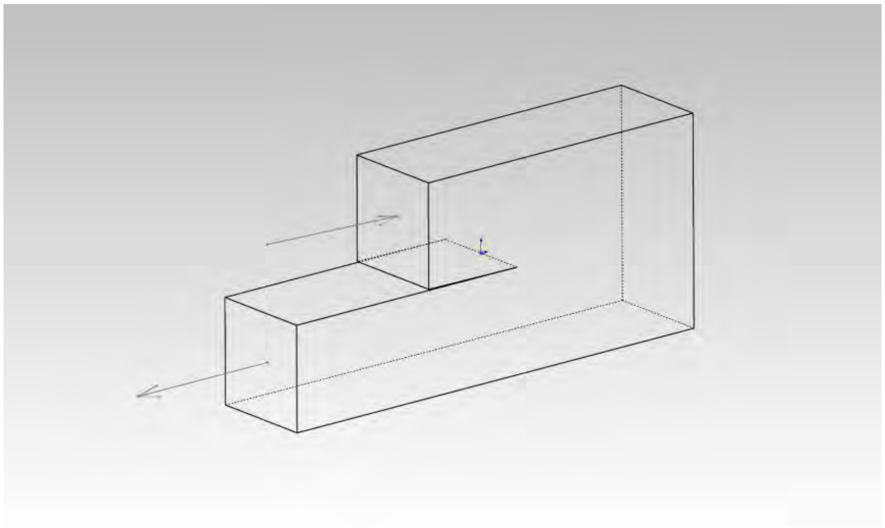

Figure 2: Typical

A typical example fo where a cutting insert is
pushing against the v hine tool (turning, milling,
broaching, etc.). The ired dimension is
achieved.

3.3 Type III Crack

In this opening mode, t ne of the applied
stresses while their size each other. Figure 3
is showing this type of c ith failures under
torsional loads. The cra pect to the plane
parallel to the plane of a