Analysis of rear Mounting Bracket

Project Report for Indian Institute of Technology, Bombay - AE-219: Supervised Learning Program (2023), under the guidance of **Prof. Krishnendu Haldar**

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Abstract

Using the fundamentals of Fracture mechanics, a straightforward analysis is carried out, which deals mainly with fatigue analysis. The simplified approach used in the paper assumes and averages the anonymous data required for essential inputs in the analysis.

Acknowledgements

I would like to extend thanks to Prof Krishnendu Haldar, for giving us timely inputs, and suggestions, also freedom and space for the project.

0.1 Introduction

The Problem statement: RD-33MK engine has two fuel cooled oiled coolers. There have been recurrent failures of the 'main' FCOC 'rear' mounting bracket. Hence, a fatigue analysis is performed to calculate whether a structure will fail after a certain number of repeated loading and unloading, so-called load cycles, rather than after one load cycle as simulated in a static analysis. The fatigue failure is due to the initiation and propagation of a crack somewhere in the component.

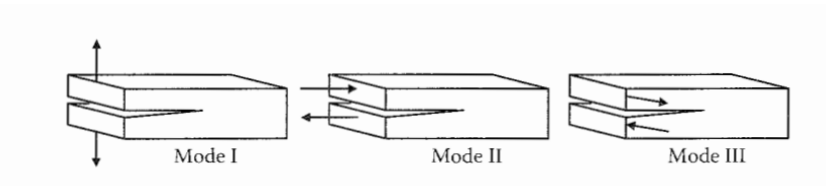
0.2 Fundamentals Concepts

0.2.1 Elastic Crack Model

Stress Intensity Factor and Fracture Toughness

Since the stress values near a crack tip are always very high (and infinity at the tip), the strength-of-material approach of failure prediction that the material fails when the stress exceeds some critical value (ultimate stress or yield stress) cannot be used here. When a cracked plate is subjected to a small load, although the stress field near the crack tip becomes very high, the plate does not fail. However, the plate fails as the applied load increases to some critical value. In the fracture mechanics approach, instead of comparing the maximum stress value with a critical stress value, the material failure is predicted by comparing the stress intensity factors KI and KII with some critical value Kc This critical value is called the critical stress intensity factor or the fracture toughness of the material.

The problem statement is a combination of mode 1 and mode 2 types of

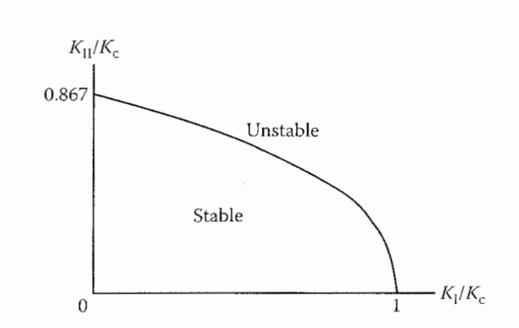


loads. As the bracket is connected between the fuel tank and chassis, when the aircraft lands, inertia of the fuel tank applies a sudden impulse on the bracket. Now this force is not exactly along the length or breadth of the bracket, as we will see in the upcoming sections; hence components of forces are such that it becomes a mixed-mode problem.

Mixed mode

KII/KI is the ratio of stress intensity factor for mode 2 and mode 1. If KII/KI=0, we consider it as a mode 1 problem. If KII/KI=∞, it is considered a mode 2 problem. Anywhere between these two values gives us a mixed condition

Under mixed mode loading, the crack propagation direction continuously changes and, finally, the crack propagates at an angle 45^o relative to the horizontal axis, as this direction is perpendicular to the maximum tensile stress. We can also obtain the failure curve for mixed loading using the equation(shown the Fig)



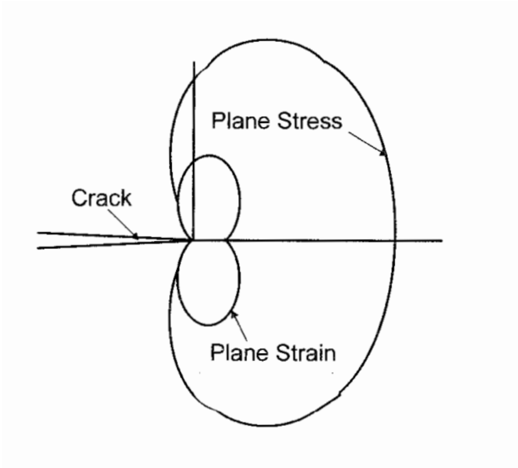
$$\left(\frac{K_I}{K_c}\right)^2 + 1.56\left(\frac{K_{II}}{K_c}\right)^2 = 1$$

The strain energy method can also be incorporated into the analysis. For mixed mode loading, the Strain energy release rate, in terms of stress intensity factors for different modes, can be given as:

$$G = \frac{1-\nu^2}{E}\left(K_I^2 + K_{II}^2 + \frac{K_{III}^2}{1-\nu}\right)$$

0.2.2 Plastic Model

The elastic solution gives an infinite stress value at the crack tip. It implies that the material very close to the crack tip cannot remain elastic when the crack body is loaded. The plastic zone size ahead of the crack tip is given as



The exact nature of the problem if it is a plain strain or plain stress is hard to distinguish but it lies mostly evident from the Fig, that it lies in the plain strain domain.

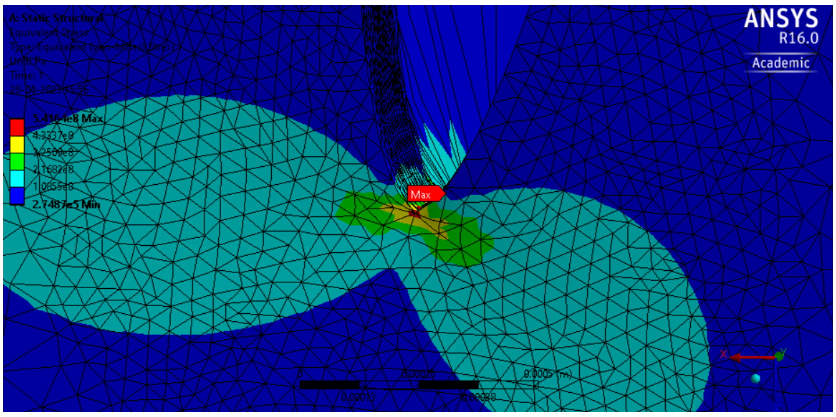


Figure 1: Small crack initiated in the bracket shows a similar pattern for plain stress problem

0.2.3 Fatigue Crack Growth

Under cyclic loadings, pre-existing cracks inside a material may become bigger and cause catastrophic failure of the structure. Structural loading under cyclic loading is also known as fatigue failure.

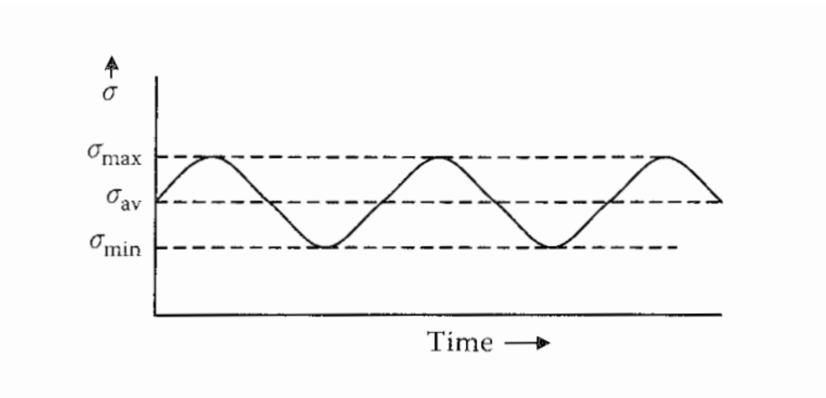


Figure 2: Oscillating Stress applied to a body

0.3 Problem Solving Approach

0.3.1 Understandings the requirement of bracket

The bracket is used to attach the fuel tank to the main chassis. There are a total of six holes, four of them are used to connect with the circular ring which surrounds the engine, and the other two are used for the rods which will be used to attach the fuel tank.

An observation that has to be made here, which is crucial in determining the final loads for the bracket, is that the bracket is at an angle to the vertical. This is why the problem is considered a mixed type(Mode 1 and 2). The vertical reaction force acting on the bracket will have components along the bracket's length and breadth.

Large fillets can be observed in the bracket to reduce the stress concentration in those specific regions. The material is considered aluminum 7075, though, in reality, it could be one of its alloys. Dimensions for the part are as given in the datasheet, with an assumed thickness of 3.5 mm. In the geometry, a small crack at the very top half of the bracket is created intentionally to observe the stress pattern at the crack tip.

Figure 3: Bracket attached to the engine

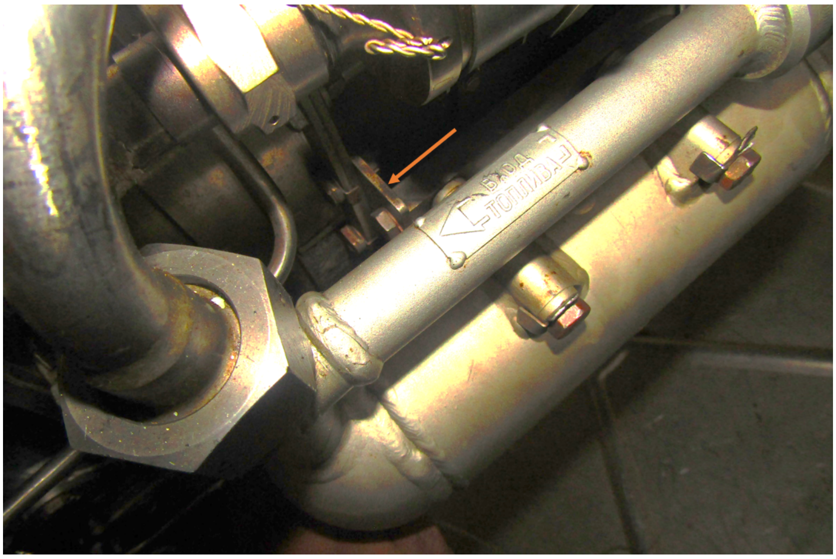


Figure 4: Fuel Tank attached to the Bracket

0.3.2 Loads

In the structural analysis, two forces have been accounted for: the reaction force due to the fuel tank and the compressive force due to the nuts which hold the bracket in place.

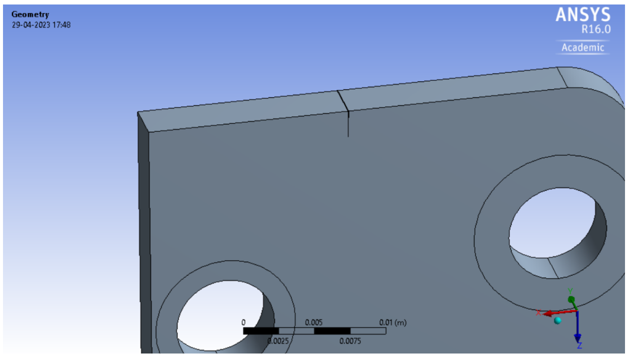


Figure 5: Small Crack at the top face

The Reaction force

The internal fuel capacity of the original MiG-29B is 4,365 L (960 imp gal; 1,153 US gal) distributed between six internal fuel tanks, four in the fuselage and one in each wing. MiG-29, like most Russian/Soviet jets, typically uses the TS-1 kerosene. Density for TS-1 Kerosene is 787kg/m^3. Hence, if all six fuel tanks are equally large, the net mass of each is roughly 858.81 kg. So the net reaction force due to the fuel tank is its mass times change in velocity in the vertical direction. The landing speed of a typical fighter jet aircraft like an F-16 is around 300km/hr, while aircrafts are designed for a specific pitch angle landing like the F-18 Hornet is designed to land at a pitch angle of 5 degrees in relation to the horizon. This angle sets the tail hook at the best angle to catch the arresting wire.

So using the correct components for the velocity, the **Force** comes out to be **6237.51N**. This load is applied at an angle of 30^o to the length of the bracket to mimic the real situation

Compressive loads

Bolt Preload is the tension created in a fastener when it is tightened. This tensile force in the bolt creates a compressive force in the bolted joint known as clamp force. Suppose proper preload, and thus clamp force, is not developed or maintained. In that case, the likelihood of a variety of problems, such as fatigue failure, joint separation, and self-loosening from vibration, can plague the bolted joint leading to joint failure.
Bolt Preload Force is defined as $\mathbf{F} = \mathbf{c} * \mathbf{A_T} * \mathbf{S_P}$ where F is preload tension force, A_T is the tensile shear area of bolt, S_P is a proof load of the bolt and c is 0.89 for permanent connections. Proof load is the maximum tensile force that can be applied to a bolt that will not result in plastic deformation.

Figure 6: The tail hook attached to the arresting wire

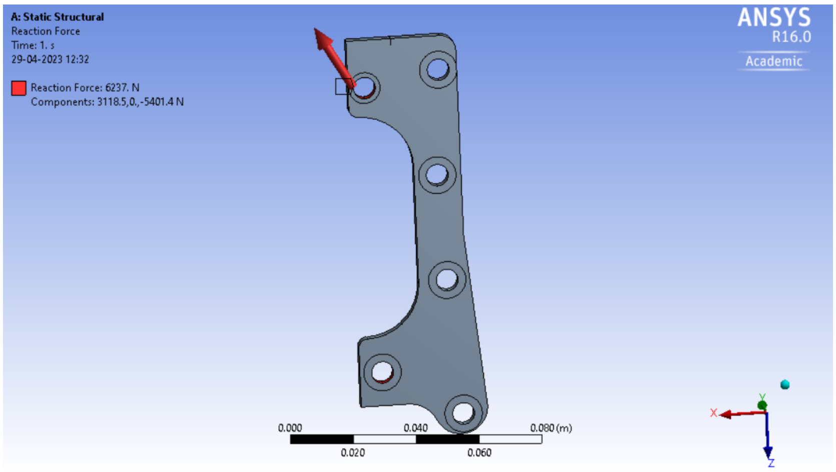


Figure 7: Applied Force at 30° to the verical

The nut used in the problem statement is considered as a standard M3 bolt with a property class of 10.9 with a permanent connection that gives the value of Preload force as **3430 N**.
Some specific area, equivalent to the bolt head in contact with the surface is chosen to apply this compressive force for all six screw holes.

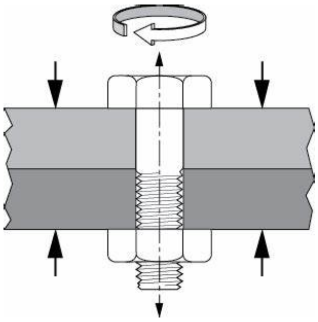


Figure 8: Bolt Preload Force

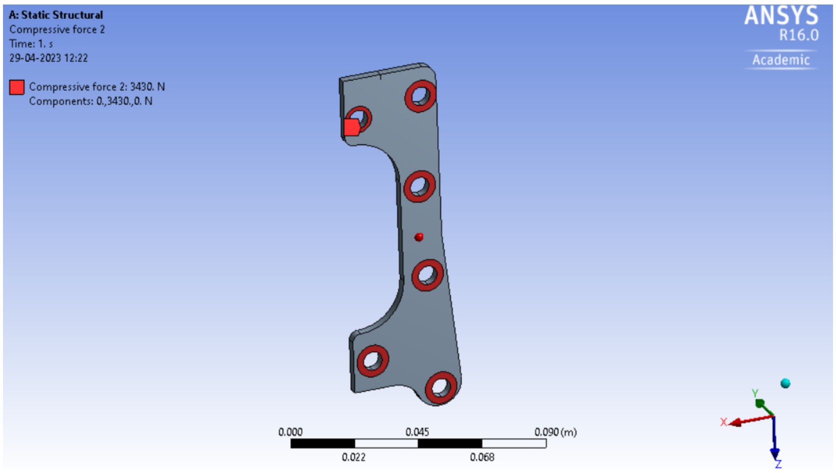


Figure 9: Compressive Force due to bolt heads

0.3.3 Boundary conditions

Boundary conditions allow a simulation design to constrain system behavior based on what is happening in the real system being simulated. As shown in Figure 5, in the frame of the bracket, the four holes shown in blue color will be considered fixed surfaces.

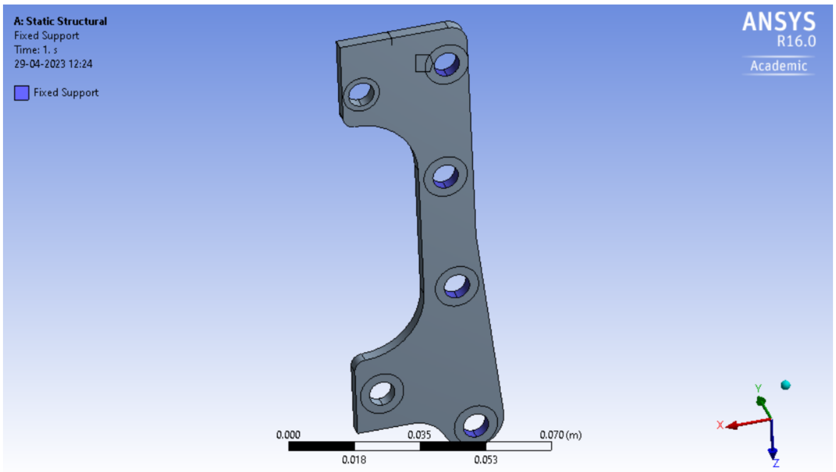


Figure 10: Fixed Holes

0.3.4 Results

Equivalent Stress is the average theoretical stress in the interested section of the component. In contrast, Max principal stress is the highest stress in the fibers of the component that are at orientation to the loading plane. 7075 tech sheet T6 temper 7075 has an ultimate tensile strength of 74,000 – 78,000 psi (510 – 538 MPa) and yield strength of at least 63,000 – 69,000 psi (434-476 MPa). The results for max equivalent stress is **3.13x10^{8}Pa**. The values are **not** well within the range near the yield stress in the middle section of the bracket. while it somewhat reaches the yield stress near the crack tip.

Total Deformation, as expected, occurs at the holes connecting the fuel tank as it pulls that specific region as soon as the aircraft lands. The values lie in the range of **1.5-7.5x10^{-5}** mm.

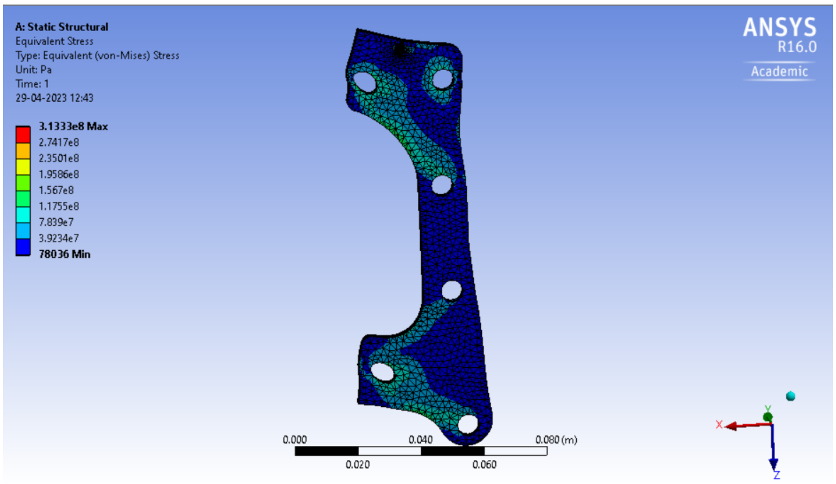


Figure 11: Equivalent Stress

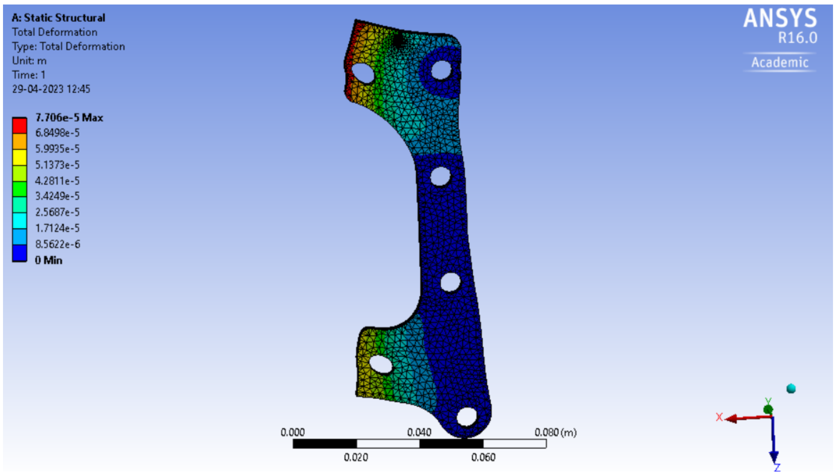


Figure 12: Total Deformation

Fatigue analysis of the part gives some intuitions over the areas with a possible chance of failing. We can see the **Safty Factor** to be almost equal to one near the crack surface and almost close to one near the holes screw holes. Here the method of **Strain Life approach** is used to analyze the life of the material. In principle, strain life is the same as stress life if the stress–strain relation is monotonic. However, when the stress exceeds the proportional limit, the stress is not unique for describing the material state, and the strain is better for describing the material state in this condition. The strain-based approach to fatigue considers the plastic deformation that may occur in localized regions where fatigue cracks begin, as at the edges of

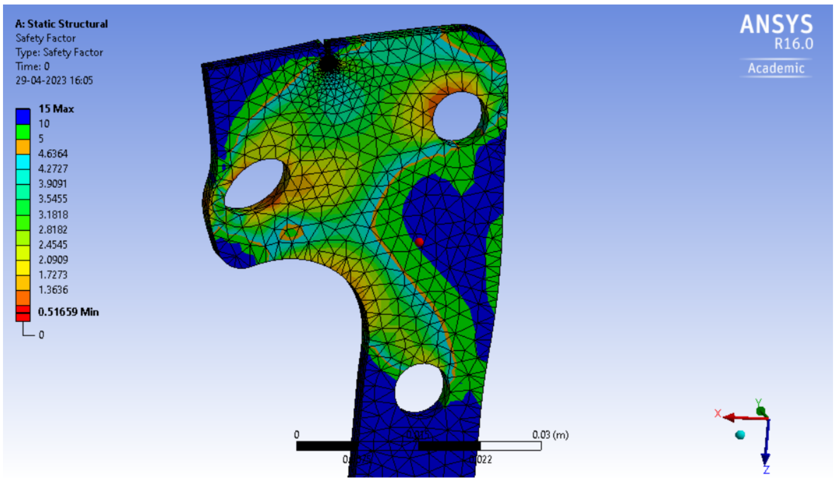


Figure 13: Saftey Factor

beams and at stress raisers.

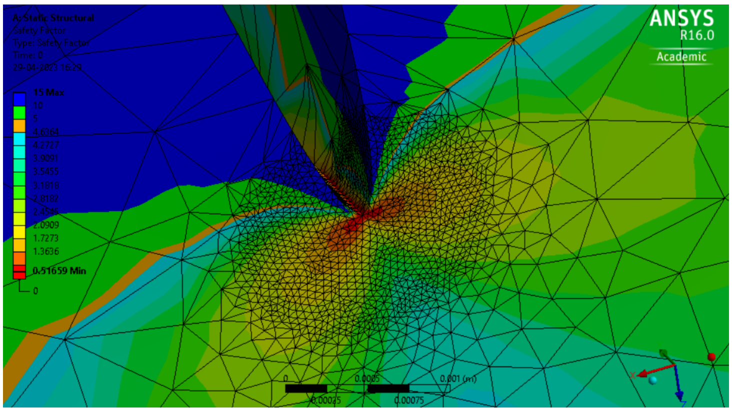


Figure 14: Saftey Factor near the crack tip

0.4 Inference

Even if the maximum Stress values are well within limits; the structure has less than one safety factor. But this value is intentionally achieved by forming a crack. This is not an ideal way to analyze fatigue because we cannot predict the precise location of the microcracks that form due to the repetitive loadings.

Further approach to the problem: Grain Analysis

Metallic materials, used in various products commonly break due to their surrounding environment. The cause of breakage can only be determined after observing the material and accurately analyzing the fractured surface. In automotive, aerospace, and other industries where safety is essential, the materials used is the basic component ensuring the quality of the product.
A fatigue fracture is a pattern in which cracking has gradually proceeded under repeated load. The appearance of the fractured material does not show stretching or necking, similar to brittle fractures, but significant plastic deformation is revealed under microscopic observation.

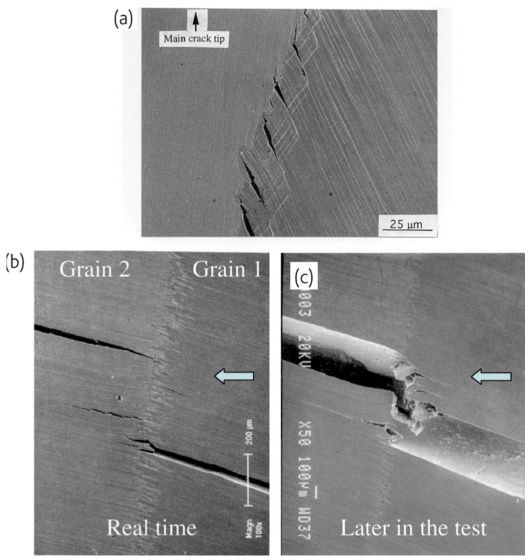


Figure 15: (a) multiple microcracking; (b) bridging ligament at the boundary caused by a large twist disorientation during the test as the crack crosses the boundary; and (c) ligament fracture later in the test, accompanied by substantial plastic deformation of the ligament. Arrows indicate the direction of crack growth.

How to inhibit Crack propagation?

If some idea for the source of these microcracks is identified, then a precise tiny crack can be generated to analyze and match the pattern we have on the actual part. The next step will be to stop there microcracks.
Voids: Tough isotropic materials, such as structural metals, resist crack formation by yielding. At the tip of the crack in such a metal, the material near the crack tip may yield and stretch a bit, which absorbs some of the work of strain relief without actually fracturing. Another way to inhibit crack formation is for the material to have round or oval voids. When a crack tip hits one of these voids, the stress concentration near the tip is greatly reduced, stopping crack elongation. Such voids may slightly reduce the material's cross-sectional area and increase the average stress, but if the voids inhibit crack extension, they can greatly increase the material's actual strength

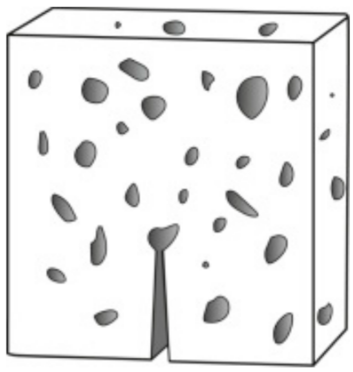


Figure 16: Voids at crack tip

Compsite material: Another very effective way to limit crack propagation is to use a composite material. A composite material is one with two or more components of different stiffness. The fatigue behavior of fiber-reinforced plastics (FRP) is highly interesting for many technical applications due to the structural components' excellent material properties and low weight. They are used in many industrial applications for structural load-bearing purposes in naval or wind power sectors. Such composites force cracks to follow a very torturous path, requiring huge amounts of energy to form new fracture surface, and this new surface will be extremely ragged and rough. While these composites will be a bit less stiff than their stiffest component, they will be much more challenging than either component alone.

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