Nomenclature of Micropitting

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Introduction

To understand a complicated subject, one needs to have a consistent and coherent system of nomenclature. It is the key to understanding the morphology and mechanism of micropitting. Unfortunately, it is typical for researchers to invent ambiguous terms for phenomena that are not well understood. It seems that the less we know about a failure mode, the more names we ascribe to it. This shortcoming is especially true for the complex phenomenon of micropitting.

Nomenclature

Tallian (Ref. 1) coined the phrase "surface distress," which he later (Ref. 2) explained included micropitting. Tallian (Ref. 1) stated that the first sign of surface distress is a "burnished" appearance that is characterized by a "high gloss" of the metal and partial or total obliteration of the original finishing marks. He went on to say, "It is now believed that this appearance arises from plastic deformation of the asperities" and continued: "In a more advanced stage of this failure, small pits form on the burnished surface, which are at times aligned along ridges of the original asperities."

In a later document (Ref. 2), Tallian introduced the term "glazing" when he stated that: "surface distress is attributed to asperity interactions causing plastic deformation (glazing) with subsequent microcracking and micropitting."

In his Failure Atlas (Ref. 3), Tallian defined the early plastic flow stage of surface distress as glazing, and the later stage as micropitting. He describes a glazed surface as showing smoothing of asperity ridges into almost featureless flat areas (with valleys still discernible), possibly with some incidental wear marks or dents. In contrast, he states that under SEM magnification, microcracks opening to the surface may be visible in the glazed areas and describes a micropitted surface as appearing "frosted" to the unaided eye, possibly with barely visible black spots representing the micropits.

Incubation

Tallian's early stage of surface distress is now confirmed to be the incubation stage for micropitting. In addition to Hertzian stress due to normal loading, sliding between gear teeth causes tractional forces that subject asperities to shear stresses. The first 10^4 to 10^6 cycles of stress occurring during run-in are an incubation period (Refs. 1, 12, 13) during which damage consists primarily of plastic deformation at asperities (Refs. 1–14). Spikes, Olver, and Macpherson (Ref. 12) give an excellent dissertation on the mechanism of the plastic deformation that occurs during the incubation period. Macroscopically, surfaces appear glazed or glossy (Ref. 12). Microscopically, surface asperities appear plastically deformed and original-machining marks might be partially or totally obliterated. Cyclic Hertzian and shear stresses accumulate plastic deformation on asperities and at shallow depths below asperities. The length of the incubation period depends on the relative hardness of the specimen and the mating components. Plastic flow produces tensile residual stresses (Refs. 10, 15) that increase the cyclic range of stresses that asperities are subjected to. With sufficient cycles, fatigue cracks initiate.

Nucleation and Growth

After incubation, micropits rapidly nucleate, grow, and coalesce. Microscopy shows a continuously cracked surface. Periodic inspection of gear tooth profiles with a gear inspection machine discloses a steady rate of surface deterioration. The process of plastic deformation, followed by initiation, growth, and coalescence of cracks may be continuous (Refs. 11, 16, 17). Damage may be extensive after only 10^6 cycles (Refs. 4, 12, 16, 18, 19).

Micropitting begins when a fatigue crack grows from the gear tooth surface at an angle to the surface. A micropit forms when a branch crack connects the subsurface main crack with the surface and separates a small piece of material. The resulting micropit may be only 10 μm deep and not resolved by the unaided eye. Subsurface crack networks are usually much more extensive than would be implied from surface features.

The main crack undermines the surface by growing deeper and spreading in a fan shape. Micropits enlarge as the back edges of the micropits crack and small pieces of surface material are dislodged. Some particles are trapped in micropits, and others fall out of craters and entrain

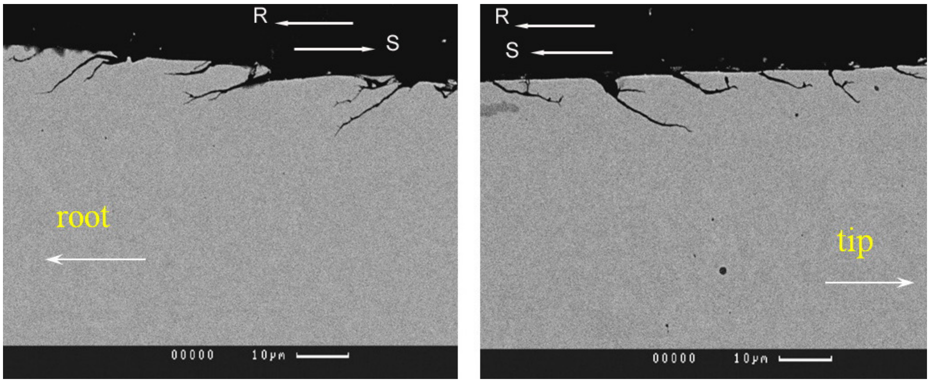

Figure 1 The image shows two polished metallurgical specimens cut transversely through gear tooth micropitting. The left shows the dedendum, and the right shows the addendum of the tooth of a driven gear. The vectors R and S indicate the rolling and sliding directions. Micropitting cracks start at the gear tooth surface and grow at a shallow angle (typically 10–30 degrees, but sometimes as steep as 45 degrees) to the surface. Image courtesy of Newcastle University.

in the lubricant. Because debris from micropitting can be as small as 1 μm, it is unlikely filters will remove much (Ref. 11). The particles act as polishing agents and polishing wear is often found on gear teeth with micropitting, in areas between micropits, and in areas without micropitting.

Ground gear teeth with longitudinal scratches often have micropits along the edges of scratches (Refs. 11, 20). On the driver, micropits nucleate at the lower edges of addendum scratches, and at the upper edges of dedendum scratches (Ref. 20). Fan-shaped growth patterns cause adjacent micropits to coalesce and form continuously cracked edges that follow along grind scratches.

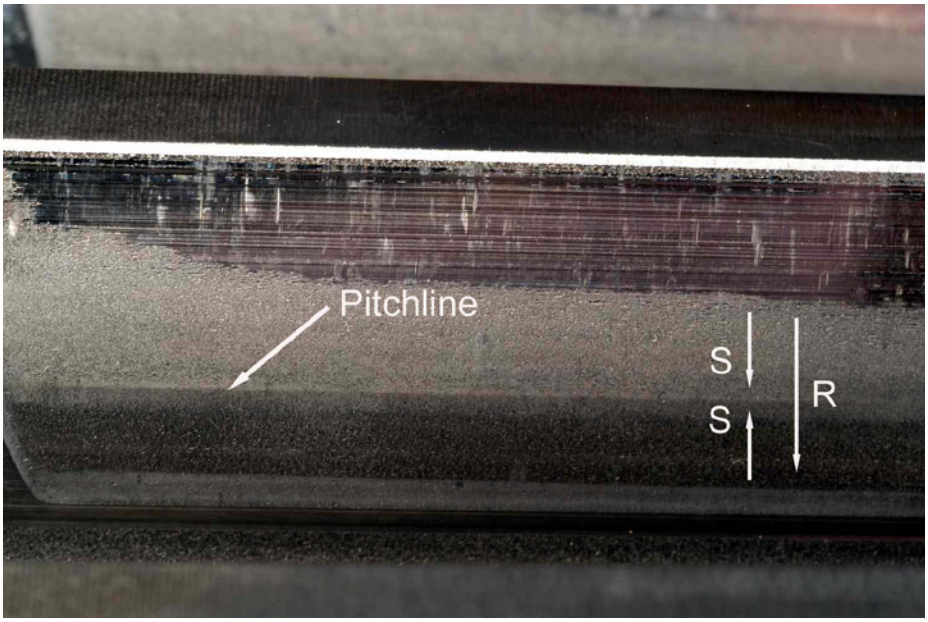

Figure 2 The image shows a driven wind turbine pinion with micropitting. The pitchline is readily discernible because the floors of the micropit craters are oppositely directed in the addenda and dedenda, which resulted in light reflection directed into the camera lens in the addenda, and directed away from the camera lens in the dedenda. This resulted in the addenda appearing light and the dedenda appearing dark.

Morphology

To the unaided eye, micropitted gear teeth appear dull, etched, or stained with patches of gray. Micropitting is difficult to see under diffuse fluorescent lighting and is best observed with intense directional lighting. A flashlight with a concentrated beam held in the proper direction effectively illuminates micropitting. With intense lighting, micropitting may sparkle or appear speckled.

Scanning electron microscopy (SEM) shows the floor of a micropit crater slopes gently downward from its origin at the tooth surface. The floor has a rough surface typical of that caused by ductile fatigue crack propagation. A featheredge forms at the back of the crater due to the plastic flow of material over the crater rim. The featheredge appears white in SEM when it becomes charged with electrons. Material surrounding a micropit generally appears smooth and featureless unless abraded.

Metallurgical sections cut transversely through micropits show cracks start at or near the gear tooth surface and grow at a shallow angle (typically 10–30°, but sometimes as steep as 45°) to the surface, as shown in Figure 1 (Ref. 21). Like macropitting, micropitting cracks grow opposite the direction of sliding at the gear tooth surface (Refs. 10, 19–23). Because slide directions reverse as the pitchline is crossed, micropitting cracks grow in opposite directions above and below the pitchline. If micropitting grows across the pitchline, it makes the pitchline readily discernible because opposite inclinations of the bases of micropit craters scatter light in opposite directions above and below the pitchline (Refs. 11, 12, 24), as shown in Figure 2. When metallurgical sections are polished and lightly etched with nital, dark etching alterations (DEA) may be found at shallow depths below surface asperities (Refs. 20, 25, 26). DEA locate areas of microscale plastic deformation.

Nonpreferred Names for Micropitting

The micropitting phenomenon has been studied since early 1960 resulting in a vast literature. As is typical of many research subjects, micropitting has a long list of terms used to describe the failure mode. However, by general consensus, the preferred name is micropitting because it aptly describes both the appearance and mechanism. Therefore, to reduce confusion, and to improve communication, the following nonpreferred names are discouraged.

- Asperity microcracking
- Asperity microspalling
- Asperity-scale distress
- Asperity-scale fatigue
- Delamination wear
- Fatigue scoring
- Fatigue wear
- Flecking
- Frosting
- Glazing
- Gray discoloration
- Gray mottle
- Gray staining
- Gray stippiness
- Microcracking
- Microspalling
- Peeling
- Superficial cracking
- Superficial pitting
- Superficial spalling
- Surface distress
- Surface fatigue
- Surface-initiated fatigue
- Surface-origin spalling

Conclusions

Micropitting begins with an incubation period during which damage consists primarily of plastic deformation at asperities. Macroscopically, surfaces appear glazed or glossy. Microscopically, asperity ridges appear as almost featureless flat areas possibly with roughness valleys still discernible. The preferred nomenclature for the damage that occurs during the incubation period is glazing.

After incubation, micropits rapidly nucleate, grow, and coalesce. Macroscopically, a micropitted surface appears dull, etched, or stained with patches of gray. Microscopically, a dense field of micropits of various sizes can be seen. The preferred nomenclature for the damage that occurs during the micropitting period is micropitting.

The root cause of micropitting is plastic deformation that occurs during the incubation period.

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