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The Anatomy of a Micropitting Induced Tooth Fracture Failure – Causation, Initiation, Progression and Prevention

by R.J. Drago, R.J. Cunningham,
and S. Cymbala, Drive Systems
Technology, Inc.



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The Anatomy of a Micropitting Induced Tooth Fracture Failure - Causation, Initiation, Progression and Prevention

Raymond J. Drago, Roy J. Cunningham, and Steve Cymbala, Drive Systems Technology, Inc.

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Micropitting has become a major concern in certain classes of industrial gear applications, especially wind power and other relatively highly loaded somewhat slow speed applications, where carburized gears are used to facilitate maximum load capacity in a compact package. While by itself the appearance of micropitting does not generally cause much perturbation in the overall operation of a gear system, the ultimate consequences of a micropitting failure can, and frequently are, much more catastrophic.

Micropitting is most often associated with parallel axis gears (spur and helical) however, the authors have also found this type of distress when evaluating damage to carburized, hardened and hard finished spiral bevel gears.

This paper presents a discussion of the initiation, propagation and ultimate tooth fracture failure mechanism associated with a micropitting failure. The subject is presented by way of the discussion of detailed destructive metallurgical evaluations of several example micropitting failures that the authors have analyzed on both parallel axis and bevel gears.

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American Gear Manufacturers Association
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Raymond J. Drago, Roy J. Cunningham, and Steve Cymbala,
Drive Systems Technology, Inc.

Foreword

Micropitting has become a major concern in certain classes of industrial gear applications, especially wind power and other relatively highly loaded somewhat slow speed applications, especially where carburized gears are used to facilitate maximum load capacity in a compact package. Although most frequently associated with lower speed gear systems, micropitting can also be observed in high and very high speed gear systems as well though the failure sequence can be somewhat different at the high speed end of the spectrum. While of and by itself, the appearance of micropitting, Figure 1 does not generally cause much perturbation in the overall operation of a gear system, the ultimate consequences of a micropitting failure can, and frequently are, much more catastrophic.

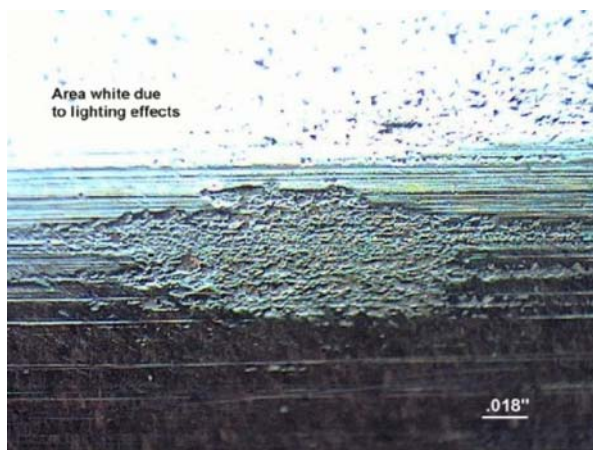


Figure 1. Typical micropitted region

Unfortunately, the micropitting phenomenon, including the underlying causes and analysis methods directed at prevention in the design stage, is not fully understood. Indeed, even the condition to which the term should be applied is subject to some discussion and disagreement. We do not propose, herein, to address the greater subject of classification, analytical evaluation and terminology

in a "Standard" sense. Rather this paper presents a discussion of the initiation, propagation and ultimate tooth fracture failure mechanism associated with a micropitting failure.

The subject is presented by way of the discussion of detailed destructive metallurgical evaluations of several example micropitting failures that the authors have analyzed as a part of larger investigations of tooth fracture failures. Micropitting is most often associated with parallel axis gears (spur and helical) however, the authors have also found this type of distress when evaluating damage to carburized, hardened and hard finished spiral bevel gears. Micropitting observed on both parallel axis and bevel gears will be addressed in this presentation. Although no specific failure "case" is presented, information has been extracted and condensed from several individual actual tooth fracture failure investigations conducted by the authors so that a better understanding of the specific conditions that lead to micropitting and the actual progression from micropitting to fracture can be better understood.

Before we can discuss the occurrence and propagation of micropitting (also known as 'grey staining'), we will have to understand what it is and how it differs from classic fatigue pitting. Micropitting has become a serious problem in high quality, usually ground or otherwise hard finished, carburized industrial gearing, especially in critical applications such as wind turbine, conveyor and some lower speed aerospace gearboxes. While the problem is more often observed in parallel axis gears, it is also observed in bevel gears where the contact conditions are "right."

Macropitting

Until fairly recently, surface durability of gears has been defined by macroscopic pitting (macropitting) in which a crack initiates at a subsurface location where the shear stress exceeds the shear allowable, Figure 2A. When such a crack propagates to

the tooth surface, a small piece (or, more often, several small pieces) of material, Figure 2C, are liberated leaving an inverted cove shaped defect, as shown in Figure 2B.

As this process is repeated, more and more pits appear and eventually the tooth surface is heavily damaged, as Figure 3A shows. Eventually, if the loads are high enough, the pitting damaged region of the tooth acts as a significant stress concentration and bending fatigue failure of the tooth may occur through the pitted region, as shown in Figure 3B.

Micropitting

More recently (over the last 10 to 15 years) a microscopic pitting phenomenon, generally referred to as micropitting, has become a very problematic failure mode in certain applications. Typically where high loading is present at lower speeds under low or marginal film thickness conditions micropitting becomes a significant risk. It is important to note, however, that though it usually appears in a somewhat different presentation, micropitting is also a factor in the operation of higher speed gears as well. In the latter instance, micropitting is frequently

present as a “hard line” that leads fairly quickly to the formation of large spalls that may lead rather rapidly to tooth fracture failures thus the original micropitting “evidence” is often lost in the failure. Extremely careful metallurgical evaluation of the fractures can, however, often pinpoint the micropitting “connection” (Figures 14C and 15 show this type of micropitting failure).

The cause of micropitting is still not fully and completely understood. Initially, it was thought that the cleanliness of the steel might be playing a significant role; however, even where very clean steels are used, micropitting still occurs. Micropitting appears to occur at local surface irregularities including tooling witness lines (Figure 4) and general surface roughness peaks. It has been demonstrated that micropitting capacity can be improved through the use of improved finishing techniques, especially “super finishing” processes which reduce the surface finish down well below 10 RMS. The use of some extreme pressure (EP) additive oils to avoid scoring type failures has also been shown, at least anecdotally, to increase the tendency for micropitting to occur, at least with some formulations.

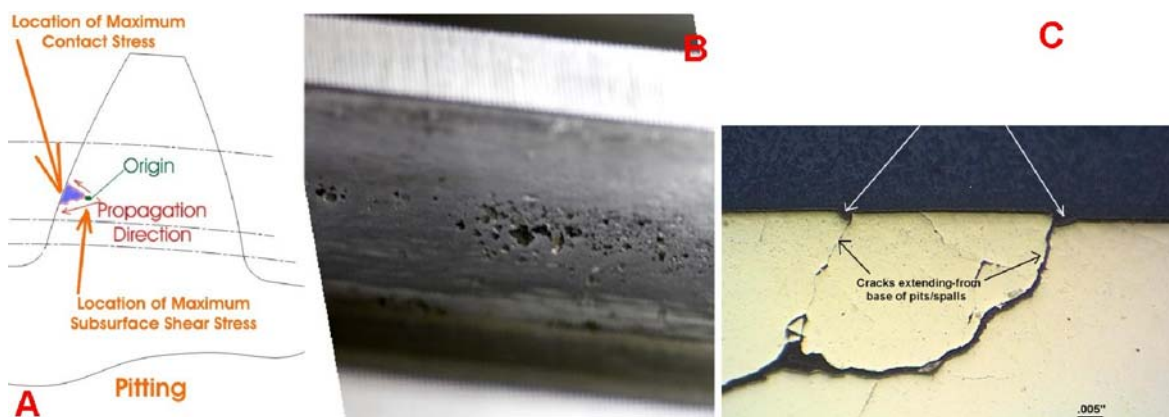


Figure 2. Classical macro pitting fatigue



Figure 3. Heavy pitting often leads to local tooth fracture