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MICROPITTING

Micropitting is a unique gear failure mode that can be eliminated by isotropic superfinishing.

MICROPITTING IS A GEAR FAILURE MODE THAT TYPICALLY occurs when higher contact stresses are applied to hardened gear teeth. Unlike most other failure modes, micropitting does not always proceed to component failure if left unaddressed. However, the direction that micropitting will take cannot be reliably predicted except with frequent inspections [1], and, as a result, steps must be taken to avoid its development.

WHAT IS MICROPITTING

Micropitting is a contact fatigue phenomenon that occurs in rolling/sliding contact environments. When micropitting begins to occur, the surface exhibits microscopic pits that are too small to be detected by the naked eye. As noted, micropitting can be progressive, leading to growth of micropits in size and prevalence. Once the progression is sufficient to be observed without magnification, the affected area will take on a gray appearance. This stage of micropitting is commonly referred as "gray staining."

Figure 1: Example of "gray staining" in the dedendum of a gear tooth

WHY DOES MICROPITTING OCCUR

Micropitting occurs most commonly with case-carburized steels that experience high loads and are operating in a mixed–film elastohydrodynamic lubrication (EHL) environment. Under these conditions, the relative roughness of the mating surfaces and the oil thickness are of the same order, and, as a result, the mating surfaces operating load is shared by the lubricant and the peak surface asperities. In a rolling/sliding contact environment, direct contact of the peak asperities leads to a sharp rise in contact pressure at the asperity level, significantly above that predicated by Hertzian contact theory. This pressure causes plastic deformation at the surface of the material, which has the effect of reducing the peak asperity height, acting akin to a "running-in" mechanism. The plastically deformed surface is highly stressed and is liable to crack under repeated cyclic loading and unloading. The cracks that form start at the peak asperities where the deformation occurs and lead to the generation of micropits.

The growth of the micropits is theorized to be the result of crack propagation caused by lubricant generated hydraulic pressure or "hydraulic pressure propagation" [2]. In short, this theory postulates that lubricant becomes temporarily trapped in surface cracks due to the plastic deformation of peak asperities resulting in a sharp rise in lubricant pressure and, ultimately, the expansion of the crack itself.

ISSUES CAUSED BY MICROPITTING

Micropitting can cause several problems for engineered components. Progressive micropitting causes a loss of component geometry, which can manifest as increased noise, vibration, and loss of efficiency. Additionally, as micropitting grows, the micropits will combine to form a macropit. Macropits are much larger and can undermine the strength of the hardened casing, which, if not caught, will lead to tooth breakage. Even prior to the formation of macropits, it is possible for the micropitting itself to lead to bending fatigue by acting as a failure initiation site.

As noted, not all micropitting will progress to component failure. Micropitting can self-arrest leading to only minor modifications to the component's geometry or profile — effectively a "run-in" step serving to correct minor manufacturing or design errors. The problem is that there is no economical way of predicting which path micropitting will take, so a solution must be sought.

ISO 15144

ISO Technical Report 15144 developed a safety factor calculation for micropitting. This report looked at a number of factors and determined that having a minimum specific lubricant film thickness in the contact area greater than the permissible lubricant film thickness is critical to avoiding micropitting and should therefore have a defined ratio:

$$S_\lambda = \frac{\lambda_{GF,min}}{\lambda_{GFP}} \geq S_{\lambda,min}\mathrm{e}$$ **Equation 1**

where:

S_λ — safety factor against micropitting
$\lambda_{GF,\,min}$ — minimum specific lubricant film thickness in the contact area
λ_{GFP} — permissible specific lubricant film thickness
$S_{\lambda,\,min}$ — minimum safety factor

The minimum specific film thickness in the contact area is derived from the local film thickness and the surface roughness:

$$\lambda_{GF,Y} = \frac{h_Y}{Ra}$$ **Equation 2**

where:

$\lambda_{GF,Y}$ — local specific lubricant film thickness
h_Y — local lubricant film thickness
Ra — the effective arithmetic mean roughness value

Based on these formulas, it is clear that there are two primary factors that must be considered in order to eliminate micropitting: lubricant film thickness and surface roughness. As discussed in the March 2016 Materials Matter column, increasing lubricant viscosity detrimentally impacts system efficiency. Lubricant additive packages (a third potential factor) have their own risks and have not been shown to be a universal solution. Therefore, improving surface roughness would seem to be the optimal solution to micropitting.

FZG TESTING METHODOLOGY

FZG micropitting gear testing is an accepted procedure for evaluating micropitting. This testing uses a back-to-back gear test rig with a tooth profile designed to show micropitting relatively quickly and involves two test phases. The first phase is a sequential load stage test where the gears are inspected after each load stage for evidence of micropitting. Failure is defined as profile deviation greater than 7.5 µm. The second phase is an endurance test designed to see the progression of micropitting over time. It is run at the highest load stages to give an accelerated picture. Failure is defined as the point at which profile deviation exceeds 20 µm.

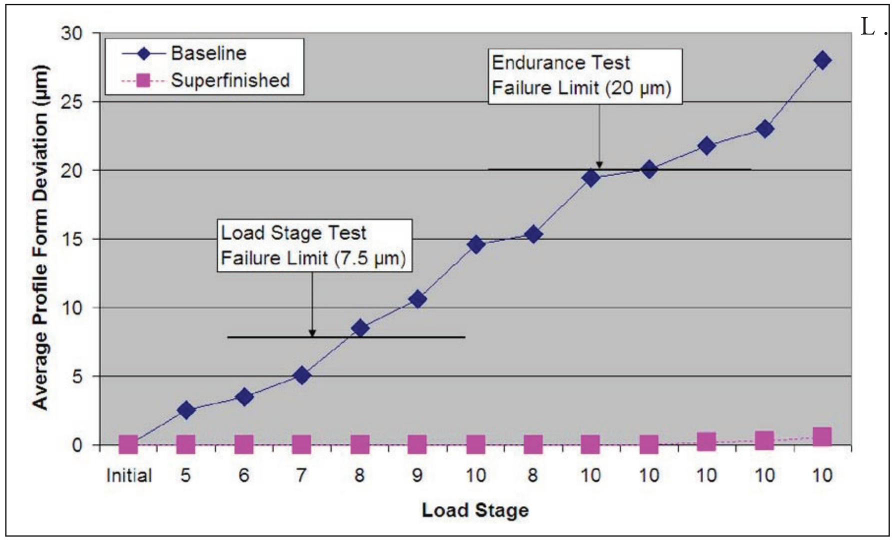

Figure 2: FZG testing results of isotropically superfinished versus ground gears

A SOLUTION TO MICROPITTING

In an effort to find a solution to micropitting, a study was conducted by REM Surface Engineering, Winergy AG, and the University of Bochum using the FZG testing methods previously described. The testing compared components with a ground surface finish against components with an isotropic superfinish — obtained using REM's ISF® Process [3]. As shown in Figure 2, the isotropically superfinished gears exhibited no micropitting and almost no profile deviation through both test methodologies. In comparison, the baseline ground gears failed the first testing phase at load stage eight and the second testing phase at the third full endurance stage. The results of the isotropically superfinished gears are even more impressive from the perspective that the profile of FZG micropitting test gears is specifically designed to induce micropitting. The total profile deviation of the ISF gears was only 0.5 µm, and no micropitting was generated.

CONCLUSION

Micropitting is a gear failure mode that, while not always inducing failure, must be treated as an unacceptable occurrence given the inability to economically or effectively predict its progression. Per ISO, lubricant film thickness and surface roughness are the critical parameters that influence micropitting. Modification of lubricant viscosity has unattractive consequences and is not a root cause solution to micropitting. Reduction of surface roughness via isotropic superfinishing is a tested and verified root cause solution to the problem of micropitting.

REFERENCES

1. B. Pinnekamp, T. Weiss, and G. Steinberger, "Micropitting – A Serious Damage? Testing, Standards and Practical Experience, " AGMA Fall Technical Meeting, Cincinnati, OH, 2011, 11FTM15
2. Robert Errichello, "Morphology of Micropitting," AGMA Fall Technical Meeting, Cincinnati, OH, 2011, 11FTM17.

Winkelmann, O. El-Saeed, and M. Bell, "The Effect of Superfinishing on Gear Micropitting, Part II, "AGMA Fall Technical Meeting, Milwaukee, WI, 2010, 08FTM10.

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