MATERIALS MATTER

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SCUFFING

The risk of scuffing, a non-fatigue-based failure mode, can be reduced via isotropic superfinishing.

GEAR MESHING IS ONE OF THE MOST complex areas of study in tribology. Meshing consists of both sliding and rolling motion and can be affected by a number of other operating parameters. This complex combination of parameters can result in a number of different gear failure modes — one of which is scuffing.

THE THEORY OF SCUFFING

Scuffing is the sudden failure of the lubricant layer during operating conditions, normally occurring under high load or high speed. It occurs in sliding environments on components such as gears and bearings. In gear mesh, it is desirable to have a film of lubricant separate the two mating components. Ideally, the lubricant should fully bear the operating load thereby preventing peak asperity contact. Full film separation of the components serves to make them last longer and operate with reduced friction. Should the lubricant break down, creating mixed or boundary lubrication conditions, then the two mating surfaces will come into direct contact. The transition from full film separation to mixed film separation and the associated surface interaction results in a sudden rise in friction and heat. This rapid increase in heat can cause the two surfaces to momentarily weld together. As the mating surfaces move out of the contact zone, the weld is torn apart, causing a gross transfer of material from one component surface to the other. This occurrence is defined as scuffing.

In gears, scuffing appears as rough-edged scratches, usually at the extreme ends of the contact path where sliding is at a maximum. It can often be found that, due to the intense surface temperatures generated by the lubricant breakdown, a scuffed region will have significantly higher austenite content than the as-manufactured surface. This effect is shallow, only about 5 microns, but it demonstrates the levels of heat generated during a scuffing event.

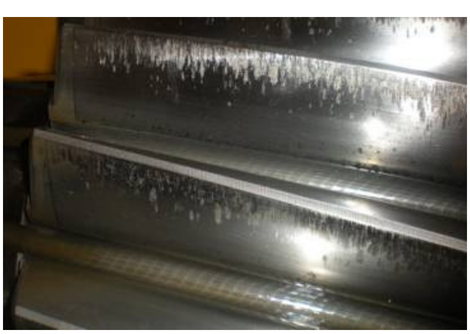

Figure 1: Example of scuffing damage

Much like fatigue-based failure modes, scuffing causes a large degradation of the surface's geometry, leads to inefficiency in the system, and can potentially cause catastrophic failure. Unlike fatigue-based failure modes where repeated loading and unloading leads to failure after many cycles, scuffing can occur at any point in a component's life cycle. As a result, designing a component to have adequate resistance to scuffing is critical to avoid premature failure.

There are a number of proposed theories as to why scuffing occurs, but the most commonly accepted line of thought is that it is related to lubricant critical temperature. This concept was first proposed by Blok in 1937 [1-3]. It is based on observations that scuffing is linked to the bulk temperature of the component and the instantaneous flash temperature rise, which occurs as the surfaces pass through the contact zone.

In 1976, Dyson [4] proposed a theory as to why the lubricant would suddenly flash off. The theory states that as the gears come into mesh, the Hertzian contact pressure is increased. As the lubricant is exposed to the peak Hertzian pressures, its viscosity increases. This viscosity increase leads to the lubricant exhibiting properties similar to that of a solid. As the lubricant exhibits more solid-phase properties, this causes a further increase in temperature due to the increase in friction between the two moving surfaces. The increasing temperature starts to offset the viscosity increase, and the competing systems form a dynamic equilibrium in the contact zone. The theory proposes that at a critical temperature, the dynamic equilibrium will cease, causing the viscosity to fall rapidly and leading to a breakdown in the elastohydrodynamic layer (EHL). This viscosity breakdown leads to the direct contact and gross welding of the mating surfaces.

ISOTROPIC SUPERFINISHING AND SCUFFING

The surface roughness of the mating components and the chosen lubricant (and its operating properties) are primary factors in determining the potential for scuffing. In gear mesh, the lubricant thickness is greatest across the pitch line where the system exhibits pure rolling action. At the extremities of the contact zone, the gear exhibits pure slide and therefore has the lowest lubricant film thickness.

Surface roughness must therefore be taken into account relative to operating lubricant film thickness in these regions. Surface roughness and texture play a critical role in determining the pressure through the concentration of the load in the micro-asperity regions (see the April 2016 Materials Matter column on power density). Furthermore, the inherent friction created by the surface roughness causes the lubricant to build up bulk temperature. Therefore, as a reasoned overview, it is logical that enhanced film thickness associated with a reduced surface roughness will have less susceptibility to a sudden lubricant film collapse.

The various aspects of isotropic superfinishing and isotropic superfinishes that have been discussed in previous Materials Matter columns include how an isotropic superfinish lowers surface roughness, creating a unique surface texture; increases gear performance; and enables maintenance of full EHL over a wide variety of operating conditions. Given the theoretical connection between improved surface roughness and reduction in scuffing risk, isotropic superfinishing should be studied in this aspect. Such a study was conducted by Professor R.W. Snidle and colleagues in conjunction with REM Surface Engineering into the effect of superfinishing on scuffing resistance using Cardiff University's scuffing twin disc test bench [5]. This test bench operates with 12 sequential, increasing load stages, each lasting three minutes. The highest load stage that the test bench can achieve is 4,150 N of load, representing a Hertzian pressure of 1.7 Gpa.

As part of the study, four surface finishes were reviewed. The investigation concluded that REM's ISF® Surface provided the most consistent scuffing resistance, as no scuffing occurred even during an endurance cycle that was conducted at the maximum load. A summary of the results is presented in Figure 2.

As shown, isotropic superfinishing has a positive influence on scuffing resistance. However, it is important to note that other studies have shown superfinished surfaces that are completely devoid of texture to exhibit inferior scuffing resistance as compared to isotropic superfinished surfaces, which, by nature, have a subtle, non-directional texture.

	Baseline			ISF®		
Test	1	2	3	1	2	3
Average Ra (μm)	0.4			0.03		
Sliding Velocity (m/s)	16	16	16	16	16	16
Scuffing Load	2320	2320	2320	4150*	4150*	4150*
Maximum Peak Hertzian Contact Pressure (GPa)	1.4	1.4	1.4	1.7	1.7	1.7
Mean Bulk Temperature of Discs (^{O}C)	189.5	186.5	191	170	N/A	155

*Did not experience scuffing failure.

Figure 2: Comparison of baseline twin disc performance versus the isotropically superfinished twin discs scuffing testing

CONCLUSION

Scuffing is a consequence of a rapid shift in the dynamic equilibrium in the contact zone between the compressed solid-like lubricant film and the temperature. Decreasing surface roughness, particularly through isotropic superfinishing, will significantly increase scuffing resistance as a result of the increased lubricant film thickness and the lower inherent friction of the surfaces. Given the difficulty in predicting scuffing and the lack of early warning signs, it seems reasonable that any scuffing-prone applications should consider utilizing isotropic superfinishing to reduce the risk of scuffing failures.

REFERENCES

1. H. Blok, in: Proc. 2nd World Petroleum Congress, Sect. IV, Vol. III (1937) pp. 471486.
2. H. Blok, in: Proc. General Discussion on Lubrication & Lubricants, u 2 (1937) pp. 225-235.
3. H. Blok, in: Proc. General Discussion on Lubrication &Lubricants, Vol. 2 (1937) pp. 14-20.
4. A. Dyson, in: Proc. Institute of Mechanical Engineers, Vol. 190, No. 1 (1976) pp. 52-76.
5. L. Winkelmann, M. Michaud, R. Snidle, M. Alanou, "Effect of Superfinishing on Scuffing Resistance," ASME DETC, Chicago, Illinois, 2003, DETC2003.

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