Superfinishing and its Effect on Micropitting

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1. Introduction

Micropitting is a prominent failure mechanism for both highly stressed case carburized gears [1, 2 & 3] and bearings that operate consistently in low speed, low load environments where boundary conditions predominate [4].

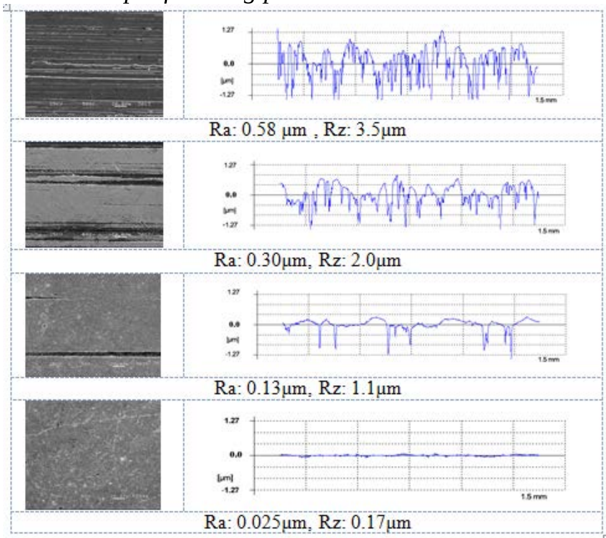
Lubricant regime is controlled by lubricant film thickness and roughness. Studies on gears investigating these two critical factors conclude that the surface roughness is more important than the elastohydrodynamic lubrication film thickness [5].

Superfinishing is an imprecise term usually applicable to technologies which reduce the surface roughness below that of a standard ground condition. Broadly two different approaches are taken; one seeks to maintain the periodic profile and reduce the peak and valley heights. The second seeks to remove the periodicity and create an isotropic surface profile.

Isotropic surfaces are formed through a variety of planarizing techniques that sequentially reduce the asperity height, starting with the peak asperities (Figure 1).

Under mixed lubrication the peak asperities are able to contact during motion, creating friction and surface damage. Removal of these asperities enables the contact to remain in the full elastohydrodynamic lubricant regime more consistently.

Figure1. Illustrates the progressive levelling effect of isotropic finishing processes.



Chemically accelerated vibratory finishing is one such subset of isotropic superfinishing. This technique is applicable to a range of metallic parts such as gears and bearings and is able to reduce the Ra <0.1µm and Rz < 1µm. It has been shown to have significant positive impact on case carburized gears [6] producing a range of benefits from noise reduction, increased efficiency, and improved lubrication.

2. Safety Factor

To assist the elimination of Micropitting in cylindrical gears the following safety factor [7] was created (Equation 1).

$$S_\lambda = \frac{\lambda_{GF,min}}{\lambda_{GFP}} \geq S_{\lambda,min} \tag{1}$$

S_λ	– Safety factor
$\lambda_{GF,min}$	– Minimum specific lubricant film thickness in the contact area
λ_{GFP}	– Permissible specific lubricant film thickness
$S_{\lambda,min}$	– Minimum required safety factor

Cassimere et al [8] investigated the theoretical impact superfinishing would have using this equation and its subcomponent, $\lambda_{GF,min}$. This is the minimum film thickness calculated in the contact area; termed $\lambda_{GF,Y}$ (Equation 2).

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

Combining these equations you generate (Equation 3).

$$S_\lambda = \frac{h_Y}{Ra \times \lambda_{GFP}} \geq S_{\lambda,min} \tag{3}$$

They deduced that by assuming the safety factor generated was 1, the h_Y and λ_{GFP} terms would be equal leaving just the residual roughness parameter (Equation 4).

$$S_\lambda = \frac{1}{Ra} \geq S_{\lambda,min} \tag{4}$$

To identify the magnitude of surface roughness's impact, the authors made the assumption that a gear with an arithmetic average roughness (Ra) of 0.51µm would have a safety factor of 1. Were this gear to be subsequently superfinished to a Ra 0.1µm, the safety factor would increase to 5, indicating an interesting design solution to prevent micropitting.

3. FZG Test Protocol

It has been shown through current micropitting theory and by mathematical manipulation of the ISO safety factor calculation that chemically accelerated superfinishing should be a powerful tool for preventing micropitting. This theory was tested by independent laboratories using FZG-Type C gears. One test utilised the Brief Test GFKT following the DGMK 575 protocol. The second test utilised the standard test GT using the FVA 54/I-IV protocol.

The two tests utilise the same gear design and test loadings, but vary in the how the lubricant is applied either sprayed (standard test) or splashed (brief test), the type of lubricant utilised, the number of load stages and duration.

Both tests require the gears to be inspected after each load stage for the average profile form deviation, the area covered in micropitting, and the weight lost. The failure criterion is exceeding 7.5μm mean profile form deviation during the load stages or 20μm during the endurance test as part of the standard test.

4. Brief Test

The brief test for micropitting was carried out by researchers at the Technische Universität München. The test utilised a lubricant (FVA 2 + 2% LZ 677 A) with a known low micropitting resistance. Each gear pair was tested twice, once on either flank.

Testing comprises of just two loaded stages for a duration of 16 hours per stage (Table 1).

Table 1. Test Conditions for the brieft test

Load Stage	Torque on Pinion [Nm]	Hertzian Contact Pressure at Pitch Point [N/mm^2]	Testing Time [Hrs]
3 (Run-in)	28.8	510.0	1
7	132.5	1,093.9	16
9	215.6	1,395.4	16

4.1 Brief Test Results

Figure 2. Brief test using ground gears.

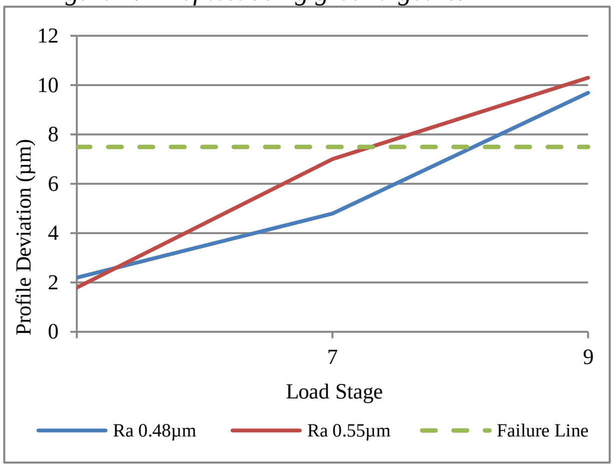


Figure 3. Brief test using superfinished gears.

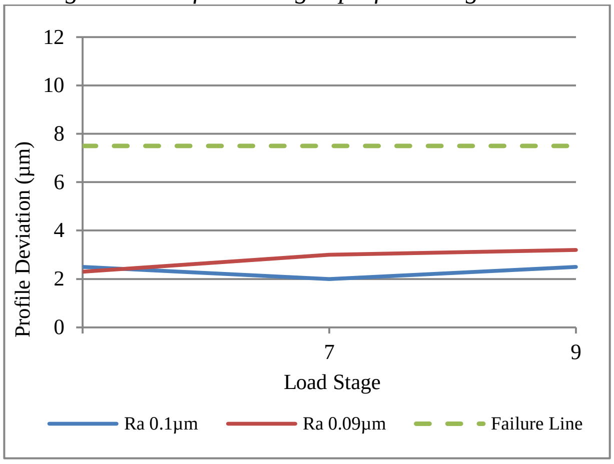
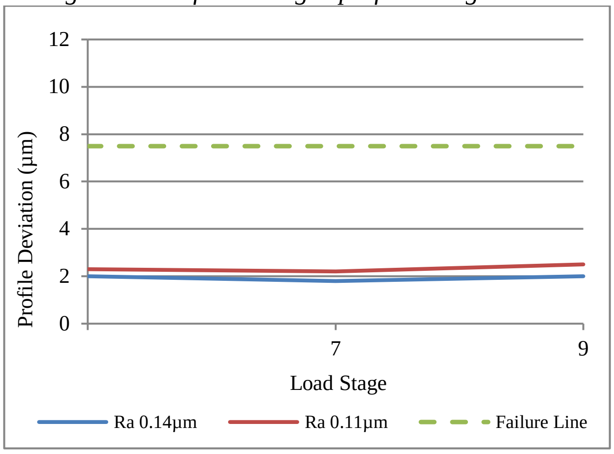


Figure 4. Brief test using superfinished gears.



To summarise the results the average profile deviation is shown in Table 3. This result indicates that isotropic superfinished gears are resilient to micropitting with minimal profile deviation documented. This is in contrast to the ground gears that showed a 16 fold increase in profile deviation compared to the superfinished gears.

Table 2. Brief test results averaged.

Condition	Average Change in Profile Deviation (μm)
Ground	8
Superfinished	0.4

5. Standard Test

The standard test was conducted by the Ruhr Univseritãt Bochum. They performed two tests, one utilising only the load stage. The second repeated the load stage test followed by the endurance cycle.

A mineral oil (ISO VG220) with an additive to reduce micropitting capacity was used in the test to aid differentiation.

Table 3. Test Conditions for the standard test.

Load Stage	Torque on Pinion [Nm]	Hertzian Contact Pressure at Pitch Point [N/mm^2]	Testing Time [Hrs]
3 (Run-in)	28.8	510.0	1
5	70.0	795.1	16
6	98.9	945.1	16
7	132.5	1,093.9	16
8	171.6	1,244.9	16
9	215.6	1,395.4	16
10	265.1	1,547.3	16
8	171.6	1,244.9	80
10	265.1	1,547.3	80
10	265.1	1,547.3	80
10	265.1	1,547.3	80
10	265.1	1,547.3	80

5.1 Standard Test Results

Test 1 utilising only the load stage had a mean contact Ra of 0.48µm for the ground gears and 0.1µm for the superfinished gears.

Figure 5. Test 1 results

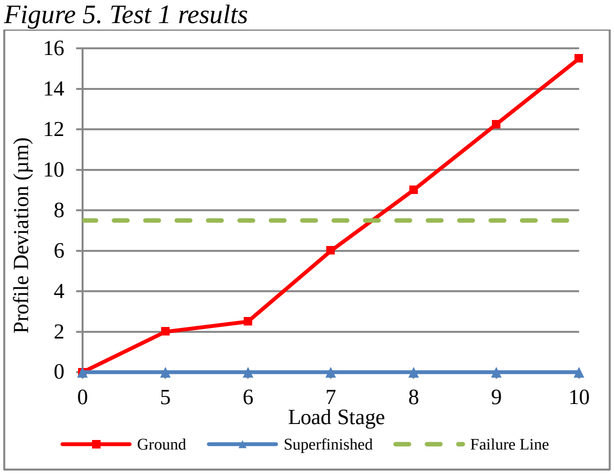


Table 4. Test 1 result after load stage.

	Ground	Superfinished
Profile Deviation (µm)	14	0
Wear (mg)	54	7
% Micropitting Coverage	60	0

Test 2 utilised the load stage and endurance test. The gears had a mean Ra of 0.465µm for the ground gears and 0.095µm for the superfinished condition.

Figure 6. Test 2 results

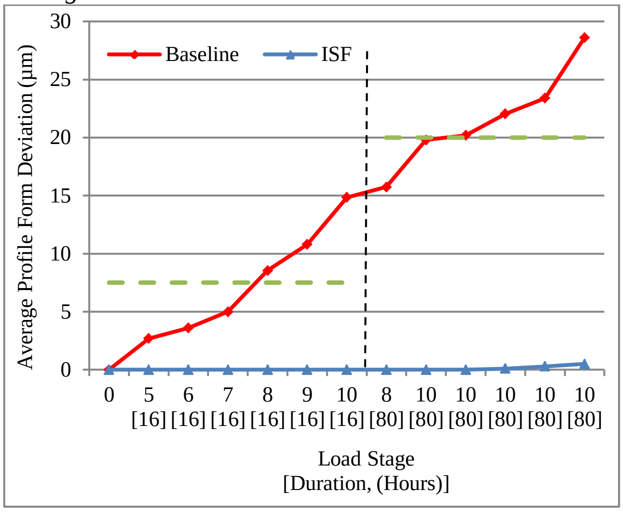


Table 5. Test 2 results after load and endurance test.

	Ground	Superfinished
Profile Deviation (µm)	28	0.5
Wear (mg)	129	6
% Micropitting Coverage	80	0

Both tests confirm the results from the Brief Test, that isotropically superfinished gears are able to increase the micropitting carrying capacity, despite the use of an unfavourable lubricant.

6. Conclusions

- Chemically accelerated superfinishing is able to reduce the gear flank roughness to <0.1µm Ra
- The ISO safety factor highlights the importance of roughness on micropitting resistance.
- Test data shows that isotropic superfinishing increases the micropitting carrying capacity of the gear.

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