The Effect of Superfinishing on Gear Micropitting Part 1

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Abstract

The most common failure mechanism of highly stressed case carburized gears is micropitting (gray staining). The standard FZG gear test (FVA Work Sheet 54) is generally used to determine the micropitting load capacity of gear lubricants. In recent years, FZG gear testing has also demonstrated its usefulness for evaluating the effect of superfinishing on increasing the micropitting load capacity of gears. Such studies, however, can only be afforded by major corporations or research consortiums whereby the data is typically kept confidential.

This paper presents the results of two detailed studies on the effect of superfinishing on FZG gear micropitting that were conducted at two leading European gear research centers:
1) Technical University of Munich *using the FZG brief test of gray staining.*
2) Ruhr University Bochum *using FVA-Information-sheet 54/I-IV.*

Both research groups concluded that superfinishing is one of the most powerful technologies for significantly increasing the load carrying capacity of gear flanks. *This paper presents the results from the University of Munich. A later paper will present the results from Ruhr University Bochum.*

Background

When seeking to eliminate gear failure of case carburized gears the most practical approach is to eliminate the primary form of failure: micropitting (gray staining). The distressed micropitted surface will, as two gears move in mesh together, increase the wear of the opposite tooth flank. As expected the longer a micropitted surface is run against another, the greater the resulting wear. This manifestation of wear causes damage to the flanks of gear teeth by enlarging microcracks and other microscopic disruptions of the surface. This damage decreases the life of case hardened gears and limits the load-bearing capacity by serving as initiation sites for catastrophic gear failure.

Various methods have been used to reduce micropitting in the past, but often sacrifice much. For instance, lubricant additive packages are able to reduce micropitting, but may also increase the wear rate or degrade under elevated temperatures or pressures. Alternatively, applying a coating to the gear flanks can be used to alleviate micropitting[1]. During testing cycles coatings may perform well, but under long term working conditions, often wear or flake off. This increased debris increases the contact area wear rate, and/or travels to and destroys bearings.

The FZG *Brief Test of Gray Staining* (BTGS) is a supplement to the FZG micropitting test[2] and is economical in terms of time and costs. The BTGS is a method of determining how variables such as lubricants, lubricant temperature, coatings and surface finishes influence micropitting.

Specimen

Three sets of FZG gears were tested; all gears were the sliding-speed-balanced tooth configuration “FZG”, type C-GF. Each set was comprised of a gear and a pinion. Geometric data of the gears, tooth quality, heat treatment and material data are consistent across all of the gear sets. Refer to Table 1 for geometric data of the gears and Table 2 for tooth quality heat treatment and material data.

Parameter		Value
Axle distance		91.5 mm
Tooth width		14.0 mm
Rolling circle diameter	Pinion	73.2 mm
	Gear	109.8 mm
Tip diameter	Pinion	82.46 mm
	Gear	118.36 mm
Module		4.5 mm
Number of teeth	Pinion	16

	Gear	24
Addendum modification coefficient	Pinion	0.1817
	Gear	0.1715
Pressure angle		20º
		22.44º
Helix angle		0º
Reference diameter	Pinion	72.0 mm
	Gear	108.0 mm
Base diameter	Pinion	67.66 mm
	Gear	101.49 mm
Transverse contact ratio		1.46
Tooth correction		Without tip and root relief; no crowning

Table 1: Geometric data of the test gear and pinion teeth for the BTGS

Material	16 MnCr 5 (DIN 1721 0)
Heat treatment	Case carburized: 750 HV 1 Case depth: EHT 550 HV 1: 0.8 - 1.0 mm (after finishing) Core strength 1000-1250 N/mm^2
Tooth quality	5 (DIN 3962) f_f = 5 µm. 5, f_f = 5 µm (DIN 3962) Pinion tooth width: 34.779 mm Gear tooth width: 35.252 mm
Inital Surface Roughness	$R_a = 0.5 \pm 0.1$ µm
Finish	Maag finish

Table 2: Test gear specifications for C-GFU specimens for all gears prior to superfinishing

All three sets were specified to have an initial roughness average (R_a) of 0.5 ± 0.1 µm. One set was to be used for baseline comparison. The two remaining sets were superfinished by vibratory finishing as well discussed elsewhere. [3,4] As a result of the superfinishing, the surface R_a was under 0.15 µm. Both sides of the gear teeth were tested.

Test conditions

In accordance with DIN51354 the BTGS is performed on a standard FZG warping test bench with splash lubrication. The test gear is installed on the motor shaft while the test pinion is the driving gear. The standard test conditions for the DGMK BTGS were used, and are compiled in Table 3, while Table 4 contains torque and Hertzian stresses for each power level.

Pinion rotational speed	8.3 meters/sec
Circumferential speed on the working circle	0.00383 meters/sec
Driving test gear	Pinion
Lubrication	Splash lubrication about 1.5 liters
Oil sump temperature	90 ± 2 °C
Running time for run-in (power level 3)	~ 1.0 hr 1.3×10^5 pinion revolutions
Running time per power level in staged test	~ 16 hr 2.1×10^6 pinion revolutions

Table 3: Test conditions in BTGS.

Power level	Torque at the pinion in [Nm]	Hertzian stress in the rolling point p_c in [N/mm^2]
3 (run-in)	28.8	510.0
7	132.5	1093.9
9	215.6	1395.4

Table 4: Power levels of the BTGS performed.

The lubricant used was FVA 2 +2% LZ 677A. This oil and additive is known to have relatively low micropitting resistance, and was selected for this test based on this criteria. Since operational temperature is a separate factor of a lubricant’s micropitting resistance, the sump temperature in all three tests was held constant. A thermostat held the oil sump at 90 ºC on all six test runs to ensure that the lubricant’s additive package would perform equally across all tests.

The test consisted of a ~1.0 hour run-in cycle at power level 3 followed by ~16 hour duration loaded cycles at power level 7 and 9 respectively. The gears were measured and observed following each loaded cycle. Each measurement was of three teeth spaced equally around the circumference of the gear. The measurement consisted of a profile form deviation, and the final measurement included a picture of the final condition of the three tooth flanks that were measured.

The test for micropitting on the FZG gears is correlated to the maximum profile deviation, or wear. This correlation is due to the deformation caused by micropitting. As such, the tests conducted for this study use this profile deviation (wear) to determine the effects of superfinishing on micropitting reduction.

Data

Concluding all test runs, each gear set was classified into BTGS low, medium, or high resistance to micropitting. The BTGS classifications are defined relative to when the wear exceeds the 7.5 µm failure limit. As shown in Table 5, BTGS low fails after the power level 7 loaded cycle, BTGS medium fails after the power level 9 loaded cycle, and BTGS high does not fail by the conclusion of testing.

Micropitting resistance	Criteria for micropitting resistance classification.
BTGS-low	Wear after Power Level 7 exceeds 7.5 µm
BTGS-medium	Wear after Power Level 9 exceeds 7.5 µm
BTGS-high	Wear after Power Level 9 does not exceed 7.5 µm

Table 5: Categorization of micropitting resistance.

In two runs, the gears specified to have a R_a of 0.5 ± 0.1 µm (or non-superfinished, baseline gears) had average micropitting resistance, according to the researcher's experience. The two runs exhibited the same results with minimum dispersion. The first run, A-1, had an arithmetic roughness average ($R_{a\ test}$) of 0.48 µm (where $R_{a\ test} = ((R_{a\ gear} + R_{a\ pinion}) / 2))$ prior to testing and ended with 9.7µm wear. The second run, A-2, had a $R_{a\ test}$ of 0.55 µm initially and finished with an wear of 10.3 µm. Both tests resulted in a failure after power level 9, and confirm that the lubricant selected exhibits average micropitting (BTGS-medium) for the investigated operational temperature range of 90 °C. The progression of the wear of these trials is present in Graph 1, and images of the final condition of the three equally spaced tooth flanks along the circumference are given in Figures 1 and 2.

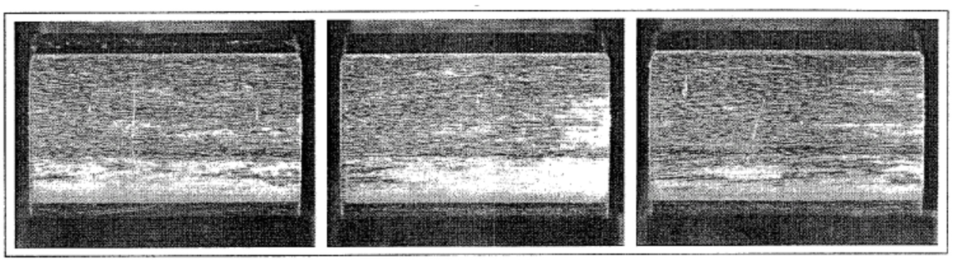


Figure 1: Evidence of micropitting on first baseline run A-1.

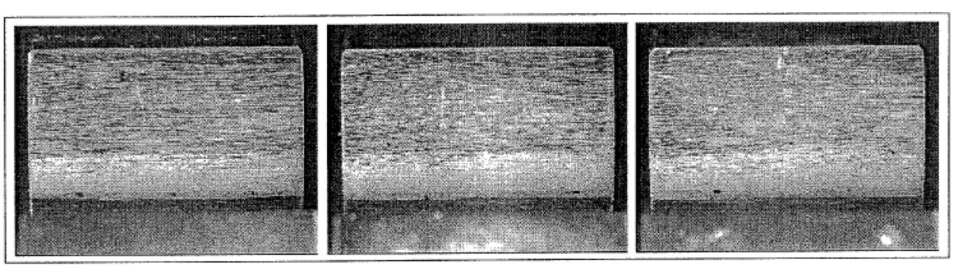
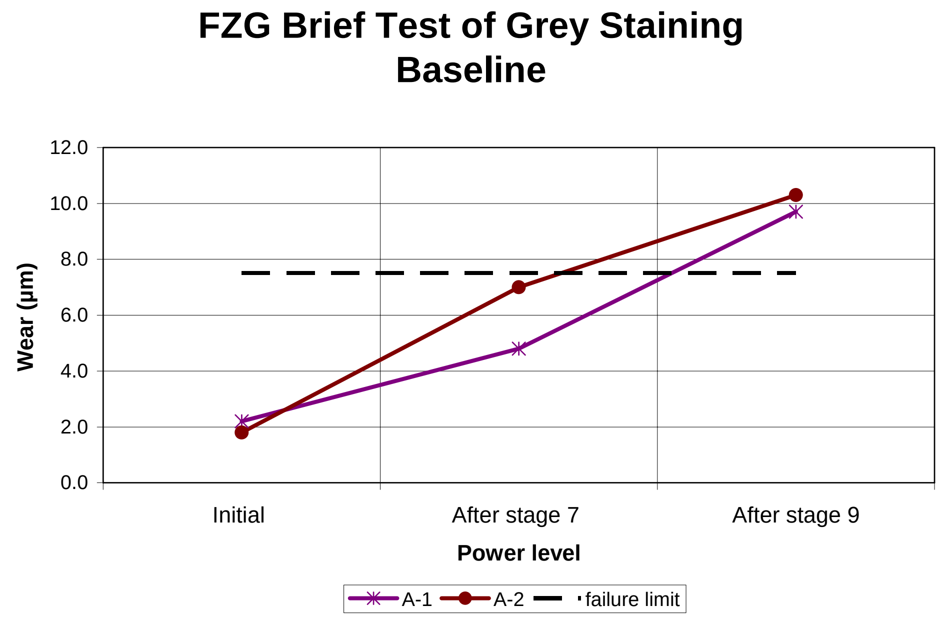


Figure 2: Evidence of micropitting on second baseline run A-2.



Graph 1: Stage by stage breakdown of the wear from BTGS on A-1 and A-2.

In the first test of superfinished FZG C-GF gears, the $R_{a\ test}$ of the controlled tooth flanks was 0.10 µm and 0.09 µm for the first and second run respectively. The first run had a wear 2.5µm while the second had 3.2 µm, shown in Graph 2. The lack of any discernible micropitting is shown in Figures 3 and 4.

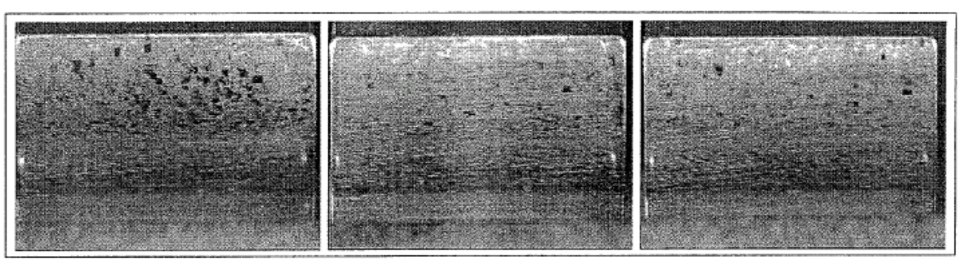


Figure 3: Image of tooth flanks following BTGS testing with no micropitting from test B-1.

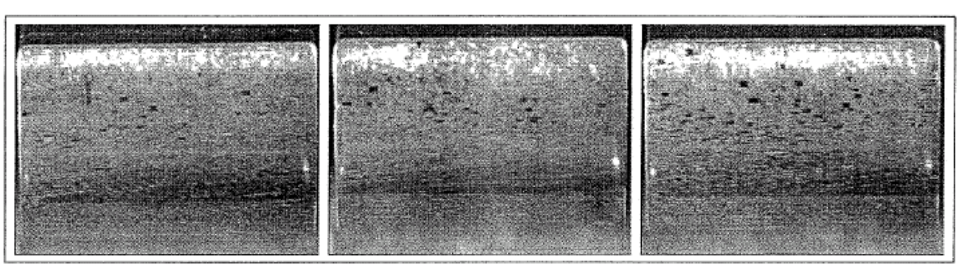
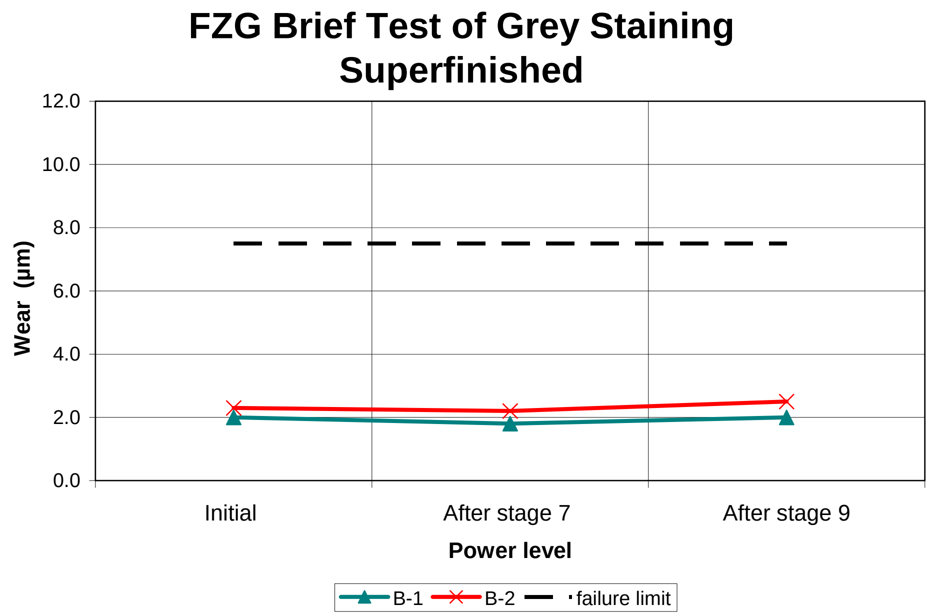


Figure 4: Image of tooth flanks following BTGS testing with no micropitting from test B-2.



Graph 2: Stage by stage breakdown of the wear from BTGS on B-1 and B-2.

In the second test of superfinished FZG C-GF gears as processed by vibratory finishing, the $R_{a\ test}$ of the tooth flanks was were 0.14 µm and 0.11 µm for the first and second run respectively. The first run concluded with a wear of 2.0 µm while the second run had a measured wear of 2.5 µm. As seen with first set of superfinished gears, wear for this second set of superfinished gears was minimal as illustrated in Graph 3. The lack of any discernible micropitting is shown in Figures 5 and 6.

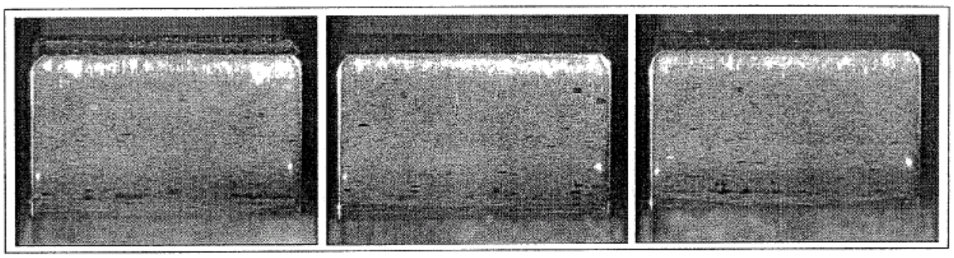


Figure 5: Image of tooth flanks following BTGS testing with no micropitting from test C-1.

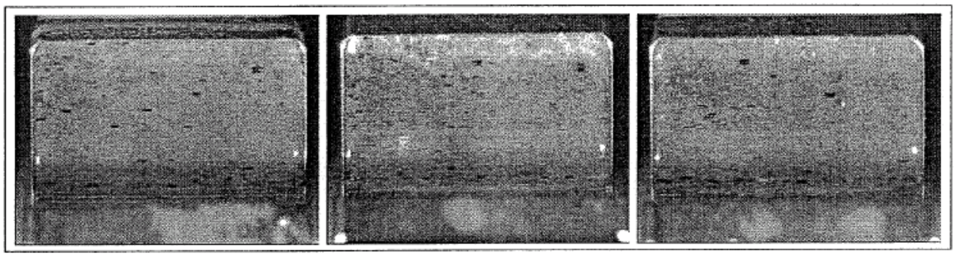
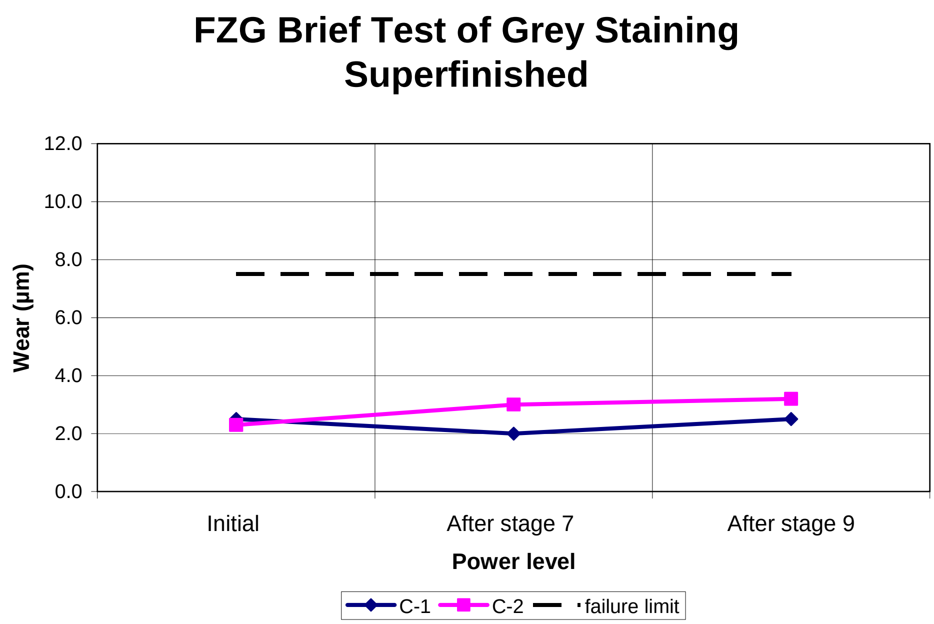


Figure 6: Image of tooth flanks following BTGS testing with no micropitting from test C-2.

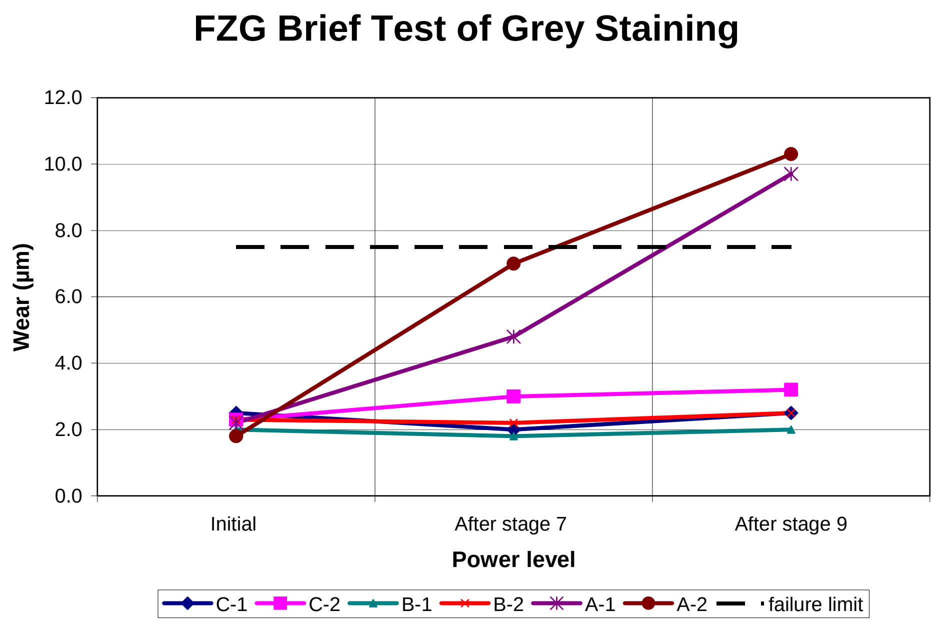


Graph 3: Stage by stage breakdown of the wear from BTGS on C-1 and C-2.

Analysis

On the baseline set, micropitting was observable by the naked eye on the gear flank. However, on both sets of superfinished FZG gears, micropitting was undetectable. By lowering the R_a to approximately 0.10 µm, wear was reduced.

The data plotted together in Graph 4 shows that the only failures were A-1 and A-2 which were the baseline samples that were ground with no superfinishing. None of the four superfinished runs came close to the failure limit even after the completion of the test. Additionally, it was noted that there was no discernible region on the superfinished gears that had micropitting. There was also not any increase in the wear after the BTGS.



Graph 4: Wear summary. A-1 and A-2 are baseline while B-1, B-2, C-1 and C-2 were superfinished. The failure limit is defined at 7.5µm.

Conclusions

Superfinishing significantly reduces micropitting, even on the BTGS which was designed to quickly induce micropitting. These findings stress the importance of surface finish for resisting the formation of micropitting.

This information could be beneficial to the lubrication industry. Superfinished gears may use a simplified additive package.

Since the superfinished surfaces did not fail during the BTGS testing, the superfinished surfaces were further studied in the more rigorous standard FZG micropitting test. These results will be provided in Part II of this paper.

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References:

[1] Joachim, Franz, Norbert Kurz, and Bernhard Glatthaar. “Influence of coatings and surface improvements one the lifetime of gears”. International Conference on Gears. March 13-15,2002. Munich Germany. VDI Report 1665.

[2] Forschungsvereinigung Antriebstechnik, E.V, “FVA Information sheet” Research Projects Nr. 54/I-IV, 1993

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[4] Arvin, J., A. Manesh, M. Michaud, G. Sroka, and L. Winkelmann. “The Effect of Chemically Accelerated Vibratory Finishing on Gear Metrology,” 02FTM1, AGMA Fall Technical Meeting, St. Louis, MO, October 2002.