# Influence of shot peening and superfinishing on gears as a repair tool of damaged faces of teeth generated by overheating when grinding.

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**Abstract**

Hard finishing by grinding of case hardened gears is a common process in the gear industry with final roughness of the flank normally Ra= 0.2 – 0.5 µm. The grinding operation has a mechanical and thermal influence on microstructure, hardness and residual stress. An improper grinding process can induce surface tempering, alter hardness and lead to an unfavourable residual stress state.

Especially in the aerospace and wind power industry all gears are checked after grinding on the flanks in case of overheated areas. Any damaged flanks show a reduction in load capacity from 6% to 32%.

The German Gear Association ( FVA ) set up a research program to test gears with overheated grinding zones. They tested flank conditions which were slightly tempered; strongly tempered and re-hardened.

The shot peening process was tested as a repair tool of these damaged gears.

The paper will present the results of the different treatments, including shot peening, followed by a superfinishing process.

**Keywords** grinding burn, surface tempering, flank-load-capacity, shot peening, superfinishing, case hardened gears

## Experimental Methods

The experimental tests were carried out with two different gear geometries and materials; $m_n$ = 3 mm, material 16MnCr5 and $m_n$ = 5 mm, material 18CrNiMo7-6. All gears of the same geometry were milled in the same way and case hardened in one lot; hardness 59 – 63 HRc. After heat treatment the gears were cleaned by grit blasting. The flanks of the test gears were finished in a discontinuous generative grinding process at the research center (FZG) of the University of Munich. The profile grinding process was carried out by a collaborating company. By a specific variation of the grinding parameter, different grades of defined grinding burn on the test pinion flanks were produced.

The tooth flanks of all test pinions were examined by surface temper etch inspection, according to ISO 14104 [2] and assigned to the corresponding test series (grinding burn grades).

Classification according to ISO 14104:

Class:
- A No tempering
- B Light tempering
- D Heavy tempering
- E Rehardening, severe overheating

Level: Maximum level of affected flank area
- 1 < 10 %
- 2 10 - 25 %
- 3 > 25 %

To check whether shot peening can be used as a repair tool of damaged faces of teeth by overheating when grinding, Metal Improvement Company shot peened the test series FB2-II, FD3-II, FE3-II and FD3-I after hard finishing.

| Shot Peening Parameter, dual process: | | 1. process | 2. process |
|---|---|---|---|
| | Shot: | MI 330 H | GP 100 |
| | Intensity: | 18 – 20 A | 3 – 5 A |
| | Coverage: | 300 % | 100% |

In the first process, we choose the high intensity and the coverage of 300 % to increase the surface hardness and to introduce residual compressive stress. Fig. 2 shows the reduction of the surface hardness as a function of increased grind burn damage. The flank hardness increases from 510 HV to 590 HV.
All shot peened gears show high residual compressive stress of -800 MPa and -1400 MPa, regardless of the state after grinding.

The gear running tests were carried out in a standard FZG back-to-back test rig with centre distance a = 91.5 mm (gear geometry II) as well as in a FZG back-to-back test rig with variable centre distance (three-axis test rig, here a = 75.6 mm, gear geometry I), as shown in Fig. 1.
The limiting number of load cycles was $100 * 10^6$. Based on these results, S-N-curves with a failure probability of 50 % were determined for each test series.

Figure 3 shows the experimental endurance limit concerning the transmissible torque (50 % failure probability) for each test series related to the endurance limit of the corresponding reference test series without grinding burn effects. There is also a significant difference regarding the grinding operation.
The Fig. 4 shows the reduction of s-n-curve, especially of the nominal contact stress, regarding the increase of the grind burn damage. The not damaged reference gear FA0 is on the level of $\delta_{H0}$ =1410 MPa.
By using shot peening plus superfinishing, the grind burn damaged gears, type FB2 showed an increase of nominal contact stress from $\delta_{H0}$ =1320 MPa to $\delta_{H0} \geq 1480$ MPa. Also the gears with re-hardened face show the same effect, see Fig. 5.

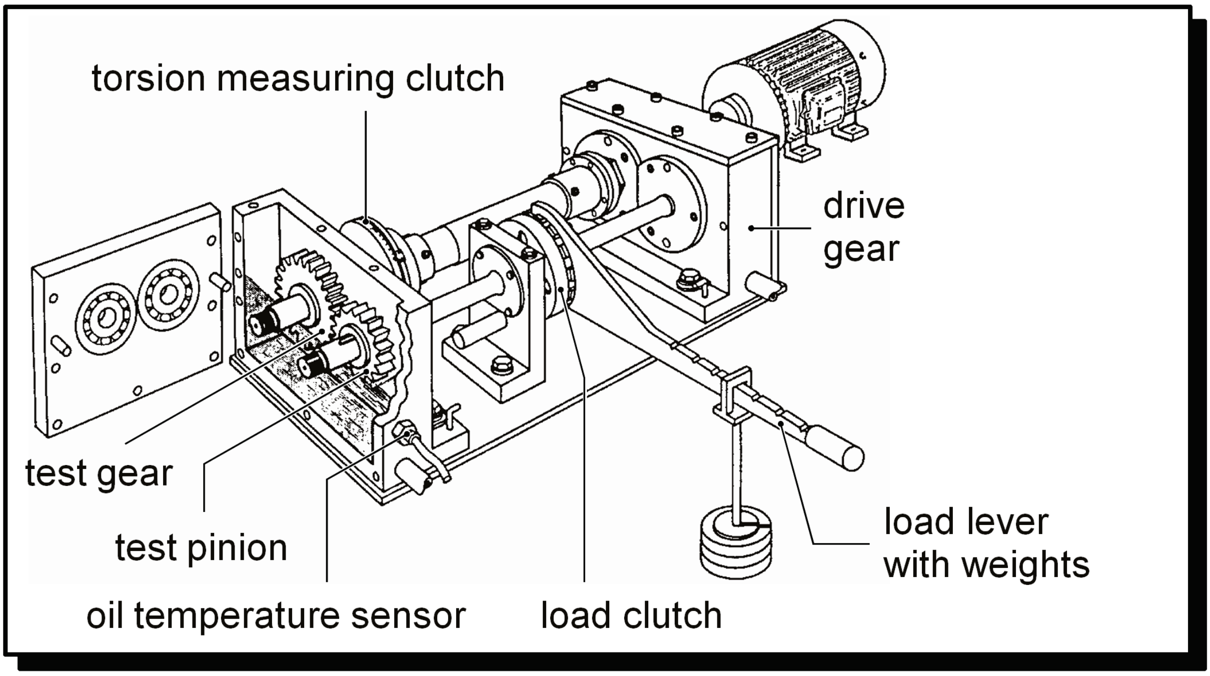
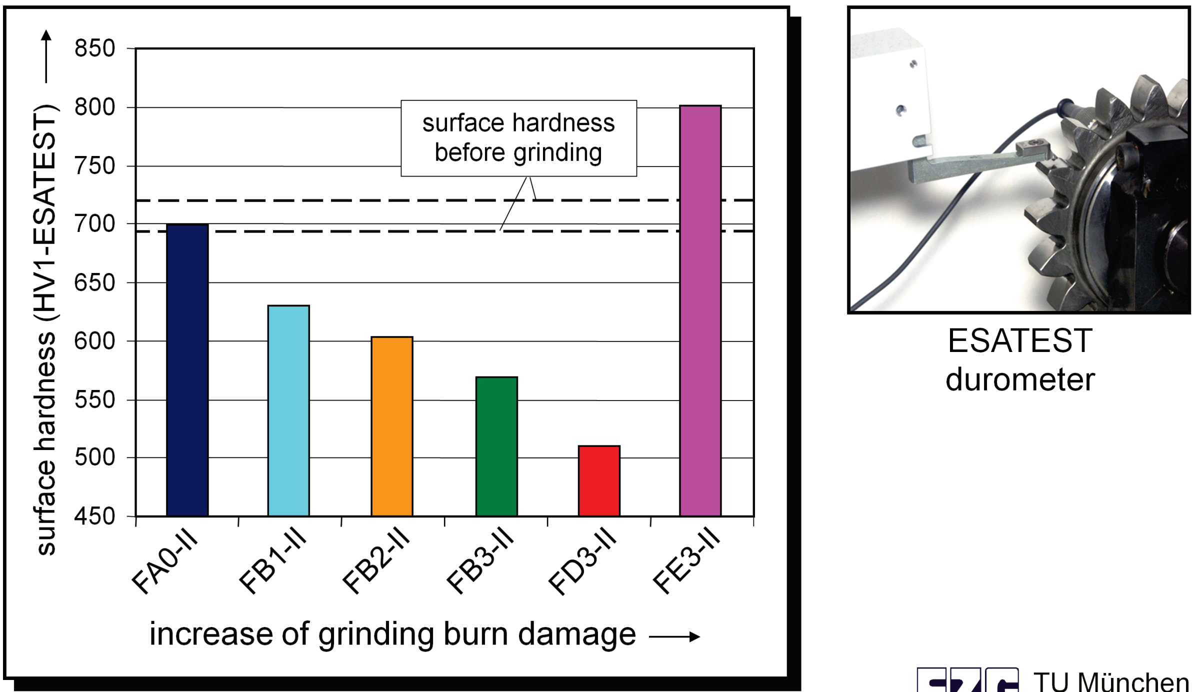



Fig. 1: FZG back-to-back test rig




$m_n$ = 5 mm, generative grinding

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Fig. 2: Surface hardness as a function of increased grind burn damage

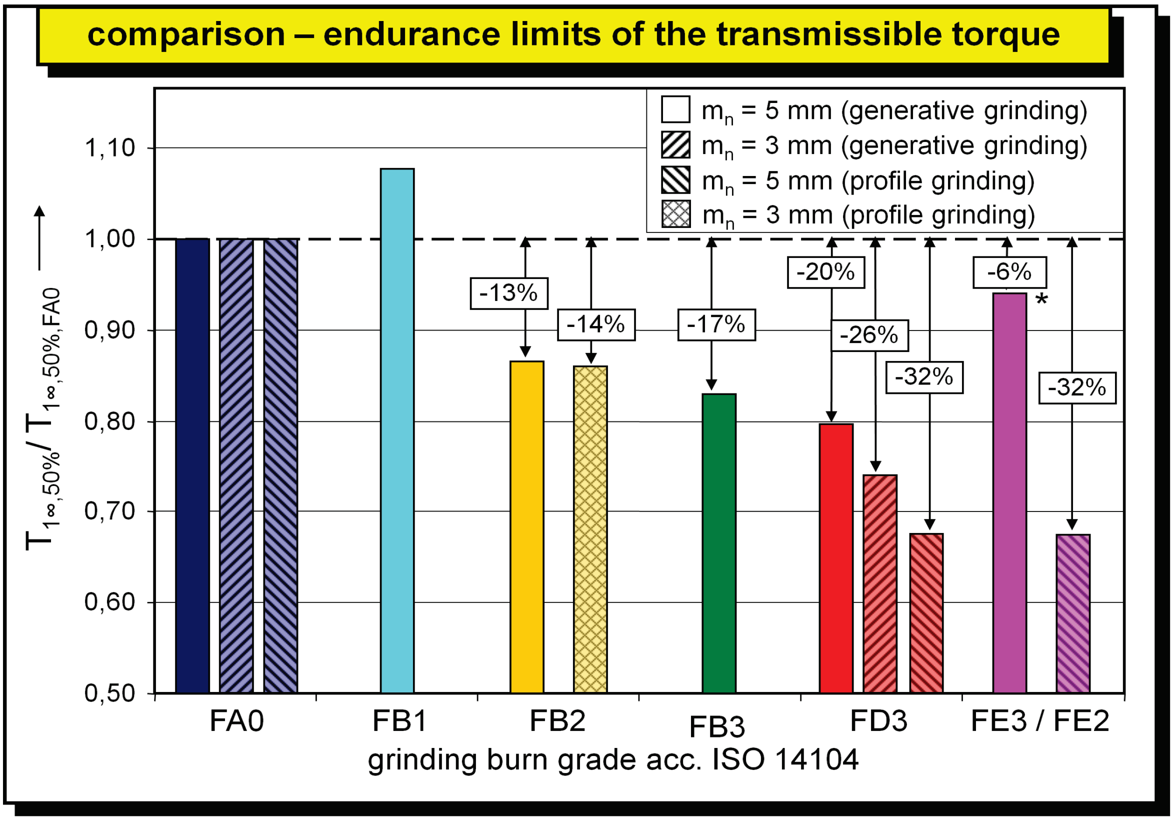


Fig. 3: Comparison of the experimentally determined endurance limit for the transmissible torque.

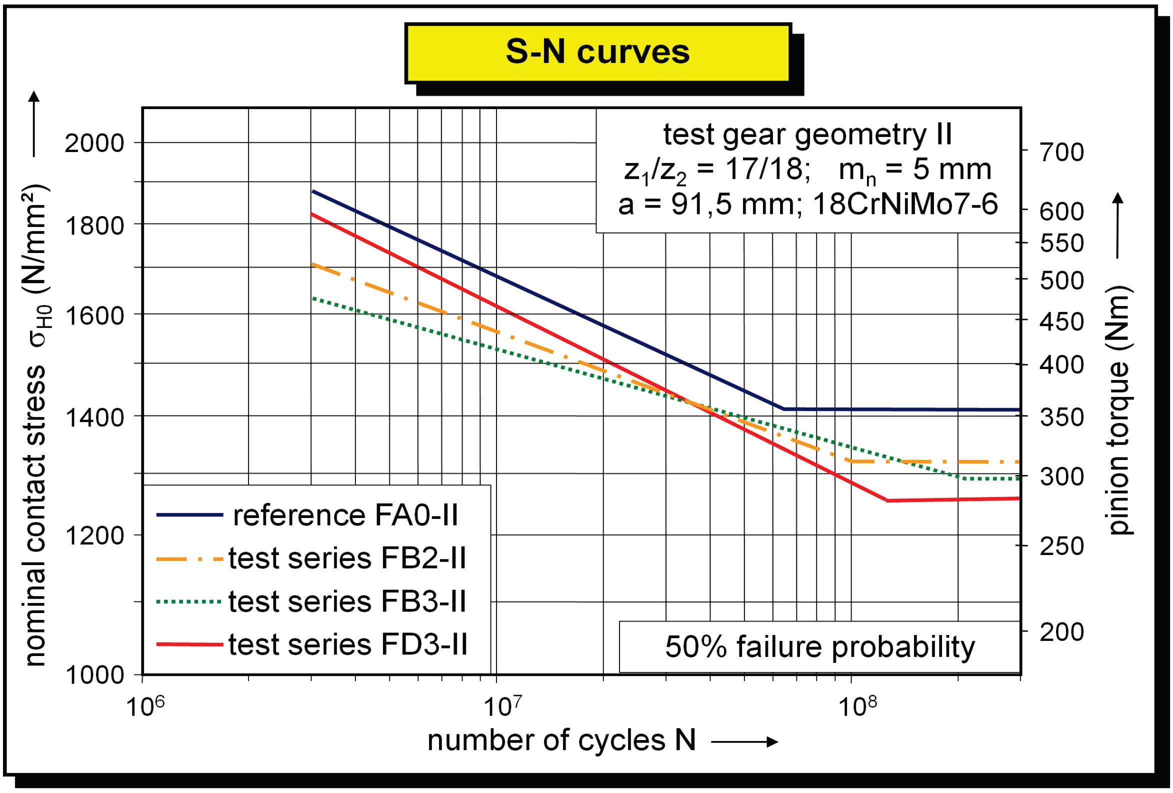


Fig. 4: Reduction of the nominal contact stress as a function of increased grind burn damage.

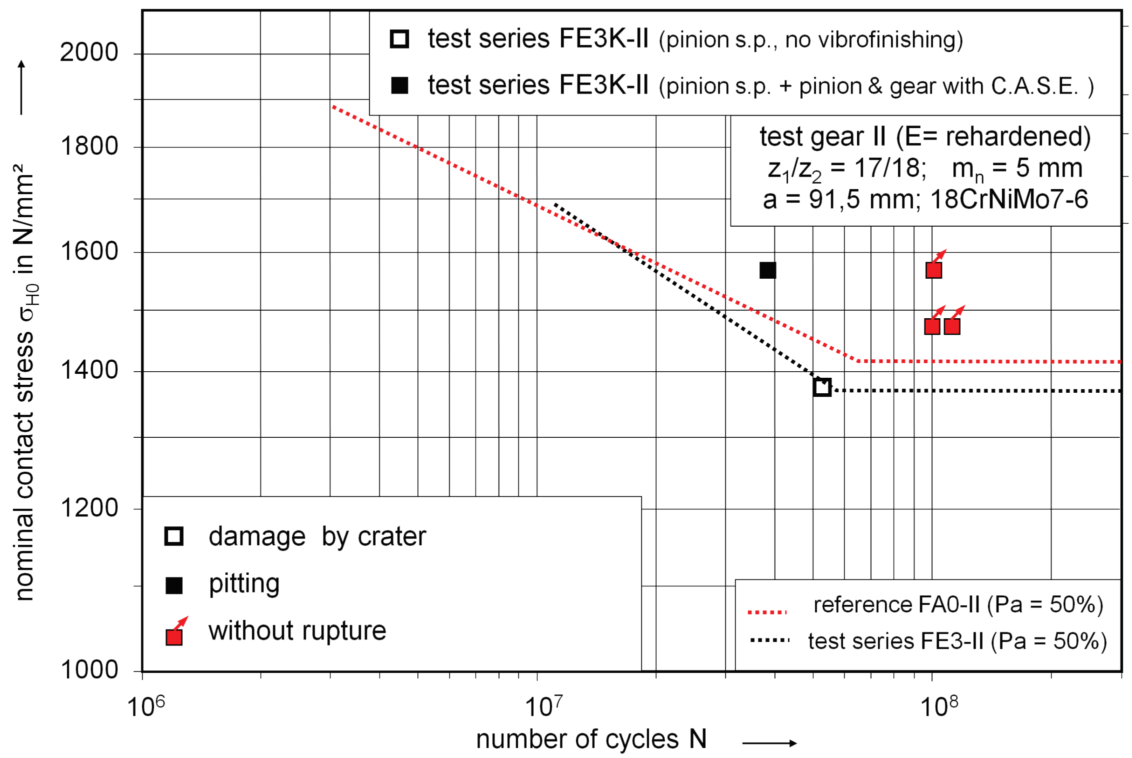


Fig. 5: S-N-curve comparison: no grind burn FA0 $\delta_{H0}$ =1410 MPa / rehardened FE3 versus the shot peened plus superfinished version

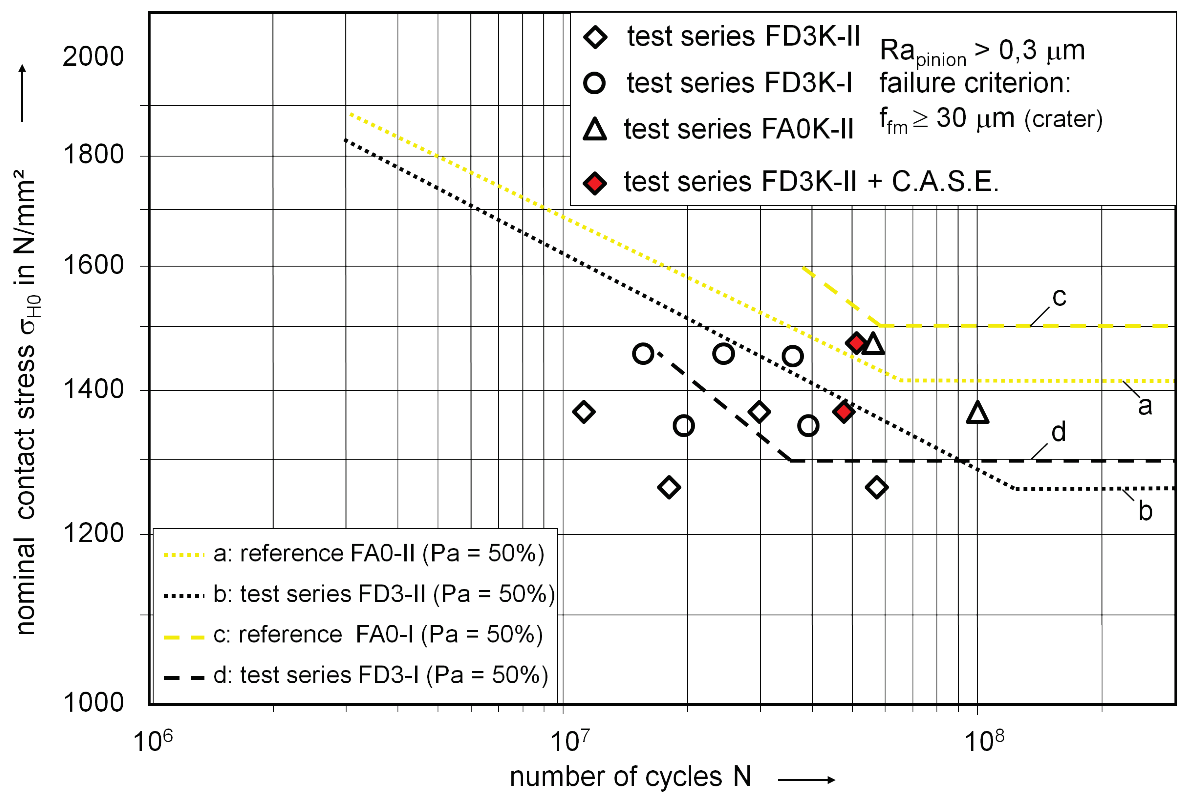


Fig. 6: S-N-curve comparison: no grind burn FA0/heavy tempered FD3 versus the shot peened plus superfinished version.

Fig. 6 shows the S-N-curves of the not tempered gears - reference (a & c) as well as the curves of the heavy tempered gears (b & d). The sampling test with shot peened plus superfinished processed gears shows that the gears reach the level of the not tempered gears. So the combination of shot peening and chemical assisted vibrofinishing is an excellent repair tool of gears.
Based on these results we set up an additional research program. The focus of this program is different finishing processes, used on not damaged gears.

## Discussion and Conclusion

Increase of the flank hardness of the strong tempered type from 510 HV to 590 HV by shot peening.
The shot peened pinions show strong wear in the area of the root-flank. The not shot peened test gear had also wear in this area. This effect is based in the high flank roughness of Ra= 0,8 – 1,0 µm.
The chemical assisted vibrofinishing of the shot peened pinions and not peened gears restrain the wear. Reduction of the roughness to -Ra= 0,15 µm.
The pitting resistance of the not damaged reference gear was reached, or exceeded.
From $\delta_{HO} = 1320\ N/mm^2$ to $\delta_{HO} \geq 1480\ N/mm^2$
If there was a failure in the running tests with the C.A.S.E. processed gear sets, the flank defect occurred at the not shot peened test gears.
Only the combination of a shot peened and superfinished pinion with an also superfinished gear allowed the complete suppression of the abrasive wear and the recuperation of the flank-load-carrying-capacity of the reference test series [1].
On account of the good results, the German Gear Association had set up a new research program, with the title:

## Optimization of the gear flank capacity

This program has been finished in December 2010, with excellent results, regarding the shot peening and chemical assisted vibrofinishing process.
The first publication of the results is not before 2014.

## References

[1] Prof. Dr.-Ing. Bernd-Robert Höhn, Dr.-Ing. Thomas Tobie, Dr.-Ing. Simon Schwienbacher, *Influence of grinding burn effects on the flank-load-carrying capacity of case hardened gears,* International Conference on Gears 2010, page 527-538.
[2] ISO 14104: *Gears – Surface temper etch inspection after grinding,* 1997