

Increasing the flank load capacity by combination of shot peening and superfinishing

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Abstract

Hardfinishing by grinding of case hardened gears is a common process in the gear industry with a final roughness of the flank normally $R_a = 0,3 - 0,5 \mu\text{m}$. 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 [1]. The shot peening process was tested as a repair tool for these damaged gears. After finishing this research program, it was set up a second program in 2009 with the focus to find out the increase of the flank load capacity by using three different surface treatments. Increasing demands on modern transmissions had led to the use of new technologies for the optimization of the flank load capacity [2]. These tested gears were "optimally processed", without any negative influence. All gears were tested on greystaining failure. This program compared mechanical vibrofinishing, chemically assisted vibrofinishing and shot peening followed by chemically assisted vibrofinishing. The paper will present the results of the different treatments, including shot peening, followed by the C.A.S.E. superfinishing process.

Keywords flank-load-capacity, shot peening, C.A.S.E. superfinish, case hardened gears, chemically assisted vibrofinishing, mechanical vibrofinishing

Experimental Methods

The experimental tests were carried out with two different gear geometries; $m_n = 3 \text{ mm}$ and $m_n = 5 \text{ mm}$, material 16MnCr5. All gears of the same geometry were milled in the same way and case hardened in one lot; hardness 58 – 61 HRC. After heat treatment the gears were cleaned by grit blasting. (S280, 0,5 mmA, 8 min. each side, shot velocity: 80 m/s) The flanks of the test gears were finished in a generative grinding process at the research center (FZG) of the University of Munich. The reference gear was ground with a roughness of $R_a = 0,3 \mu\text{m}$. One variant was chemically assisted vibrofinished, with a roughness of $R_a = 0,11 \mu\text{m}$.

The next variant was controlled shot peened and chemically assisted vibrofinished, with a roughness of $R_a = 0,09 \mu\text{m}$. Additionally there was one variant mechanically vibrofinished, with a roughness of $R_a = 0,1 \mu\text{m}$. The gear running tests were carried out in a standard FZG back-to-back test rig with a center distance $a = 91.5 \text{ mm}$, (DIN ISO 14635-1) as well as in a FZG back-to-back test rig with variable centre distance (three-axis test rig, here $a = 200 \text{ mm}$), as shown in Fig. 1. The limited number of load cycles was $100 \cdot 10^6$. Based on these results, S-N-curves with a failure probability of 50 % were determined for each test series. With the experience of the first research program, we choose the following shot peening parameter. Please note, these gears have no damaged faces of teeth by overheating when grinding. We took into consideration, the maximum residual stress distribution and an optimum surface roughness. With respect to the economy, the surface roughness has considerable influence on the processing time of the vibrofinishing.

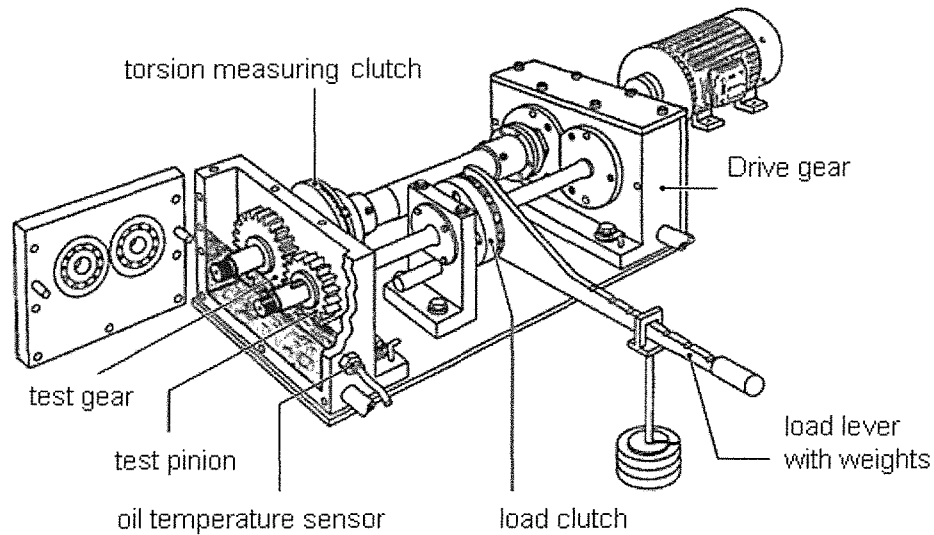
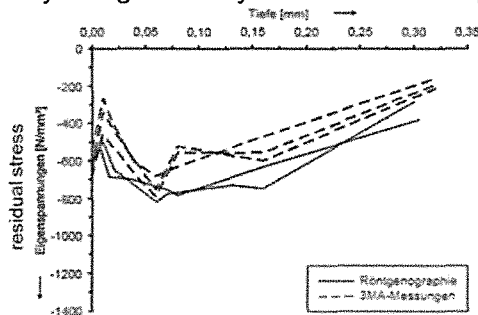


Fig. 1: FZG back-to-back test rig

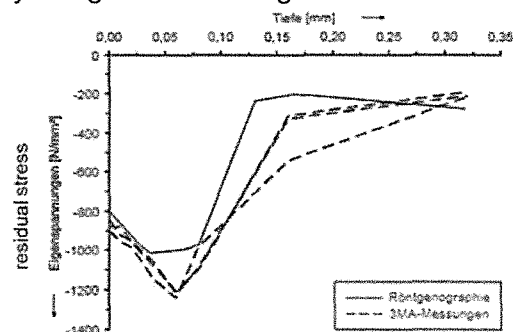
Shot Peening Parameter, dual process:	1. Process	2. Process
Shot:	MI 230 H	MI 110 H
Intensity:	12 – 14 A	5 – 6 A
Coverage:	200 %	100%

In the first process, we chose the high intensity and the coverage of 200 % to generate the residual stress distribution into depth. With the second shot peening process, we increased the compressive stress in the surface shell. All shot peened gears showed high residual compressive stress of -800 MPa, near the surface and the maximum residual stress of approximate -1300 MPa. The results of the measured stress distribution are shown in Fig. 2. The stress distribution was measured by using the x-ray diffraction technique and by using the micro magnetic method.



Eigenspannungstiefenverläufe Variante E7 (reinigungsgestrahlt + chem. unt. gleitgeschliffen (GSC1))

Stress distribution
Sand blasted, chemical vibrof.



Eigenspannungstiefenverläufe Variante E3 (festigkeitsgestrahlt + chem. unt. gleitgeschliffen (GSC2))

Stress distribution
Shot peened, chemical vibrof.

Fig. 2: Residual Stress distribution of sand blasted and shot peened gears after the chemical vibrofinishing process

Table 2: Parameters of the two different chemically assisted vibrofinishing processes (GSC1 and GSC2)

	Process 1	Process 2 (MIC)
Vibro stones	FM-9-Mix, FM-47-Mix	DS 55 A/C
Oxidation time	45 min	130 min
Cleaning time	180 min	100 min

There is only a difference of the root strength between the sand blasted and shot peened gears as shown in Fig.3. The increase of the shot peened gears is approximate 17%. The mechanical and chemical vibrofinishing has no influence regarding the root-strength. The different surface roughness shows also no influence on the root-strength.

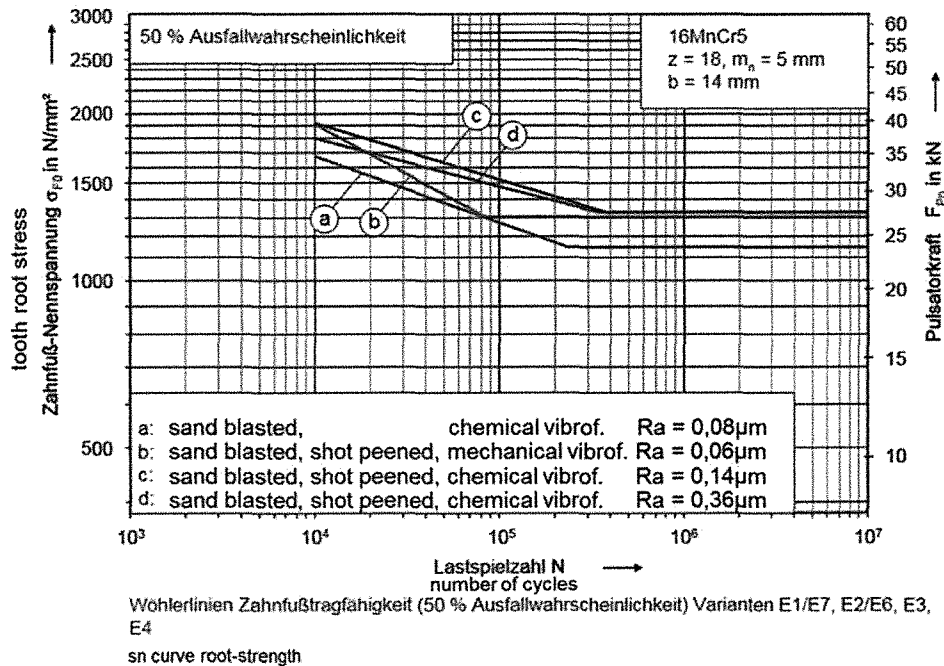


Fig. 3: S-N-curves of the root-strength

Figure 4 shows the S-N-curves of the optimized variants. The test results confirm the results of the base research program. The chemical vibrofinishing and in particular the combination of shot peening and chemical vibrofinishing increase the flank-load capacity significantly. The nominal contact stress of the ground gears is $\sigma_{H0} = 1484$ N/mm². Compared to the ground reference variant, the vibrofinished version shows a nominal contact stress of $\sigma_{H0} = 1649$ N/mm². By combination of shot peening, followed by chemical vibrofinishing the max. nominal contact stress increases up to $\sigma_{H0} = 1796$ N/mm². Compared to the ground reference variant, this is an increase in pitting resistance of 21%.

Table 3 shows the overview of the major research results. The increase of the pitting resistance is 21%, but only reached by the combination of shot peening, followed by chemical vibrofinishing. The increase of the load carrying capacity against micro pitting is more than one load stage. The increase of the scuffing load capacity is approximate. 3 load stages.

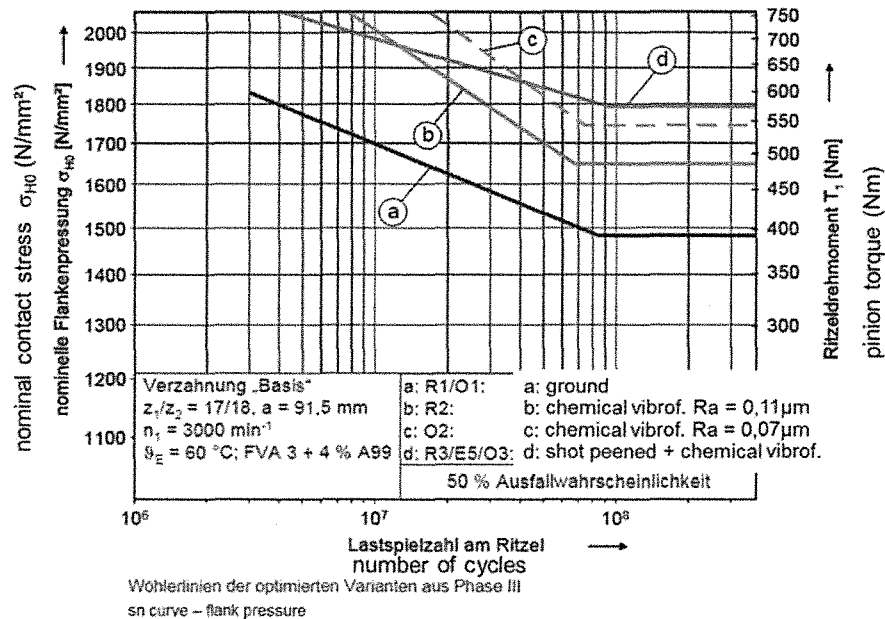


Fig. 4: S-N-curves out of the running tests, regarding the flank pressure.

Table 3: Overview of the major research results

	ground	chemical vibrofinish	shot peened + chemical vibrofinish MIC
pitting resistance	1,00	1,11	1,21
	micro pitting load stage	micro pitting load stage	micro pitting load stage
load carrying capacity against micro pitting	9	>10	>10

Discussion and Conclusions

- Basic research program (damaged faces of teeth generated by overheating when grinding)
 Increase of the flank hardness of the strong tempered type from 510 HV to 590 HV by shot peening.
 The pitting resistance of the not damaged reference gear was reached, or exceeded, from $\sigma_{HO} = 1320 \text{ N/mm}^2$ to $\sigma_{HO} \geq 1480 \text{ N/mm}^2$
 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].
- Optimization of the flank load capacity I

The combination of shot peening and chemical vibrofinishing increases the pitting resistance of gears by 21%.

The increase of the load carrying capacity against micro pitting is more than one load stage.

The increase of the scuffing load capacity is appr. 3 load stages.

Based on the good results, the German Gear Association had set up a new research program, with the title:

Optimization of the gear flank load capacity II

This program started in October 2012, and will be finished in September 2015.

References

[1] B.-R. Höhn, T. Tobie, S. 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] K. Stahl, T. Tobie, P. Koller, Steigerung der Zahnflankentragfähigkeit durch Kombination von Strahlbehandlung und Finishingprozess, FVA-Heft Nr. 957