Shot Peening of Components to Improve Fatigue Strength

W. Schütz, Industrieanlagen-Betriebsgesellschaft mbH, Ottobrunn, FRG

Introduction

Shot peening has been employed by industry for more than 50 years to improve the fatigue strength of components. Later on, other applications like peen forming, improvement of the stress corrosion resistance, increase of surface roughness for better adhesion of vulcanised rubber-metal-elements or for decorative purposes came into use.

Since better fatigue properties are (and will be) the main objectives of shot peening, it is important to recognise some "fatigue fundamentals"

- Shot peening induces residual compressive stresses

- Residual compressive stresses improve fatigue strength. They act like mean stresses, but only as long as they are not relaxed.

- The residual compressive stresses are relaxed if the local yield strength of the material in the critical section is exceeded by, for example, service-induced stresses.

- Local stresses due to the service loads are higher in the notched sections than in the unnotched sections (because $K_t > K_f$).

- Consequently shot peening will result in a large increase of fatigue strength when the yield strength of the material in question is high and, at the same time, the service-induced stresses are low.

- That is, considerable gains in fatigue strength may be expected from shot peening high strength materials, combined with loads near the fatigue limit where only a small relaxation (or none at all) may occur.

- Lower gains may be expected from low-strength materials and in the finite-life region of the S-N-curve* or under the variable amplitude loads so typical for most components of land-, air- and sea vehicles as well as engineering structures, see Fig. 1. These variable amplitude loads result in stress spectra characterized by a few large cycles - far above the fatigue limit - while the majority of the cycles lie below this limit.

- For actual components - and especially for mass-produced ones - the scatter of fatigue-life or -strength is a most important value. To increase the mean fatigue life by some method, while also increasing the scatter is counterproductive.

* This results in the well known convergence of SN-curves of shot peened and not shot peened components in the finite life region.

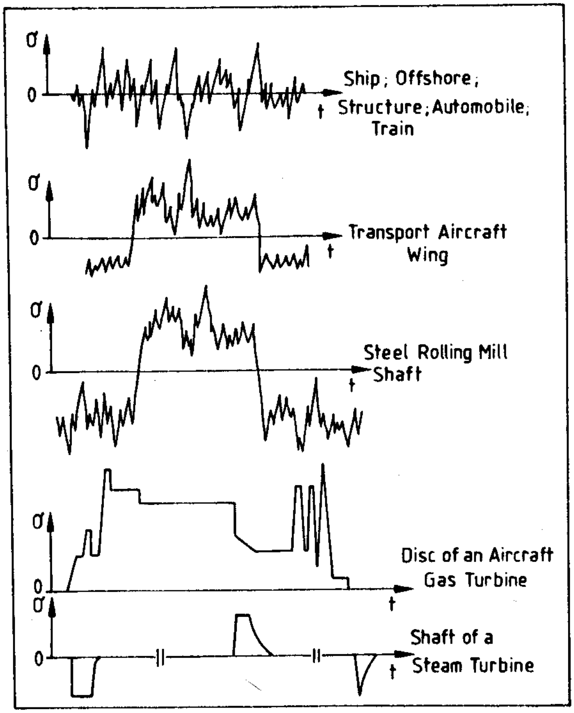


Fig. 1: Typical load sequences (schematical)

From the above "fundamentals" a number of conclusions must be drawn, among them:

- Investigating the effect of shot peening on unnotched specimens will give quantitatively incorrect answers
- Rather, the component itself should be tested, if at all possible; at least specimens should be tested with similar stress concentration factors and notch radii.
- The actual stresses due to the service loads must be simulated as closely as possible, i.e. a shot peened crankshaft has to be tested at or near the fatigue limit, while a component which sees only a few thousand variable amplitude cycles should be tested under this type of spectrum.

- If the improved fatigue-life or-strength due to shot peening is to be exploited fully, the scatter must be determined. It must not be larger than in the not shot peened condition. It can only be determined by fatigue tests on the components themselves.

Examples of Shot Peened Components

In the following several examples of components will be discussed, where the effects of shotpeening on fatigue life or fatigue strength has been investigated in the author's department and elsewhere.

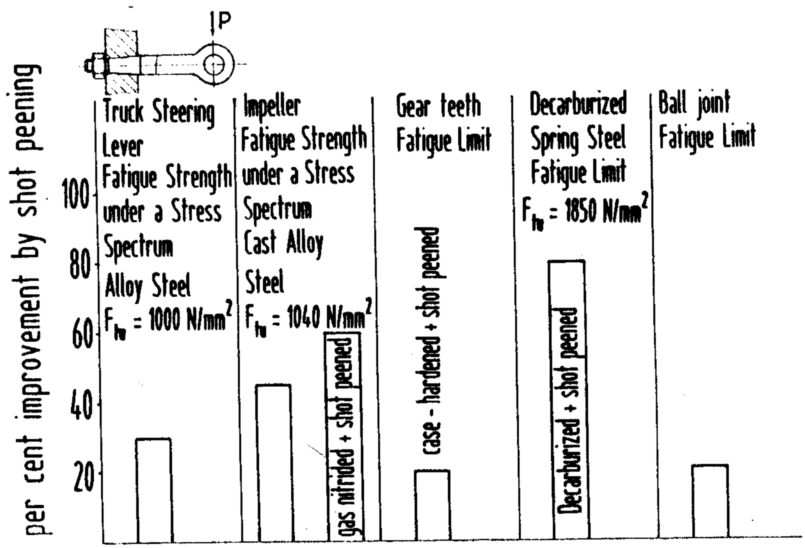


Fig. 2: Fatigue strength improvement of components by shot peening

Fig. 2 shows, beginning from the left

- a tapered truck steering lever which failed at the end of the hub due to the severe stress concentration plus fretting: The fatigue strength under a stress spectrum was increased by about 30 per cent by shot peening. It is well known that the detrimental effect of fretting can be mitigated by the beneficial effect of shot peening.

- a cast alloy steel impeller for an automatic gear box for trucks: Shot peening improved the fatigue strength under a stress spectrum by about 45 per cent; by gas nitriding plus shot peening about 60 per cent was achieved.

- Shot peening of case hardened gear teeth of automobile gears produced a 20 per cent improvement of the fatigue limit; similar examples are discussed further on.

- Rough forged surfaces often suffer from decarburisation. This is especially detrimental for high strength steels as used for example in leaf springs. Shot peening often more than compensates for this effect. This is shown by the fourth example in Fig. 2: The fatigue limit of this spring steel with an ultimate tensile strength of 1850 N/mm^2 was increased by no less than 80 per cent.

- Ball joints are used in automobile steering systems. Their critical section usually is the entrance of the tapered shank into the socket. Shot peening raised the fatigue limit of such a ball joint by about 20%.

As mentioned above, shot peening is beneficial even for hard surfaces, i.e. for case hardened, nitrided or induction hardened components. The beneficial effects of both treatments on fatigue strength is complementary, so to speak.

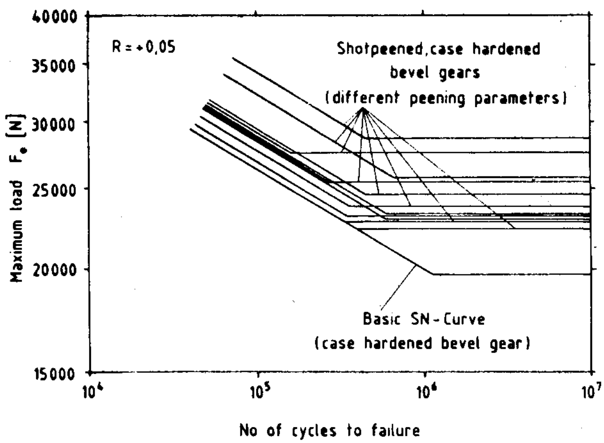


Fig. 3: Shotpeened, case hardened bevel gears (different peening parameters)

Fig. 3 shows an example of a case hardened bevel gear used in an autombile rear axle: By optimising the shot peening parameters in eleven steps it was possible to obtain an increase of the fatige limit, of about 45% without an increase in the scatter. The corresponding 12 test series comprised about 700 fatigue tests.

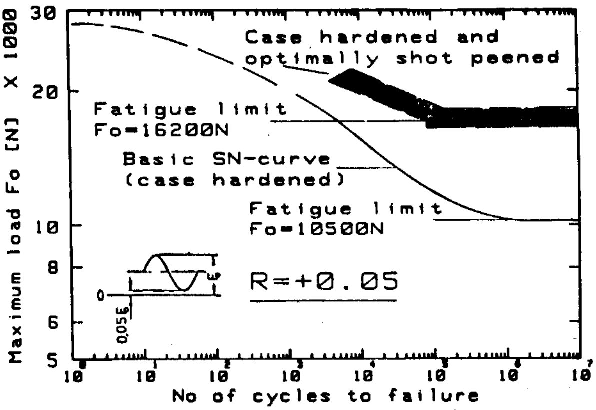


Fig. 4: SN-curves for gear teeth

In Fig. 4 some results of a similarly large programme (about 1000 tests) on shot peening case hardened gear teeth of an automobile transmission are presented. After about 10 optimising steps, in which the shot peening parameters were varied systematically, the result was an increase of the fatigue limit of about 60%, without an increase of the scatter, as can be seen from Fig. 4, which compares the SN-curve of the optimally shot peened gears with the basic, i.e. not shot peened ones.

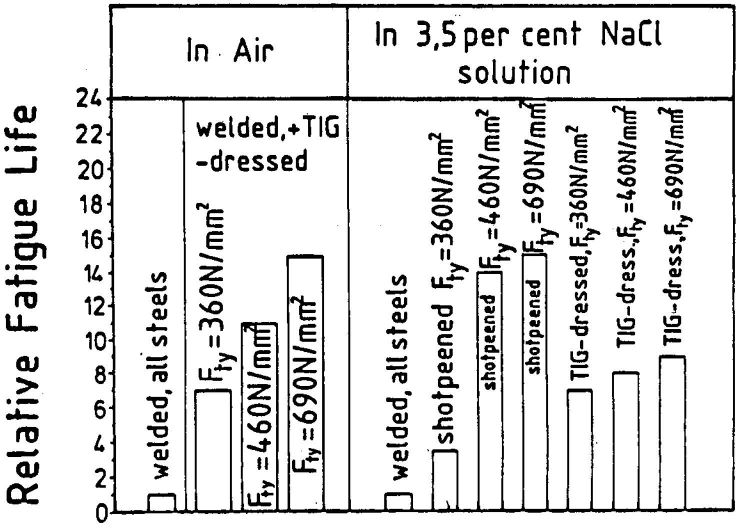
Shot peening is also helpful against the detrimental effect of corrosion on fatigue life. In Fig. 5 the results of a large German research programme [2] are presented:

Six different typical offshore steels with three different yield strengths were tested in the welded condition under a wave spectrum in air and in artificial sea water. As was to be expected, all steels had very similar fatigue lifes, because they were welded. However, shot peening (and TIG-dressing as well) increased the fatigue life the more, the higher the yield strength of the steel was, up to a factor of about 15 in air.

In seawater, however shot peening produced larger increases than TIG-dressing, see right side of Fig. 5. This probably can be explained in the following way: TIG-dressing only reduces the stress concentration factor of the weld. Corrosion produces pits, thus slightly increasing the stress concentration again. However shot peening induces residual compressive stresses which are similarly beneficial in air and in seawater.

Further examples on the effect of shot peening on fatigue strength of weldments are given in [3].

Spheroidal cast iron components are increasingly employed in automobiles, because of cost consideration. In cases where they do not quite match the fatigue strength of the replaced forged components, shot peening can be used to advantage.



<u>Fig. 5:</u> Fatigue strength of welded joints under a wave spectrum in air and in artificial sea water

In the experience of the author, residual compressive stresses - be they produced by shot peening or by surface rolling - are especially beneficial for spheroidal cast iron components. This may be due to the pronounced "mean stress sensitivity" [4] of this material.

For example, in [5] cast and forged automobile crankshafts are compared. The forged ones in the untreated condition generally were superior; shot peening, however, resulted in at least equal, if not higher fatigue limits for the crankshafts of spheroidal cast iron; for more examples of shot peening cast components see [6-8].

Fig. 6, taken from [8], shows the fatigue strengths under constant and variable amplitudes in air and in artificial sea water for the spheroidal cast iron GGG 40. The very severe effect of corrosion on the fatigue limit was reduced, but not neutralised by shot peening. However, under variable amplitude the corrosion effect was much smaller and it was almost completely compensated for by shot peening.

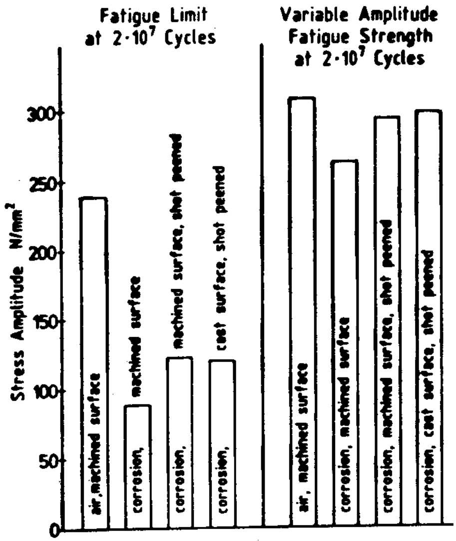


Fig. 6: Effect of shot peening on corrosion fatigue strength of spheroidal cast iron GGG 40

Further examples on shot peening components are given in [9].

References

(1) R. Schäfer, W. Schütz: "Reibkorrosion an Turbinenschaufeln von Titan unter Reibbeanspruchung", IABG-Report TF-1950 (1986)

(2) D. Grimme, B. Müsgen, E. Lachmann, W. Oberparleiter, R. Olivier, H. Rückert, W. Schütz: "Untersuchungen zur Betriebsfestigkeit von geschweißten Offshore-Konstruktionen in Seewasser", IABG-Bericht TF-116, LBF-Bericht Nr. 4681 (1984)

(3) K. Hoffmann, B. Müsgen: "Improvement of the Fatigue Behaviour of Welded High-Strength Steels by Optimised Shot Peening", Int. Offshore Conf. on Steel in Marine Struct., Delft (1987)

(4) W. Schütz: "Werkstoffoptimierung für schwingbeanspruchte Bauteile", Z. f. Werkstofftechnik, Heft 4 (1971), pp 189 - 197

(5) T. Sonnenschein, H.G. Trapp, H. Walter, A.W. Rist: "Gegossene Kurbelwellen für Großserien" MTZ 9 (1969), MTZ 12 (1971)

(6) F. Mahnig, H.G. Trapp, H. Walter: "Gegossene Pleuel für Fahrzeug-Dieselmotoren", MTZ 77, Heft 3 (1975), pp 77 - 81

(7) H.G. Trapp, H. Walter: "Gegossene Pleuel", MTZ 33, Heft 2, (1972) pp 41 - 45

(8) Fischer, E., F. Mahnig, H.P. Walter: "Betriebfestigkeit von Sphäroguß bei Korrosionseinfluß", ATZ, Februar (1987)

(9) W. Schütz: "Kugelstrahlen zur Verbesserung der Schwingfestigkeit von Bauteilen", Z. Werkstofftechnik 17 (1986), pp 53 - 61