Effects of Shot Peening on the Corrosion Fatigue Properties of Spring Steels

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Introduction

Besides heat treatment and mechanical surface strengthening methods to improve the fatigue limit, corrosion preventing procedures have to be employed for longer durability of safety components such as vehicle springs.
These springs are corrosion protected by different systems of varnish coats today. A preceeding shot peening process not only results in an improvement of fatigue strength but also in a clean and enlarged metallic surface giving better adhesive conditions for the varnish coat.
Shot peening, however, can not fundamentally modify the state of active corrosion fatigue in which low-alloy, high-strength spring materials are when attacked by tap water or sodium chloride solution without or with a damaged corrosion protection layer.
Although the basic mechanisms of corrosion fatigue of steels in active or passive conditions have been examined in detail already (1 - 4) only little information is known about the corrosion fatigue behavior of spring steels (5).
To study the corrosion fatigue properties of three typical spring steels and to determine optimal corrosion protecting methods, extensive research work is being carried out. This paper deals with some results of corrosion fatigue tests with the spring steel 50 CrV 4 and the comparison between mechanically polished and shot peened specimens.

Corrosion fatigue testing program

The test program reported on here totally encompasses the following materials and conditions:

- 3 spring steels (50 CrV 4 , 55 Cr 3 and 54 SiCr 6) ,each in
- 2 tensile strengths (approx.1600 and 1900 N/mm^2),
- 2 types of smooth specimens with 10 mm diameter for rotating bending tests and 14 mm diameter for alternating torsion tests,
- 2 modes of stressing: rotating bending without mean stress ($\sigma_m = 0$, $R = -1$) and alternating torsion with mean stress ($\tau_m = \tau_a$, $\tau_u = 0$, $R = 0$) ,
- several surface conditions of the specimens (ground, mechanically polished ,shot peened , shot peened and varnish coated or electro zinc plated ,
- 2 corrodents (tap water from Darmstadt, 5% sodium chloride solution (NaCl)) ,
- reference tests in laboratory air ,
- 3 kinds of exposure to corrosive conditions (immersed, continuously (1/1) sprayed , periodically (1/4) sprayed = periods of 15 minutes spraying and 45 minutes without spraying during corrosion fatigue testing .

Results of corrosion fatigue tests

Because of limited space this paper can only report on results of 50 CrV 4 specimens with approx. 1900 N/mm^2 tensile strength not taking into account specimens with corrosion protecting layers.

- mechanically polished specimens

Fig. 1 shows the results of rotating bending tests with mechanically polished specimens of spring steel 50 CrV 4 in different corrosives and exposure conditions.
Whereas the S-N curve of specimens immersed in 5% NaCl - solution during test is almost the same as that of continuously (1/1) NaCl-sprayed specimens, periodically (1/4) NaCl- and 1/1 tap water-sprayed specimens have longer lifetimes. The S-N curve of 1/4 tap water -sprayed specimens takes a distinctly different course : below a stress amplitude of ±250 N/mm^2 no more fractures occur until to 10^8 cycles.
Both other materials tested (54 SiCr 6 and 55 Cr 3) exhibit a very similar behavior in comparison with Fig. 1 under these conditions , so do also the specimens of all three materials with the lower tensile strength of approx. 1600 N/mm^2.

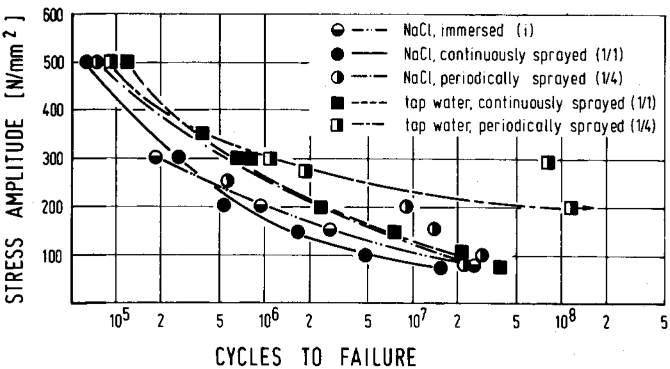

Fig. 1 :S-N curves of mechanically polished 50 CrV 4 rotating bending specimens under different corrosives and exposure conditions

The results of alternating torsion tests with mechanically polished 50 CrV 4 specimens under different corrosive conditions are to be found in a relatively narrow region of scatter (see Fig. 2). Shorter lifetimes of periodically sprayed specimens can here be explained by drops of corrodent which keep contacting the bottom side of the not rotating specimens and causing additional corrosion attack during the normally dry periods of testing.
The S-N curves of the other spring steels tested and of specimens with approx. 1600 N/mm^2 tensile strength are all very similar to those shown in Fig. 1 .

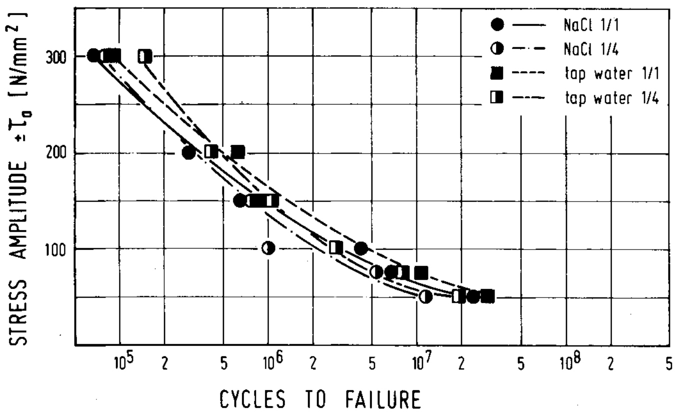

Fig. 2 : S-N curves of mechanically polished 50 CrV 4 alternating torsion specimens under different corrosives and exposure conditions

- shot peened specimens

Shot peening of the test specimens was performed in a spring factory using a four-wheel blasting machine and rounded cut steel wire of 0.8 mm diameter (Almen intensity : A = 0.57 mm).

Rotating bending tests with shot peened 50 CrV 4 specimens in laboratory air prove a fatigue limit of about 800 N/mm^2 . Considering this value the S-N curves of shot peened specimens under corrosion fatigue conditions are remarkably influenced , see Fig. 3 . For comparison the results of mechanically polished specimens (as shown in detail in Fig. 1) are presented here as region of scatter.
At high stress amplitudes shot peened specimens exhibit much longer lifetimes than polished specimens with a distinct difference caused by the corrosive conditions.Improving lifetime is to be found in the sequence NaCl immersed or 1/1- sprayed, 1/4 NaCl-sprayed,tap water 1/1 and 1/4 sprayed.
But the S-N curves of shot peened specimens take a much steeper course than those of the polished ones , and lifetime-values of both types of specimens meet each other at low stress amplitudes at approx. $15 \cdot 10^6$ cycles in NaCl - solution.
In contrast to the results in NaCl - solution tap water - sprayed rotating bending specimens are less affected in their lifetimes, especially if they are periodically sprayed.

According to Fig. 3 the results of alternating torsion tests with shot peened 50 CrV 4 specimens under corrosion conditions are represented in Fig. 4 , also using the mechanically polished specimens' region of scatter for comparison.
The torsional fatigue strength (R = 0) in laboratory air amounts to approx. 500 ± 500 N/mm^2 .

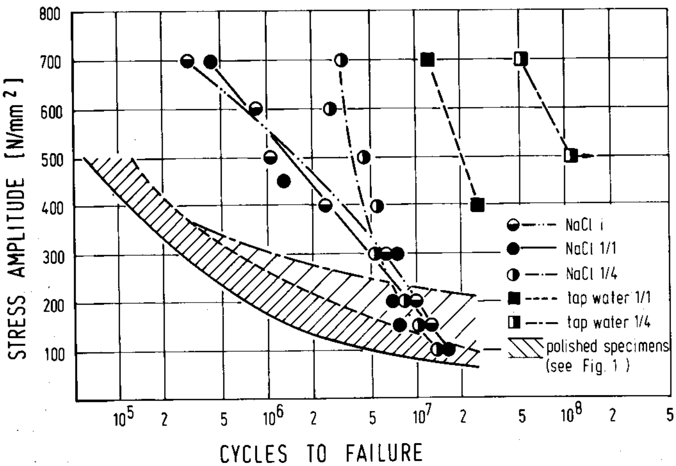

Fig. 3 : S-N curves of shot peened 50 CrV 4 rotating bending specimens under different corrosives and exposure conditions

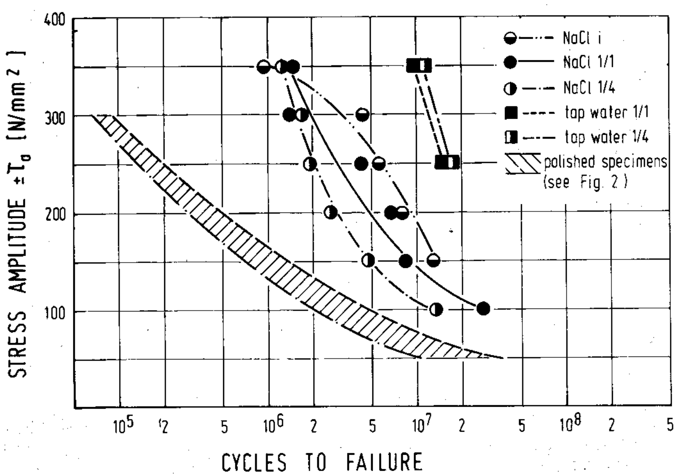

Fig. 4 : S-N curves of shot peened 50 CrV 4 alternating torsion specimens under different corrosives and exposure conditions

Similar to rotating bending shot peened alternating torsion specimens show longer lifetimes than polished specimens with a more severe influence by NaCl - solution than by tap water. But there are some changes to be noticed in detail :The sequence of life - time values is turned round as earliest failure is caused by 1/4 NaCl - spraying followed by 1/1 spraying or immersion.
The results of tap water corrosion fatigue tests are nearer to the NaCl - area than they are in rotating bending tests , and 1/4 tap water-sprayed specimens fail after almost the same numbers of cycles as continuously sprayed specimens .

Examination of corrosion pits and cracks

After fracture the corrosion fatigue specimens were cleaned and visually inspected by microscope.According to stress mode, level of stress amplitude , number of cycles to failure and corrosive conditions different kinds of corrosion attack at the surface can be observed.For an example Fig. 5 shows a surface region of a rotating bending specimen with cracks in circumferencial direction,whereas cracks due to alternating torsion often arise in both 45 °- directions inspite of the torsional mean stress, see Fig. 6.

Metallographic sections were prepared near to the fracture areas of the specimens, pits and cracks in the surface region of these sections were evaluated by microscope .The depth of pits only and the total depth or length of pits with arising cracks were measured ,mean values were calculated for every single specimen .

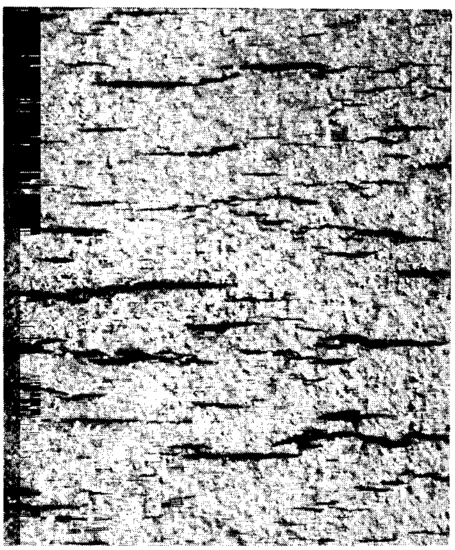

Fig. 5 :corrosion fatigue cracks at the surface of a shot peened rotating bending specimen after fracture ($16 \cdot 10^6$ cycles ,σ_a = ± 100 N/mm², NaCl 1/1 sprayed)

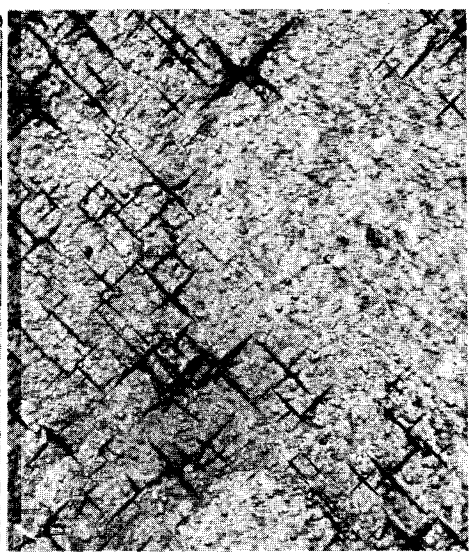

Fig. 6 :corrosion fatigue cracks at the surface of a shot peened alternating torsion specimen after fracture ($27 \cdot 10^6$ cycles , τ = 100 ± 100 N/mm² , NaCl 1/1 sprayed

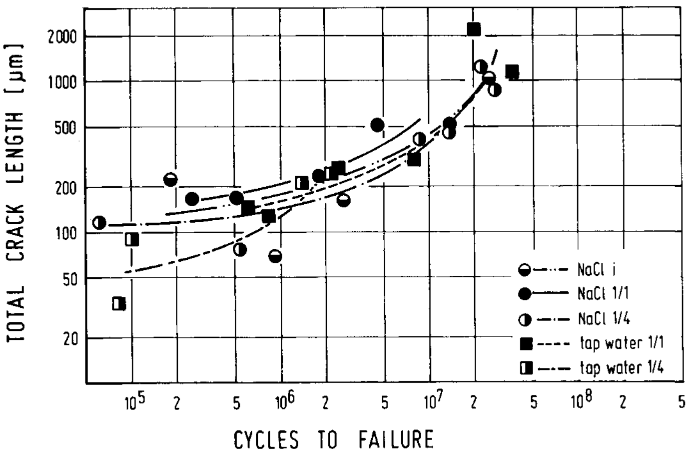

Fig. 7 :Total crack length of mechanically polished 50 CrV 4 specimens after rotating bending test under different corrosive conditions

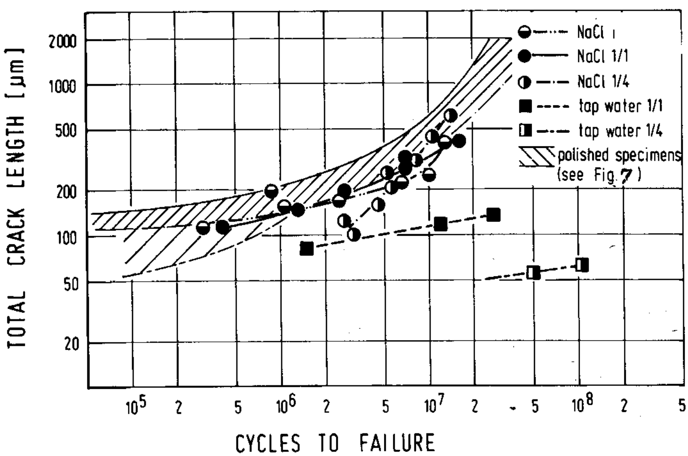

Fig. 8 :Total crack length of shot peened 50 CrV 4 specimens after rotating bending test under different corrosive conditions

The results of the crack examinations are plotted in Fig. 7 to 9 , where only the total crack length after failure is recorded versus lifetime (because of better survey the also measured pit depths are not presented here).
Fig. 7 shows that the developement of corrosion fatigue crack lengths of mechanically polished rotating bending specimens is a function of test time respectively of the number of cycles and almost independent of the corrosion conditions.

This fact corresponds with the S-N curves of these specimens ,see Fig. 1 .
The total crack lengths of shot peened specimens after rotating bending test are plotted in Fig. 8 and compared with the polished specimens' region of scatter. It is obvious that the crack lengths of shot peened NaCl 1/1 or immersed tested specimens are within or near to the scatter of polished specimens . However ,it has to be noticed that the stress amplitudes are partly much higher for shot peened specimens.
The crack lengths of 1/4 NaCl-sprayed specimens are smaller at first and grow faster with the number of cycles.
Tap water-sprayed specimens have distinctly smaller corrosion crack lengths than NaCl-sprayed , with another clear difference between 1/1 and 1/4 spraying.
The results presented in Fig. 8 also well correspond with the course of the S-N curves , see Fig. 3.

Finally Fig. 9 shows the crack lengths of shot peened specimens after alternating torsion test. According to the S-N curves (see Fig. 4) 1/4 NaCl-sprayed specimens have longer cracks than NaCl 1/1 or immersed tested specimens.
Tap water-sprayed specimens exhibit slightly smaller cracks without significant difference between the spraying modes.

Conclusion

The tests carried out show that the fatigue limits of low-alloy , high-strength spring steels without protection against corrosion are severely diminished by corrosion fatigue with NaCl-solution or even with tap water .The S-N curves of mechanically polished specimens take a continuously falling course under corrosion fati-

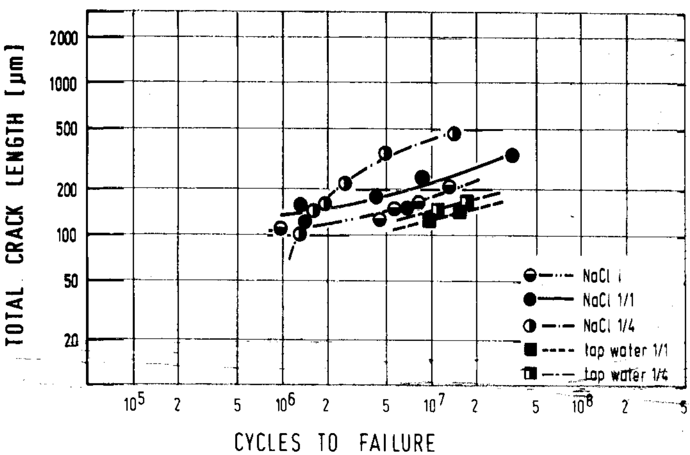

Fig. 9 : Total crack length of shot peened 50 CrV 4 specimens after alternating torsion test under different corrosive conditions

gue conditions ,and lifetimes of 10 to 20 · 10^6 cycles can only be reached at stress amplitudes of approx. 15 % from the fatigue strength in laboratory air.
Very similar results were obtained for all three spring materials tested, for both tensile strengths examined in rotating bending (R = -1) as well as in alternating torsion tests (R=0).
Corroson fatigue testing of shot peened specimens exhibits enlarged lifetimes at high stress amplitudes in comparison with polished specimens, but also steeper S-N curves.
Whereas the corrosive and exposure conditions have only a slight influence on the results of polished specimens,they cause a sequence of S-N curves with very remarkable distances in the case of shot peened specimens.These distances are more significant for rotating bending results , which can be explained by missing mean stress.
An examination of corrosion fatigue crack lengths in the surface region of the specimens after fracture proves,that there is a close inverse correspondence between S-N curves and crack lengths.
Relatively low stress amplitudes of about half fatigue strength in laboratory air cause fast propagating cracks in polished specimens by means of corrosion attack. Shot peened specimens exhibit surface cracks after some 10^5 cycles,too. But the propagation of these cracks is hindered by the residual compressive stresses in the surface zone.
Under the influence of NaCl-solution corrosion pits arise during some days of testing time respectively some 10^6 cycles.These pits contribute to the crack propagation or steadily reach the depth of the residual compressive stress layer ,afterwards followed by faster crack propagation and final fracture.

References

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