EFFECT OF SHOT-PEENING ON THE FATIGUE STRENGTH OF SPRING STEEL AFTER EXPOSURE TO CORROSION

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INTRODUCTION

Corrosion is a process which can be neither retarded, nor glossed over. Over a shorter or longer period of time corrosion destroys the majority of objects which are made by man, regardless of the material from which they are made. There are numerous methods and technologies for protecting the surfaces of metallic objects, most often by depositing on them or forming of coatings or layers which block the direct action of corrosive environments, for minimizing or eliminating surface or volume corrosion. It is known that residual compressive stresses which can be generated by various manufacturing and other technological processes will be conducive to a rise of longevity of mechanically loaded components working in a corrosive environment [1].

Known and widely used in many countries is the process of enhancing the fatigue strength of materials by the application of shot-peening, a dynamic surface deformation treatment. Advantages stemming from the shot-peening are the result of the effect of compressive residual stresses, together with strengthening by cold working.

The objective of this investigation was to show to what extent shot-peening affects the fatigue strength of spring steel, additionally exposed to a corrosive environment.

EXPERIMENTAL

For the present investigation a chromium-silicon spring steel (50HS) with the chemical composition (in wt.%): 0.52C, 1.076Cr, 1.075Si, 0.54Mn, 0.15P, 0.008S, 0.038Mo, 0.115Ni, 0.23Cu, 0.0248Al, 0.035W were used. The steel was hardened and tempered to 45–47 HRC. In previous investigations carried out at IMP, the following methods were adopted: As corrosive medium a solution was selected containing ammonium sulphate $(NH_4)SO_4$ and sodium chloride (NaCl) concentrations of with 0.4 and 0.05% respectively. The solution was further made more acidic by concentrated sulphuric acid, to a level of pH=3.01–3.04. The corrosive medium was replaced by fresh additions every 48 hours, when the pH value rose to the level of 5.5–6.5. Specimens were hold in the corrosive environment for t = 720 h (4 weeks). Specimens for the investigation of quasi-static strength, fatigue strength and weight loss measurements were placed in a beaker on special hangers and in a sieve, immersed in the corrosive medium to a prescribed level. The corrosive medium was agitated during the course of the test by means of a magnetic mixer in order to avoid the deposition of hydrogen or air bubbles on the surface exposed to corrosion. The removal of corrosion products from the specimens was accomplished by an electrochemical method, in which the specimen constituted the cathode in a bath, composed of: sodium hydroxide of $100g/dm^3$, and sodium gluconate of $100g/dm^3$ .The current density and temperature were kept at $10\ A/dm^2$ and 50^oC to 70^oC, respectively. By the same token, the action of the corrosive medium was

stopped. It was observed that measured areas of the specimens were uniformly attacked by corrosion.
In addition to tensile tests [2], fatigue test were conducted in rotating beam loading (R = -1) with Schenck-type fatigue machine, operating with a constant bending moment along the length of the specimens [3]. The tests were carried out with at a frequency of 100 Hz up to 10^7 cycles. Fatigue performance was determined on the following conditions (Table 1).

Table 1: Test versions and surface conditions

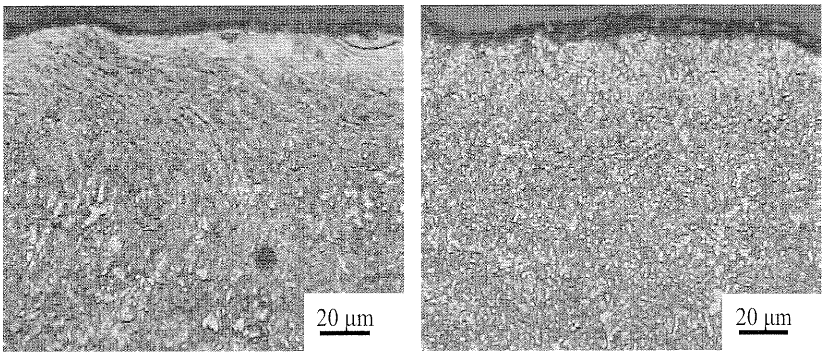
Test version	Surface condition
I	un-peened
II	shot peened
III	un-peened + corroded
IV	shot peened + corroded

Micro-hardness in near-surface regions of the various conditions were carried out.
A Zwick-brand micro-hardness tester operating at a load of 1 N was used to determine the Vickers.

The corrosion rate was determined by mass loss measurement on specimens representing the four experimental versions.
The surface roughness measurements of the working surfaces were taken, using the Hommel type T20 tester and LV50 stylus over a length of 5 mm.
Fractographic, investigations were carried out on the fatigue fracture surfaces of the various conditions, using the JEOL type JXA-50A scanning electron microscope (SEM) and the Neophot 2 optical microscope.
In order to obtain compressive residual stresses in the surface layer of the specimens, shot-peening was performed using a pneumatic stand of own design and STG-G3 shot of 0.6 mm diameter having a hardness of 700HV. Peening was done to the Almen intensity of 0.45 mmA_1.

RESULTS AND DISCUSSION

Cross sections of the near-surface microstructures after shot peening (versions II and IV) are shown in Figs. 1.



a) shot peened (Version II) b) shot peened + corroded (Version IV)

Fig.1: Near-surface microstructures of 50HS grade steel, hardened and tempered etched with 2% Nital

The near-surface plastic deformation caused by shot peening can clearly be seen in Fig. 1a. The depth of plastic deformation was determined to be about 0.2 mm. After exposure to the corrosive environment the zone of plastic deformation decreased from 0.2 mm (Version II, Fig. 1a) to approx. 0.07 mm (Version IV, Fig. 1b), i e., part of the work-hardened zone was removed by corrosion.

The corrosion rates of un-peened and shot peened specimens amounted to v_{corr} = 0.0785 mg/cm^2 h and v_{corr} = 0.0536 mg/cm^2 h, respectively.
Results of the surface roughness measurements are given in Table 2.

Table 2: Surface roughness values of the various conditions

Test version	Surface roughness R_a [μm]		R_a [μm] (average)
I	0.650	0.725	0.688
	0.975	1.200	1.088
II	5.475	5.275	5.375
	5.225	5.850	5.538
III	1.550	1.825	1.688
	1.350	1.800	1.575
IV	5.400	4.000	4.700
	4.650	4.275	4.463

Measurements of surface roughness (R_a) on the various versions are shown in Table 2. There is a 5-fold increase in surface roughness from Version I (un-peened) to Version II (shot peened). Despite of that, the corrosion rate of shot peened specimens was 26% lower than that of un-peened specimens as presented before. Shot peened specimens (Version II) showed increased values of micro-hardness in the subsurface zone, up to a distance of 0.2 mm from the surface. On the other hand, shot peened specimens exposed to corrosion (Version IV) exhibited a drop in micro-hardness in the subsurface zone. Presumably, this is mainly due to the partial removal of the cold worked layer by the corrosive environment.
The ultimate tensile strength, UTS and the fatigue strength, σ_{a10^7} (R = -1) of the various conditions of the hardened and tempered 50HS grade steel are given in Table 3. Shot peennig improves the 10^7 cycles fatigue strength (σ_{a10^7}) of the hardened and tempered 50HS grade steel from 780 MPa (Version I) to 860 MPa (Version II) which corresponds to a rise of 10.5%. The exposure to the corrosive medium dropped the fatigue strengths of the un-peened and shot peened conditions to 640 MPa (Version III) and 780 MPa (Version IV), respectively. Note that the fatigue

strength of the shot peened + corroded condition (Version IV) is as high as the un-peened not corroded condition (Version I) indicating that shot peening is able to compensate the effect of the aggressive environment.

Table 3. UTS and σ_{a10^7} (R = -1) values of the various conditions of hardened and tempered 50HS grade steel

Test version	UTS [MPa]	σ_{a10^7} [MPa]
I	1637	780
II	1653	860
III	1648	640
IV	1623	780

The relatively small drop in fatigue strength of shot peened specimens exposed to the corrosive medium is mainly due to the presence of compressive residual stresses of considerable values in near-surface regions as illustrated in Fig. 2.

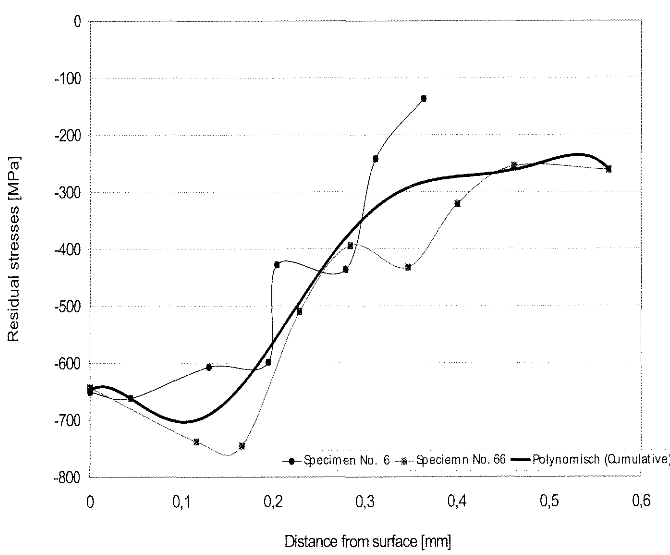
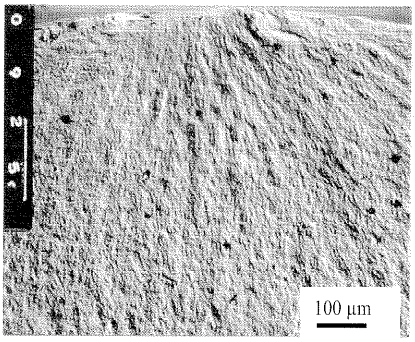
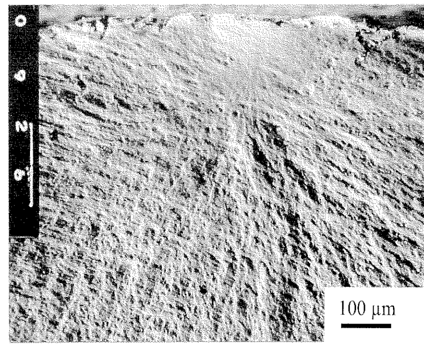


Fig. 2: Residual stress distribution after shot peening

After shot-peening, residual compressive stresses were measured in near-surface regions up to a depth of 0.55 mm. While the residual compressive stress at the surface was about 650 MPa , the maximum was located at a depth of 0.1 mm below the surface and amounted to roughly 700 MPa (see Fig. 2).

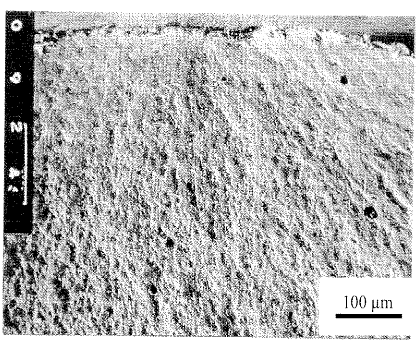
Fracture surfaces are illustrated in Fig. 3. As shown in the SEM fractographs, fatigue crack initiation occurred at the surface independent of the surface condition.

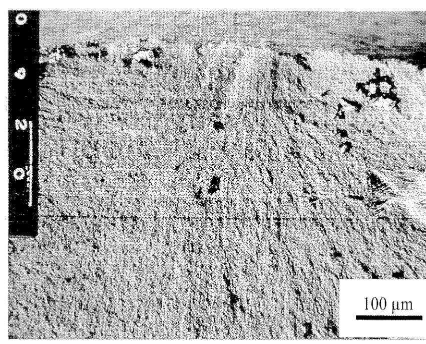




a) un-peened (Version I)

b) shot peened (Version II)





c) un-peened + corroded (Version III)

d) shot peened + corroded (Version IV)

Fig. 3: Fatigue crack nucleation sites in 50HS grade steel, hardened and tempered (SEM)

CONCLUSIONS

Based on the results obtained, it is concluded that the fatigue strength (σ_{a10^7}) of the hardened and tempered 50HS can significantly be improved by shot–peening:

1. Although shot peening resulted in a 5-fold increase in surface roughness relative to the un-peened reference, the corrosion rate was 26% lower indicating an increase in corrosion resistance due to shot peening.
2. After a one-month pre-corrosion, the fatigue strength of un-peened specimens decreases from 780 MPa to 640 MPa , I e., by 18 %.
3. Under the same conditions, the fatigue strength of shot peened specimens decreases from 860 MPa to 780 MPa, I e., by only 10.5 %.
4. The fatigue strength of shot peened and pre-corroded specimens was as high as the fatigue strength of the un-peened specimens without pre-corrosion (780 MPa).