Effect of Shot-Peening on Fatigue Behavior of Compressive Coil Springs

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ABSTRACT

The fatigue properties of compressive coil springs of stainless steel have been investigated. It was found that the optimum peening conditions exist which give the maximum increase in the fatigue strength. The master diagrams of peened and unpeened springs have been obtained, and they are found to be useful for the spring designers.

KEYWORDS

Shot-peening; coil spring; residual stress; fatigue strength; master diagram.

INTRODUCTION

Shot-peening (SP) technology has been successfully used in the treatment of different kinds of springs. The fatigue strength of springs can be notably improved by shot-peening (Zimmerli, 1952). After forming into coil spring, the inner surface of spring exhibits tensile residual stresses, $+\sigma_r$, which result in the decrease of fatigue strength. The tensile $+\sigma_r$, however, can be changed into compressive $-\sigma_r$ using SP from which the fatigue strength can be improved. The different peening intensities were used to affect the inner and outer surface $\sigma_r$ of coil springs for which the fatigue strength were investigated in the present paper.
MATERIALS AND TEST PROCEDURES

The material used is precipitation hardened stainless steel. The chemical composition is 0.09% C, 5% Mn, 4% Ni, 3% Mo, 0.7% Al. The mechanical properties of 4 mm diameter wire are listed in Table 1. The spring configurations and dimensions are shown in Fig. 1.

Table 1. Mechanical properties of 4 mm diameter wire

<table>
<thead>
<tr>
<th>Young's modulus $E$ [GNm$^{-2}$]</th>
<th>Shear modulus of elasticity $G$ [GNm$^{-2}$]</th>
<th>Ultimate strength $T_b$ [MNm$^{-2}$]</th>
<th>Yield stress $T_{0.2}$ [MNm$^{-2}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>199</td>
<td>83</td>
<td>1940</td>
<td>1860</td>
</tr>
<tr>
<td>Shear ultimate strength $T_b$ [MNm$^{-2}$]</td>
<td>Shear yield stress $T_{0.3}$ [MNm$^{-2}$]</td>
<td>Hardness</td>
<td>HRC</td>
</tr>
<tr>
<td>1640</td>
<td>1400</td>
<td>53</td>
<td></td>
</tr>
</tbody>
</table>

The coil spring production process are summarized as follows: forming into coil spring → aging ($520^\circ$C, 2hr.) → shot-peening → reverse compressing until the spring arrering a stable dimensions → measuring elasticity → fatigue testing.

The compressive fatigue testing machine was used. The testing frequency is 20Hz. The shear stress of spring is calculated by

$$T = \frac{3P_D K}{\pi d^3}$$

where P is the elastic force (according to actual measurements), K is the correct coefficient ($K=4c-1/4c-4+0.615/c$, $c$ is spring index $C=D_m/d$), $D_m = D-d$. 

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Fig. 1. Spring configuration and dimensions (in mm)

<table>
<thead>
<tr>
<th>D</th>
<th>d</th>
<th>t</th>
<th>H₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>3</td>
<td>9.6</td>
<td>57</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>5</td>
<td>30</td>
</tr>
</tbody>
</table>

The shot-peening of springs was carried out by an air-blast machine with glass beads (0.1~0.3 mm) and cast steel shot (0.5 mm). Variations of velocity were carried out in order to obtain different peening intensities from 0.12N to 1.2N (0.6N~1.2N intensities are calculated from 0.2A~0.4A).

The surface $\sigma_r$ in the axial direction was measured by X-ray diffraction method using Cr-Kα radiation.

EXPERIMENTAL RESULTS AND DISCUSSION

The results of surface $\sigma_r$ of different springs were shown in Fig. 2. It can be seen that the inner surface tensile $\sigma_r$ can be changed into compressive $-\sigma_r$ by using SP, and the surface $\sigma_r$ increase gradually with the increase of peening intensities then decrease.

![Graph showing the relation between inner and outer surface stresses and peening intensity](image-url)

Fig. 2. Relations between surface $\sigma_r$ and peening intensity for C=6.
The relations between cycles to failure, Nf, and the peening intensities, N, for different C and stress ratio R were shown in Fig. 3 and Fig. 4 respectively.

![Fig. 3. Relations between logNf and N of springs under R = 0.1, max = 1100 MNm⁻² (wire diameter d = 2mm)](image)

![Fig. 4. Relation between logNf and N of springs for C = 6 under R = 0.1, max = 1000 MNm⁻² (wire diameter d = 2mm)](image)

From Fig. 4 it can be seen that there is an optimum peening intensity condition resulting in the highest fatigue strength of springs, the amount of which is about 0.4N. Both maximum surface - \( \sigma_f \) (Fig. 2) and maximum fatigue strength (Fig. 4) are at the same peening intensity conditions which are near 0.4N mm.

Under the optimum SP conditions and different fatigue testing conditions \((L_m, L_a, R)\), the results of median fatigue strength at Nf=10^6 and Nf=10^7 cycles of springs were obtained. According to the test datum, the fatigue limits at 10^7 cycles with 99.9% probability of survival were calculated. The calculated
Fig. 5. Master diagrams of springs having d=3mm (a) and d=2mm (b), 99.9% probability of survival for $10^7$ cycles and the median fatigue strength for $10^6$ cycles.
results together with the median fatigue strength at $N_f=10^6$
cycles were shown in Fig.5. It can be seen that the shot-peening
can notably increase the fatigue properties of different
kinds of springs. Besides, under the harsh fatigue testing
conditions, the cycles to failure are no less than $10^5$ cycles
for peening springs.

For the unpeened springs, the fatigue cracks initiate at the
inner surface because of existing surface tensile $\sigma_f$.

After shot-peening, however, the fatigue crack initiation
appears to be at the subsurface of springs. The area of
fatigue crack propagation in the fracture surface of peened
springs is bigger than that of unpeened springs.

CONCLUSIONS

The conclusions obtained from the test results mentioned may
be summarized as follows:

1. The shot-peening can notably improve the fatigue pro-
   perty of compressive coil springs of stainless steel.

2. There are an optimum peening intensity conditions result-
   ing in the increase of fatigue strength of coil springs.

3. The compressive residual stresses are an important factor
to improve the fatigue resistance of coil springs.

REFERENCES

Zimmerli, F. F. (1952), Metal Progress, No. 6, 97-106