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 sucesfully 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 exibits 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 σ_r of coil springs for which the fatigue strength were investigated in the presend 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 dimentions are shown in Fig.1.

Table 1. Mechanical properties of 4 mm diameter wire

Young's modulus E GNm^{-2}	Shear modulus of elasticity G GNm^{-2}	Ultimate strength σ_b MNm^{-2}	Yield stress $\sigma_{0.2}$ MNm^{-2}
199	83	1940	1860
Shear ultimate strength τ_b MNm^{-2}		Shear yield stress $\tau_{0.3}$ MNm^{-2}	Hardness HRC
1640		1400	53

The coil spring production process are summarized as follows: forming into coil spring ⟶ aging (520°C, 2hr.) ⟶ shot-peening ⟶ reverse compressing until the spring arrering a stable dimentions ⟶ measuring elasticity ⟶ fatigue testing.

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

$$\tau = \frac{8D_m K}{\pi d^3} P$$

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 $C=D_m/d$), $D_m=D-d$.

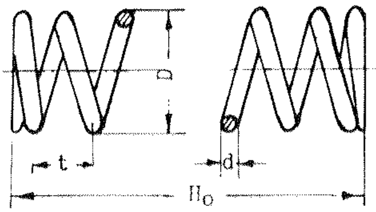


Fig.1. Spring configuration and dimentions (in mm)

D	d	t	H_0
18	3	5.6	57
14	2	5	30

The shot-peening of springs was carried out by an air-blast machine with glass beats (0.1~0.3 mm) and cast steel shot (o.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 culculated from 0.2A~0.4A).

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

EXPERIMENTAL RESULTS AND DISCUSSION

The results of surface σr 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 σr increase gradually with the increase of peening intensities then decrease.

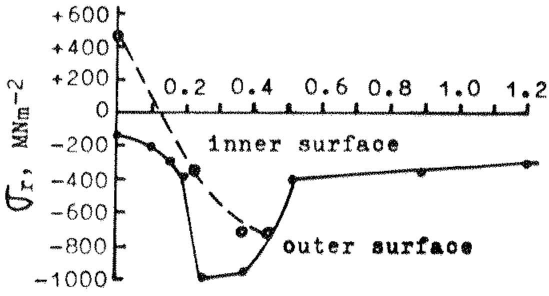


Fig.2. Relations between surface σr and peening intensity for C=6.

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.

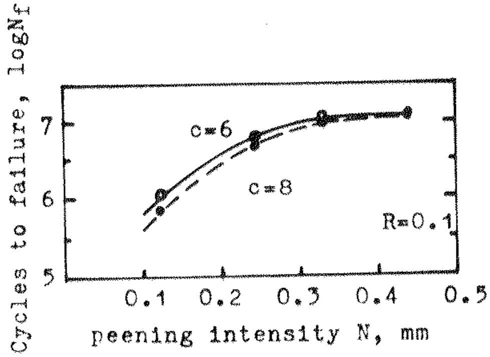


Fig.3. Relations between logNf and N of springs under τ_{max} = 1100 MNm^{-2} (wire diameter d = 2mm)

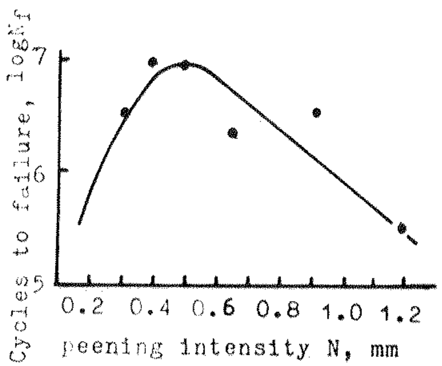
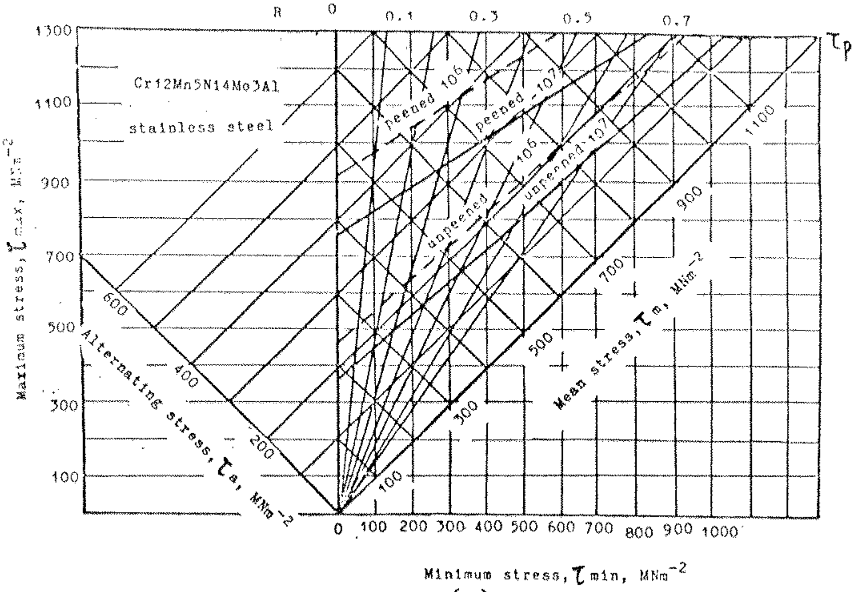


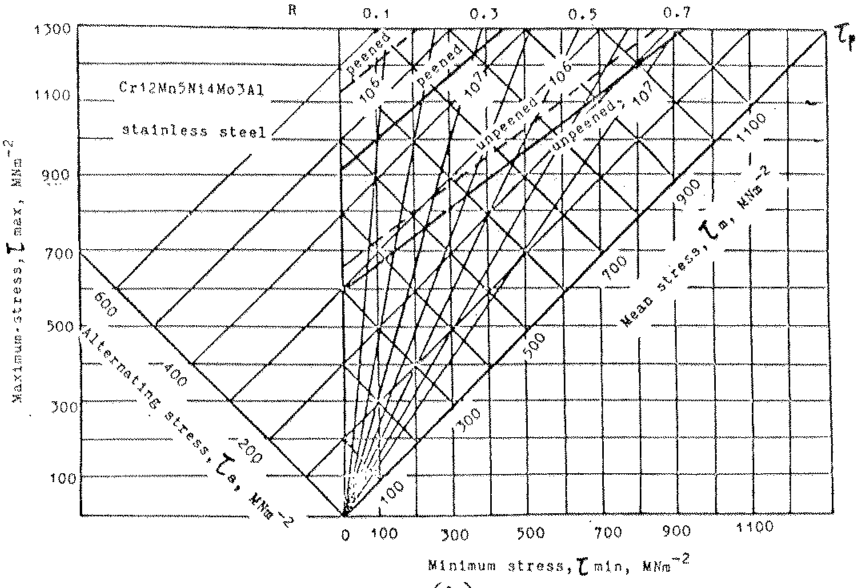
Fig.4. Relation between logNf and N of springs for C = 6 under τ_{max}=1000 MNm^{-2} and R = 0.1 (wire diameter d=2mm)

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 $-\sigma r$ (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 (τm, τa, 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 culculated. The culculated



(a)



(b)

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 $Nf=10^6$ 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 becouse of existing surface tensile σr.

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 property of compressive coil springs of stainless steel.

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

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

REFERENCES

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