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 it is 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, + σr, which results in the decrease of fatigue strength. The tensile + σr, however, can be changed into compressive - σr using SP which leads to the improvement of fatigue strength of the part. Different peening intensities were used to affect the inner and outer surface of coil springs for which the fatigue strength were investigated in the present paper.

MATERIALS AND TEST PROCEDURES

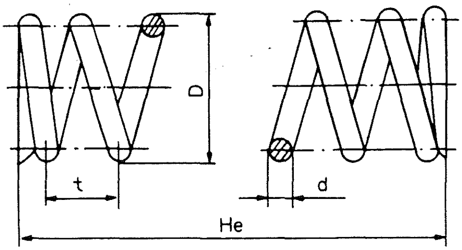
The material used is the precipitation hardening stainless steel. The chemical compositions are 0.09% C, 12% cr, 5% Mn, 4% Ni, 3% Mo, 0.7% Al. The mechanical properties of 4 mm diameter wire are listed in Table 1. The spring configurations and dimensions are shown in Fig. 1.

The coil spring production process are summarized as follows: forming into coil spring → aging (520°C, 2 hr.) → shot-peening → presetting → measuring elasticity → fatigue testing. The compressive fatigue testing machine was used. The testing frequency was 1200 cpm. The shear stress of spring is calculated by

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 τb MNm^{-2}	Shear yield stress $\tau_{0.3}$ MNm^{-2}	Hardness HRC
1640	1400	53



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

Fig. 1 Spring configuration and dimensions (in mm)

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

where P is the elastic force (according to actual measurements), K is the correct coefficient

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} ,$$

C is spring index, $C = D_m/d$, $D_m = D-d$.

The shot-peening of springs was carried out by an air-blast machine with glass beads (ϕ: 0.1 ∿ 0.3 mm) and cast steel shot (ϕ: 0.5 mm). Variations of velocity were carried out in order to obtain different peening intensities from 0.12 N to 1.2 N (0.6 N ∿ 1.2N intensities are calculated 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 are shown in Fig. 2. It can be seen that the inner surface tensile + σr can be changed into compressive - σr by using SP, and the surface σr increase gradually with the increase of peening intensities then decrease.

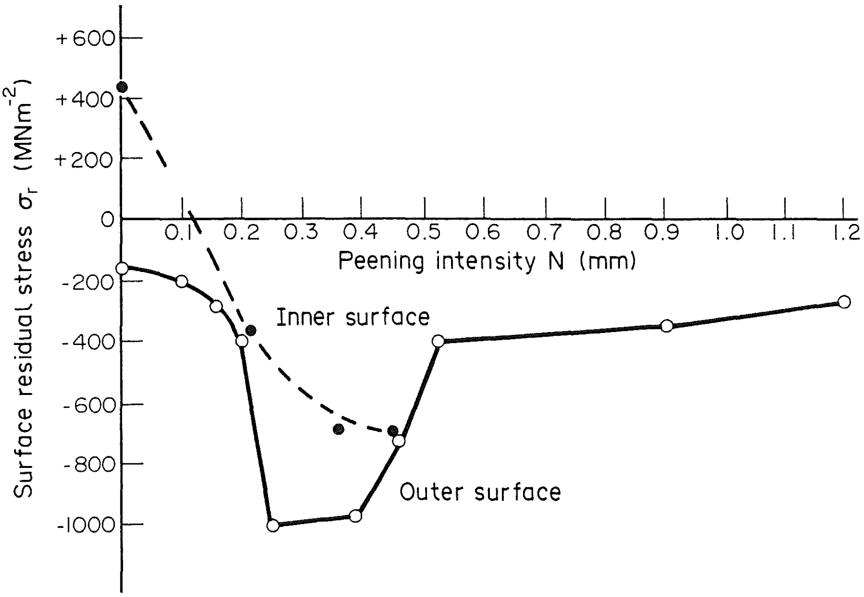


Fig. 2 Relations between surface σr and peening intensity for C = 6

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.

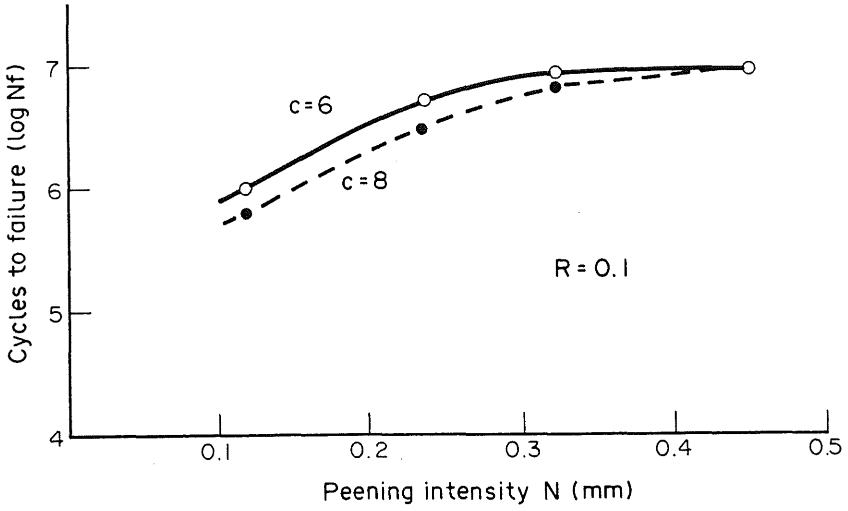


Fig. 3 Relations between log Nf and N of springs under τ_{max} = 1100 MNm^{-2} (wire diameter d = 2 mm)

From Fig. 4 it can be seen that there are optimum peening intensity conditions resulting in the highest fatigue strength of springs. Both maximum surface - σr

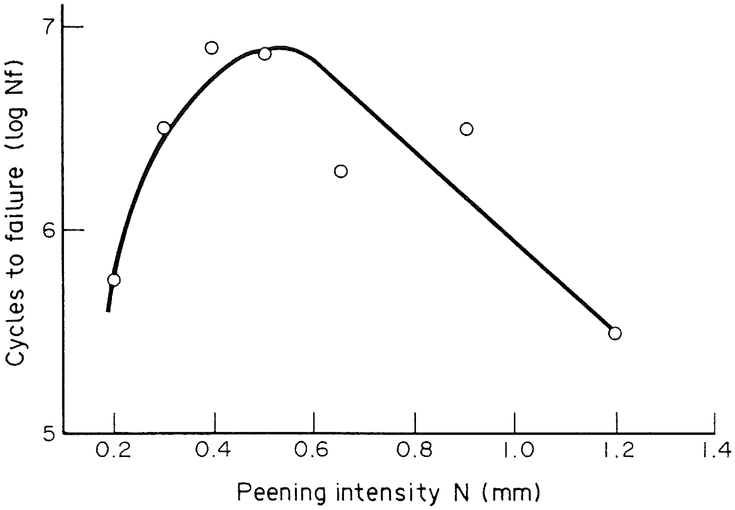


Fig. 4 Relation between log Nf and N of springs for C = 6 under τ_{max} = 1000 MNm^{-2} and R = 0.1 (wire diameter d = 2 mm)

(Fig. 2) and maximum fatigue strength (Fig. 4) are at the same peening intensity conditions which are near 0.4 N 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. Then according these test datum, the fatigue limits at 10^7 cycles with 99.9% probability of survival were calculated. The calculated results together with the median fatigue strength at Nf = 10^6 cycles are 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 σr. After shot-peening, however, the fatigue crack initiation appears to be at the sub-surface of springs. The area of fatigue crack propagation in the fracture surface of peened springs is bigger than that of unpeened springs.

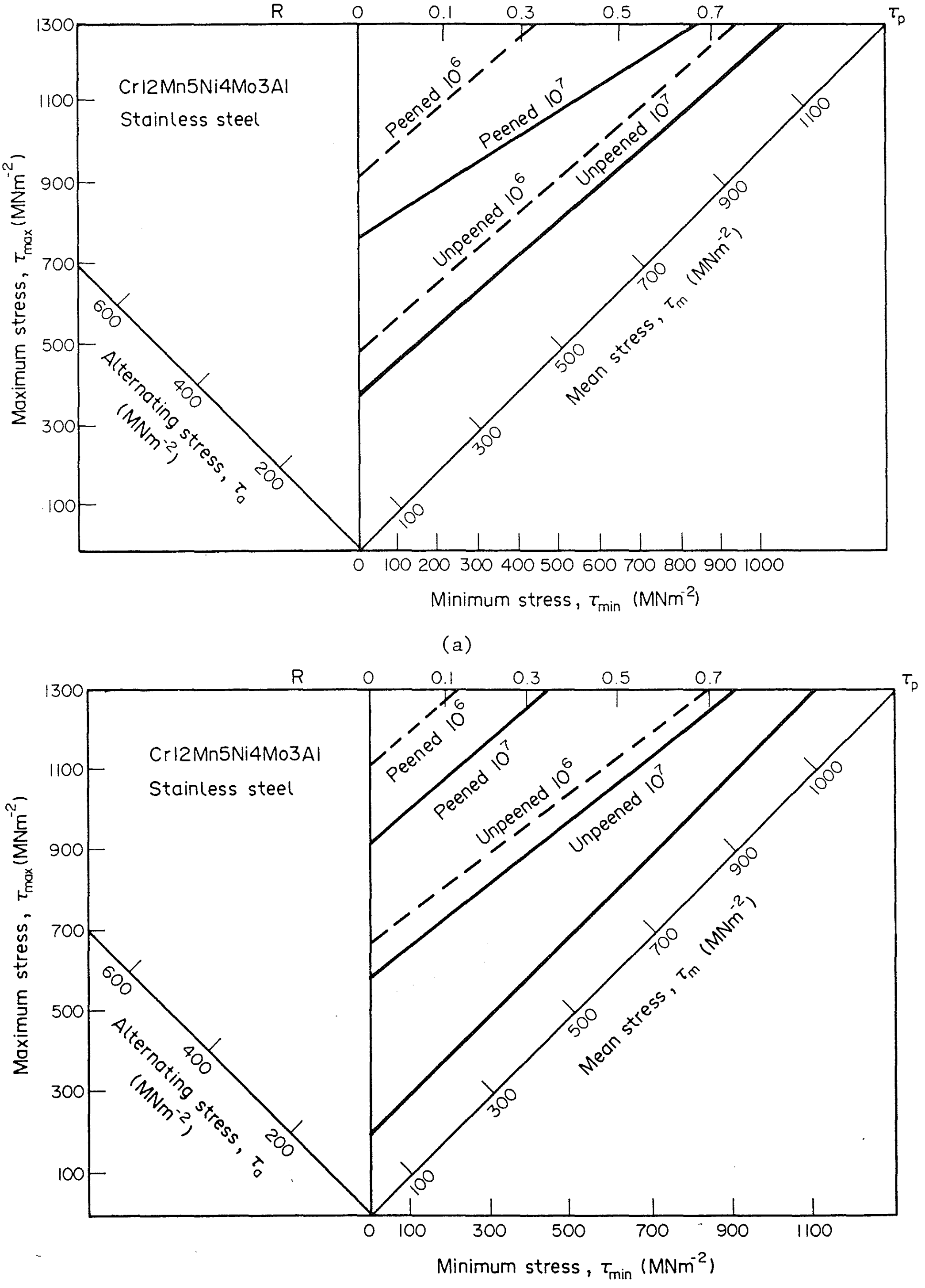
CONCLUSIONS

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 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 resistance of coil springs.



(b)

Fig. 5 Master diagrams of springs having d = 3 mm (a) and d = 2 mm (b), 99.9% probability of survival for 10^7 cycles and the median fatigue strength for 10^6 cycles

REFERENCES

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