SHOT PEENING ON TORSION FATIGUE

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Introduction

The effect of shot peening on bending fatigue has been well documented. Compressive residual stress, work hardening and surface topography are of major factors which influence the bending fatigue strength. When a crack initiates in the sub-surface layer, surface topography will be less important and the compressive residual stress may keep the crack from going through the outer layer to the vary surface.

For torsion fatigue, the loading stress is shear stress. Since the mean stress during cyclic torsion does not change the fatigue strength, naturally, the biaxial compressive residual stress induced by shot peening are throught to be of little effect on torsion fatigue strength.

Most papers claimed that hardness is the only factor which influences to the torsion fatigue behaviour. (1,2). But the experimental facts show that the fatigue strength of spiral spring, which is mainly under torsion load, can be greatly improved by shot peening with no much change on hardness. (3). This paper trys to clarify the effect of biaxial compressive residual stress on reverse torsion fatigue limit.

Presetting is often employed in spiral spring manufacturing, and prestrain is proved to be beneficial for bending fatigue, (4) but for torsion it needs to be clarified. So prestrain was also carried out to examine its effect on torsion fatigue behaviour.

Specimens and experimental procedure

A French spring steel 45SCD6 is used in this experiment, its chemical constituents are (in wt%).

C	Si	Mn	Cr	Ni	Mo	S	P
0.47	1.40	0.78	0.75	0.16	0.23	0.001	0.011

The torsion fatigue specimens are machined as Fig. 1.

All specimens were oil quenched after 900°C austenitizing for 30°, then tempered at 330°C for 1 hr.

Hardness (HRc)	Yield strength (MPa)		ultimate strength (MPa)
	torsion	tension	
51	750	1400	1700

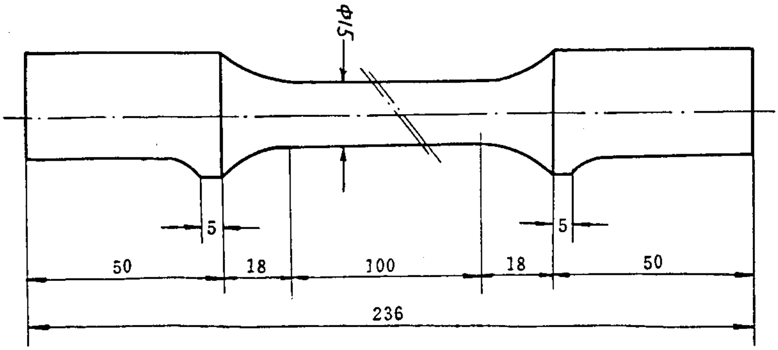


Figure 1 : Torsion specimen

Shot peening intensity was 35-40A (10^{-2}mm), with shots S230 (mean diameter 0,6 mm), and coverage 120 % . Pressetting for spring was simulated by applying a torque over the specimen, the angular displacement applied is equal to 1,9 times the angle corresponding to the yield limit. Plastic defomation occured under this torsional moment, after unloading the gripping flat surfaces of Fig.1 specimen should be ground to keep them aligned .

Torsion fatigue tests were carried out on a Schenck Flato 100 machine. The base line for fatigue limit was $2x10^6$.

The reverse torsion fatigue limits were determined with 50 % confidence.

Residual stress was measured on Rigaku MSF-2M by X-ray diffraction analysis with Cr-K^{α} radiation, (211) plane, and $\sin^2\Psi$ method. Fractography was studied in JSM-35C scanning electronmicroscope. Hardness was tested on Buhler Micromet II with 100g load.

Results

Different combinations of prestraining and peening, namely shot peening, prestrained then shot peening and shot peened then prestraining were examined. Their torsion fatigue curves are shown in Fig.2. The ground specimen was also tested for comparision. The fatigue limits are listed as follows :

state	Ground	shot peened	prestrained+ shot peening	shot peened+ prestraining
τ-1(MPa)	390	510	460	490

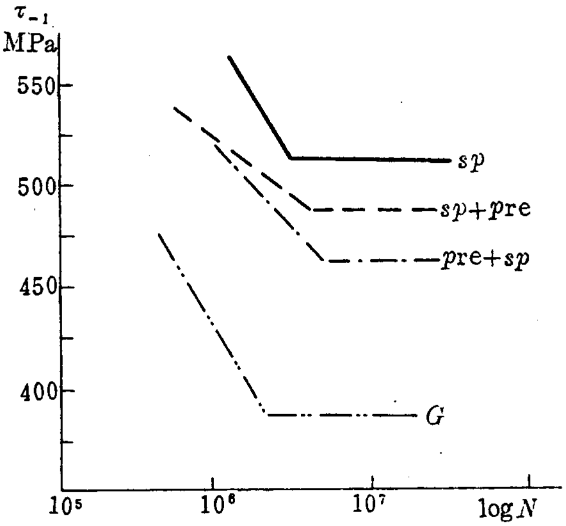


Figure 2: Torsion fatigue curves

The shot peened then prestrained specimens showed fairly large scatter for fatigue test data.

The residual stress distribution curves are shown in Fig. 3,4. In order to check the effect of prestrain and reverse torsion on the residual stress distribution in different directions, i.e. axial, tangential and 45° before and after fatigue limit tests were chosen for stress measurement.

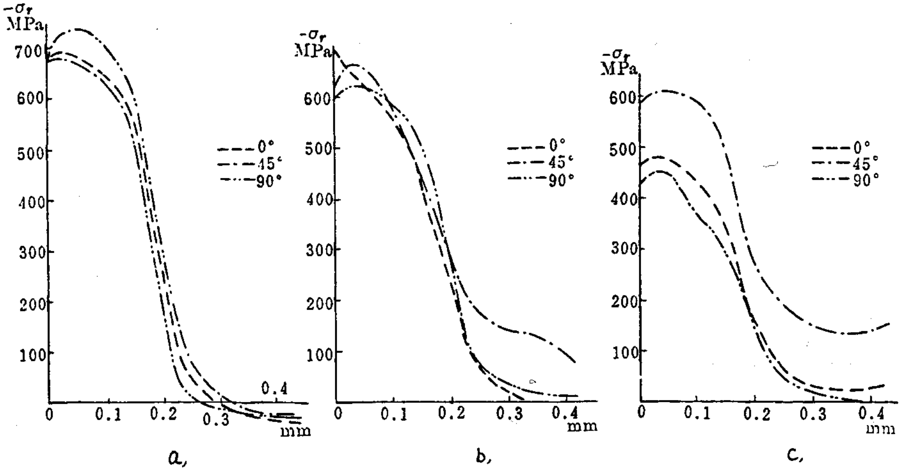


Figure 3 : residual stress curves for a, shot peened, b, prestrained+ shot peened and c, shot peened + prestrained before fatigue.

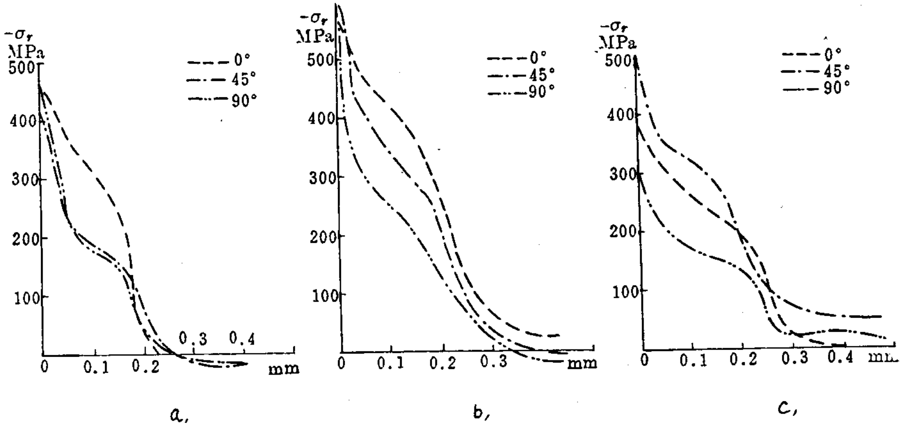


Figure 4 : Residual stress curves for a, shot peened, b, prestrained + shot peened and c, shot peened + prestrained after fatigue.

Hardness distributions through the depth are shown in Fig. 5 . A softened layer, around Hv 400 appeared in the sub-surface is co-existed with a hardened layer about 0.05mm in the outer surface. The hardened layer is even thinner for shot peened then prestrained specimen.

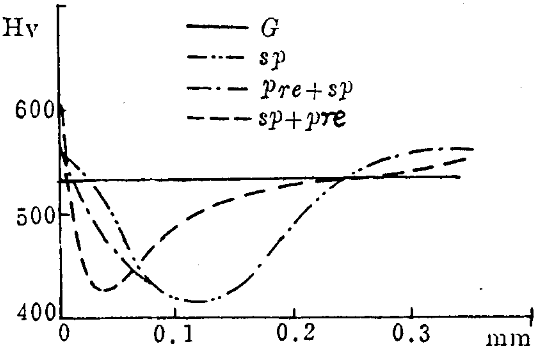
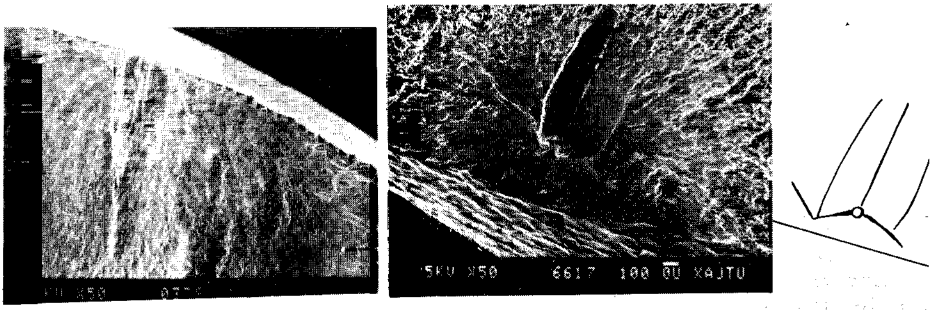


Figure 5 : hardness distribution curves

It is noticed that the hardness for the hardened layer is 50 about Hv higher and more than 100 Hv lower for the softened layer then the ground one.
Fractography study for the fracture surfaces about the fatigue limit loading shows cracks initiate on the right surface for ground specimen (Fig.6a) but turn into sub-surface layer after work hardening, the initiation depths are somewhere in between 0.3 to 0.6mm. All sub-surface crack initiations are started from inclusions . Fig. 6b.



a b c

Figure 6 - fatigue crack origin area, a, Ground specimen, b, shot peened specimen, c, Sketch of b.

All specimens fractured near the fatigue limit levels exhibit inclined crack paths about 45 degrees to the axial direction. A typical fatigue fracture origin for shot peened specimen is shown in Fig. 6b, its sketch is as Fig. 6c. Two small patches divided by a mid-rib are 90 degrees apart and 45 degrees to the axial direction. This is caused by reverse normal stresses during cyclic torsion. When the patches grew up to the sizes as shown in fig. 6b, the right hand side patch became predominant and propagated along its original direction, the left hand side patch turned over and tended to be coplaner with the right hand one.

Discussions

It is known that shear stress will not change the torsion behaviour when the specimen is fractured by shear stress in high torsion stress region. (5). However, according to fractography, the specimen fractured near the fatigue limit is caused by normal stress. This agrees well with the criterion that if the torsion fatigue strength τ_{-1} is lower than 70 % of the shear yield strength τ_s, the fatigue failure will be caused by normal stress (6). All torsion fatigue limits in this experiment are less than 0.7 τ_s , so normal stress in 45 degrees to the axial direction is responsible for the failure . In that case compressive residual stresses by shot peening will increase the torsion fatigue limit.

For torsion fatigue of engineering material, crack initiates at inclusion site and cyclic number for crack initiation Ni is only 5 % of failure cyclic number Nf (7) . Since crack propagation is of large fraction of the endurance life, it is important to keep the crack from growth. Hardness does increase after surface hardening but it is only involved in a very thin outer surface layer. Fig. 5 shows the work softening layers extend even thicker than the hardened ones. On account of cracking initiated in the deepth of 0.3 - 0.6 mm, and the fractography exhibited low crack growth rate region in the fatigue origin area, it seems unlikely hardness plays predominant role for increasing the torsion fatigue limit of work hardened specimen.

Prestrain, regardless before of after shot peening, decreases the torsion fatigue limit. In comparison with Fig. 3 a and c, it is noticed that compressive residual stress of shot peened specimen were released after prestraining particulary in the axial and tangential direction due to shear stresses by torsion. The change of compressive stresses may cause the difference of fatigue limit, but from fig. 3 a and b, the residual stress distributions of shot peened and prestrained + shot peened are similar but their fatigue limits are different, so ther must be some kind of damage induced in the prestraining process. A group of specimens have been tested under push-push loading in Xian Jiatong University. The stress state of push-push is even "softer" than torsion, the specimen was cut after push-push fatigue and cracking can be clearly detected on the cross section .(8). Angular displacement of prestrain may create damage or initiate a crack in the inclusion site, and the compressive residual stresses are relaxed to a certain extent. Shot peening after prestraining may rebuild the residual stress distribution shape but the damage cannot be cured. The difference of prestraining + shot peening and shot peening + prestraining is not important, because the fatigue data of latter one are very scatter, its allowable strength for application should be much lower and will be of no substancial difference with the prestrained and shot peened one.

Conclusions

1. Fracture of spring steel under reverse torsion is caused by normal stresses at the fatigue limit level, even for those after surface work hardening.

2. Compressive residual stresses are main factor in the increase of torsion fatigue limit.

3. Torsion prestrain may induce damage or cracks and decreases the torsion fatigue limit of shot peened specimen in pure alternating torsion.

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