THE EFFECT OF SHOT PEENING ON CONTACT FATIGUE LIFE OF CARBURIZED STEEL

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ABSTRACT

With carburized and hardened 20CrMnTi steel ring specimens,contact fatigue experiments were performed under sliding-rolling conditions. The contact fatigue lives of shot-peened specimens was compared with those of non-shot-peened specimens. The hardness distributions, residual stress distributions and their changes during the process of contact fatigue were measured. The microstructure and failure characteristics were inspected and analysed. The relations between the factors mentioned above were discussed.
It is established that there are three kinds of cracks: surface cracks, shallow subsurface cracks and deep subsurface cracks. With different conditions of growth and joining-up, these cracks would develop into pittings,shallow spallings or deep spallings. Under high contact stresses together with shot-peening, a shallow subsurface crack usually occurs and develops into shallow spallings just below the strengthened layer. A certain relexation of residual compressive stress will occur rapidly near the shot-peened surface layer. Under ordinary service loadings of gears (the contact stress lower than 225kg/mm^2),shallow spallings would hardly occur; the initiation and propagation of surface cracks were depressed by shot-peening and the contact fatigue lives of the shot-peened specimens, therefore, would be improved.

KEYWORDS

Surface crack; shallow subsurface crack; deep subsurface crack; pitting; shallow spalling; deep spalling.

FOREWORD

The fact that bending fatigue strength of gear tooth is increased considerably by shot-peening has been proved and well utilized in industry. But there are still arguments about the effect of shot-peening on contact fatigue life . It is known that shot-peening will bring about strengthening of the surface layer,produce large compressive stress and will change the surface topography. It is necessary to observe the effect of the changes on the behaviour of carburized steel under contact fatigue conditions.

According to the changes of properties in the surface layer and the fatigue characteristics of the specimens during the process of contact fatigue, this paper will discuss the effect of shot-peening on contact fatigue life of a carburized steel.

EXPERIMENTAL CONDITIONS

1. Material. The main and the matching specimens were prepared by a same process with a same material. The main chemical composition is shown in table 1.

TABLE 1 Main Chemical Composition of Specimens

Material	C	Cr	Mn	Ti	P	S
20CrMnTi	0.21	1.09	1.0	0.025	0.02	0.008

2. Specimens. Ring specimens with diameter 60 mm and contact width 4 mm is shown in Fig.1.

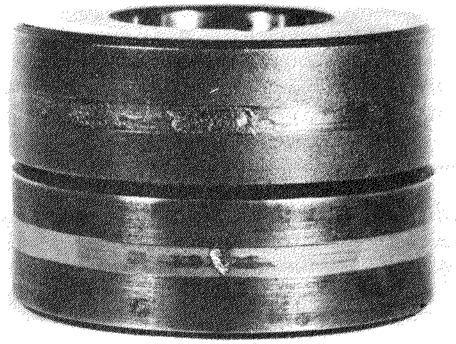

Fig.1. Failure characteristics of specimens.
Shot-peened, upper; Non-shot-peened, lower.

3. Heat-treatment. The specimens were carburized at 930°C, pre-cooled to 870°C, quenched in oil and then tempered at 180°C for 2 hours. The depth of the carburized layer is 1 mm. The microstructure of a transverse section is shown in Fig.2. Hardness distribution is shown in Fig.3.

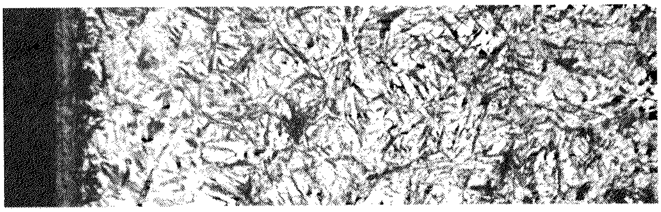

Fig.2. Microstructure of specimen which was shot-peened and rolled. Transverse section, 400X.

4. Shot-peening. Having been carburized and hardened, the specimens were shot-peened under the following conditions.

Shots: steel, diameter 0.8-1.0 mm;
Shot velocity: 60 m/s;
Almen intensity: 0.20 - 0.23 C;
Surface roughness: 0.70 μ (C.L.A.); The surface roughness of non-shot-peened specimens were 0.68 μ (C.L.A.).

5. Contact fatigue test.

Testing machine: The contact fatigue testing machine is of the type JPM-1. As soon as a spalling occurs, vibration will be generated. A detecter picks up the vibration signal and orders the machine to stop. The main specimen ran at 1500 rpm. The slip ratio was -25%.

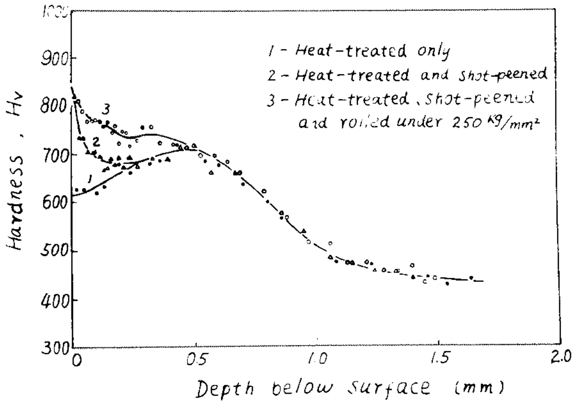

Fig.3. Hardness distribution and its change after rolling contact test.

Lubrication: The specimens were spray-lubricated with 30 lubricating oil. Its main properties is shown in Table 2.

TABLE 2 Main Properties of Lubricating Oil

Kinematic Viscosity (cst)	27-33	Welding Load, Pb(kg)	44
Flash Point (open) (°C)	180	Seizure Load, Pd(kg)	190

6. Residual stress measurment. The residual stresses were measured by standard X-ray instrument with Cr anode, 0°-45° method. To measure the subsurface stresses of the specimen an electrolytic polishing method was used. The values obtained were not modified.

EXPERIMENTAL RESULTS AND DISCUSSIONS

1. Contact fatigue lives of shot-peened and non-shot-peened specimens.

Fig.4 shows the contact fatigue lives of shot-peened and non-shot-peened specimens. It is established that the lives of shot-peened specimens are lower than the non-shot-peened specimens under high contact stresses. With the reduction of contact stresses, the difference in contact fatigue lives between them become smaller. However, when the contact stress is lower than 225 kg/mm², the contact fatigue lives of the shot-peened specimens become higher than the non-shot-peened specimens.

2. The change of surface roughness of specimen during contact fatigue testing.

It was found that the surface roughness of the main specimen, which worked at negative sliding, changed quickly. After a running of only $2X10^3$ cycles,it changed from 0.70μ(C.L.A.) to a steady value of 0.38μ(C.L.A.) and the rolling track became very smooth. The surface roughness of the matching specimen,which worked at positive sliding, changed only slowly. This was particularly so for the shot-peened specimens with a strengthened surface layer. For example, even if shallow spalling occurs at $6.9X10^5$ cycles on the main specimen (with negative slip),the surface roughness of the shot-peened positively sliding specimen still remained at 0.62μ(C.L.A.). While the surface roughness of matching non-shot-peened specimen,which worked at positive sliding, already changed from 0.68μ to 0.40μ(C.L.A.) for the same cycles of testing.

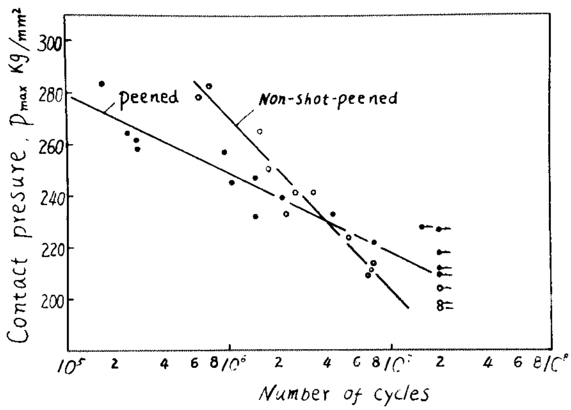

Fig.4. Contact fatigue lives of shot-peened and non-shot-peened specimens.

Wilde(1980) pointed out that the roughness of the surface,and particularly,the surface of the load roller which is positive sliding has a dominant effect on pitting fatigue. As previously stated,during the testing,the change of surface roughness of a positively sliding specimen is slow. Therefore,it had been playing a role in the long period of contact fatigue life. This is an important factor of decreasing contact fatigue life under high contact stresses.

3. The distribution of hardness and its change during the rolling contact testing.

Let us go back to Fig.3. Curve 1 is the non-shot-peened hardness distribution curve. The hardness at the surface is lower than that at the subsurface,and in this case, the maximum hardness occurs at a depth of 0.5 mm. When the specimen is further shot-peened, the surface layer is strengthened,and its hardness is increased. However,this strengthening effect gradually diminished along the depth, so that there appears a "valley" which start at the depth of 0.1 mm around. When the shot-peened specimen was under contact fatigue testing,a high contact stress will give rise to uneven plastic deformation of the specimen. Due to the very fact that the "soft-belly" in the "valley",but not the strengthened surface layer,it is at the shallow subsurface,that cracks will initiate, develop and give rise to spallings.

If a shot-peened specimen is under the contact fatigue testing with lower contact stresses,the testing will produce the rolling strengthening effect,which shifts the "valley" to a biger depth,as illustracted by curve 3 in Fig.3. The minimum hardness happened at depth of 0.3 mm in this case. This strengthening effect due to rolling will give a larger contact fatigue life of the specimen and whenever cracks and spallings take place, they are no longer shallow cracks and shallow spallings but deep cracks and deep spallings.

4. Residual stress in the surface layer and its change during the contact fatigue testing.

After shot-peening,residual compressive stress will be developed in the subsurface with a peak value as large as $-100kg/mm^2$ at a depth of 0.1 mm below the surface layer, as shown in Fig 5. According to Xu Jia-zhi.,Sheng Bang-jun and Zhang Ding-quan's work (1981), this residual compressive stress will depress the propagation of surface cracks. Under high contact stress, however,surface axial cracks and shallow subsurface cracks will develop and the peak of residual compressive stress will partly relax(Fig 6). The full benifit of compressive residual stress near the surface layer, was partly lost.

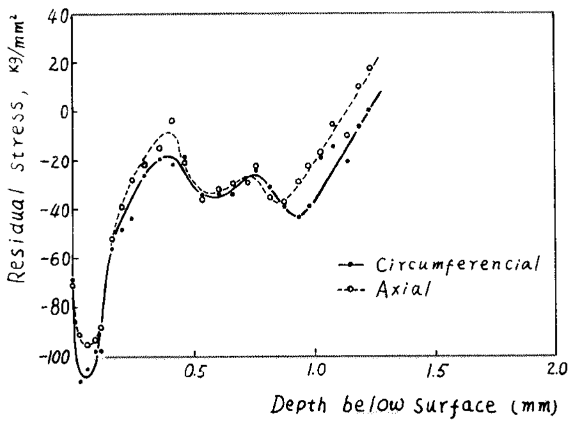

Fig 5. Distribution of residual stress after heat-treatment and shot-peening.

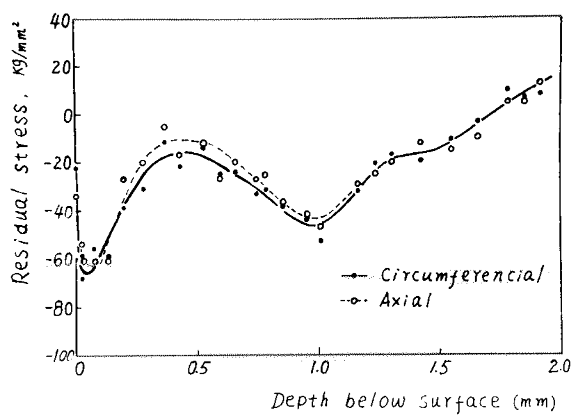

Fig 6. Distribution of residual stress after heat-treatment,shot-peening and rolling for $5X10^5$ cycles at $265kg/mm^2$.

5. The characteristics of cracks and spallings.

Fig.1 is the photograph of contact fatigue failure specimens(shot-peened and non-shot-peened). It was found that there were three kinds of cracks: surface cracks, shallow subsurface cracks and deep subsurface cracks.Surface cracks initiated from the surface. Shallow subsurface cracks were produced in a depth ranging from 0.015 mm to 0.05 mm. Deep subsurface cracks occured in a depth ranging from 0.3 to 0.5 mm.

Under high contact stresses,shallow subsurface cracks and shallow spallings occured easily in the shot-peened specimens (Fig.7). On the other hand, when non-shot-peened specimens were tested under this high level of contact stresses, rolling deformation and wear set in, but shallow spalling hardly happened in our experiments.

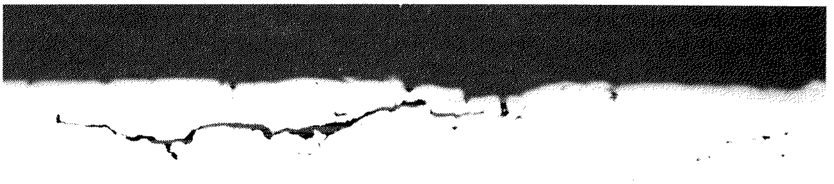

Fig.7. Shallow subsurface cracks and shallow spallings. Transverse section, 400X.

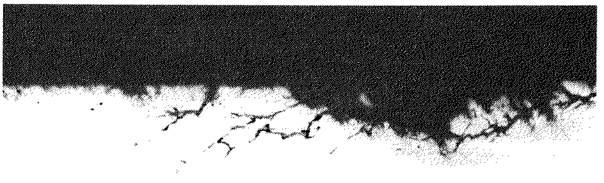

Fig.8. Surface cracks and pittings in the non-shot-peened specimen. Transverse section, 400X.

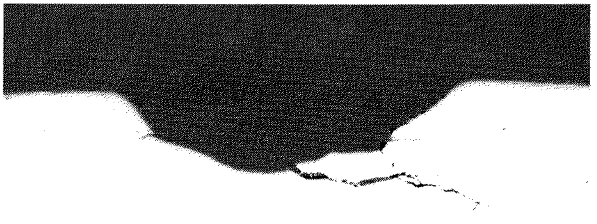

Fig.9. Deep subsurface cracks and deep spallings. Transverse section, 30X.

Under lower contact stresses,surface cracks and pittings occured easily in the non-shot-peened specimens (Fig.8),but to our knowledge, this type of failure was never observed in the shot-peened specimens. The type of failure encontered in shot-peened specimens under lower stresses is deep spallings as shown in Fig.9.However we observe several cases of this type of failure in the non-shot-peened specimens under lower stresses,but this happened at a much fewer number of testing cycles than the shot-peened specimens.

SUMMARY

Summarizing the results investigated in this experiment,we recognized the effect of shot-peening on contact fatigue lives of carburized steel as follows.

1. The shot-peening process bring about the strengthening of the surface layer,resulting in a rough surface with a high ability to resist plastic deformation. Also the change of roughness of a positively sliding specimen during the contact fatigue test is slow. Therefore,it had been playing a role in the long period of contact fatigue life. This is an important factor of decreasing contact fatigue life under high contact stresses.
2. There are three kinds of cracks: surface cracks,shallow subsurface cracks and deep subsurface cracks. The surface cracks initiate from 0.015 to 0.05 mm; the deep subsurface cracks occur at a depth ranging from 0.3 to 0.5 mm. Under different contact stresses the effect of shot-peening on the initiation and propagation of these cracks are different. Due to the different conditions of growth and joining-up of these cracks ,pittings,shallow spallings or deep spallings will be resulted.
3. Under high contact stresses,shallow subsurface cracks below the layer strengthened by shot-peening initiate and propagate quickly;the residual compressive stress near the surface layer partly relaxed. In conseqence,shallow spallings occur easily. The contact fatigue lives of the shot-peened specimens are,therefore,decreased. Under ordinary service loading conditions of gears (the contact stress lower than 225 kg/mm^2)the initiation and propagation of surface cracks are depressed due to the surface strengthening and the compressive stress near the surface layer. Shallow spallings would hardly occur,and the contact fatigue lives of the shot-peened specimens could be improved.

REFERENCE

Xu Jia-zhi., Zhang Ding-quan, and Sheng Bang-jun (1981). The Fatigue Strength and Fracture Morphology of Leaf Spring Steel after Pre-stressed Shot-peening. Proceeding 1st International Conference on Shot-peening.

Wilde.R.A (1980). In Maurice A.H.Howes (Ed), Source Book on Gear Design, Technology and Performance, A.S.M., Section, pp300-312.