Shot Peening of the Gear Surface with Ground Cracks

Tan Yuxu, Ma Baotian, Ren Liping, Xi'an Jiaotong University, China
Ye Qingrong, Qishuyan Locomotive and Cars Technology Institute, China

Introduction

Tiny cracks always occur on the ground surfaces of case hardened machine particulary for carburized gear with abusive grinding. Most of cracks are within the depths from 0.05mm to 0.15mm. According to the statistical data for locomotive driving gears in a factory there were 5-10% products which were suffered from tiny cracks on the teeth parallel to the gear profiles. In general case the cracked ones should be treated as waste products thus it will cause economical loss. In order to ensure the safety of cracked gears in operation, by some means or other to put the gears into use will be a valuable research work. If the surface of gear contour was undergone shot peening, it would form a surface strengthened layer. The depth of this layer is about 0.2-0.4mm. Compressive residual stress was induced in the layer. If the depths of ground crack is shallow, the front of crack does not cross over the compressive stress area that the cyclic contact stress can not lead to early surface spalling. The gear with ground cracks has the same ability to resist contact fatigue stress as the normal gear. Experiments and analyses were made systematically on the locomotive driving gears so that we can confirm the rationality about the use of gears with ground cracks.

Experimental Procedure

1. Parameters of experimental gear
Diesal locomotive driving ND2 gear (Photo. 1): Module m=11; Number of teeth z=17; driving power p=200kw

2. Chemical composition and heat treatment
Chemical composition of ND2 gear

C	Mn	Si	Cr	Mo	S	P
0.21	1.00	0.30	1.23	0.25	0.01	0.016

Heat treatment
Carburization: 930°C for 16.5 h, furnace cooling, tempered at 610°C for 3 h.
Heated at 850°C for 70 min oil quenched, tempered at 200°C for 1.5 h.
Surface hardness: HRC 58-60.

3. Grinding and Shot Peening
Speed of wheel: 35m/sec
Grinding amount: rough grinding a = 0.10mm
simifine grinding a = 0.04-0.05mm
fine grinding a = 0.01-0.03mm
Coolant: diesel oil
Shot peening parameters:
Diameter of chilled iron shot: d = 0.5-0.8mm
Intensity: f = 0.40A(mm)
f = 0.50A(mm)
Coverage: c = 150

4. Measurement of crack length, residual stress and the amount of retained austenite

Crack length measurement:
Macrosnalysis: Surface cracks were photographed by MEF-3 metalloscope, see Photo 1.
Lengths of ground cracks were measured by tool microscope.
SEM analysis: The profiles of ground cracks were photographed by JSM-35C scanning electron microscope, see Photo 2.
Crack depth-crack length curve is shown in Figure 1.
Measurement of residual stress:
Residual stress was measured by MSF-2M X-Ray stress analyzer. Residual stress-layer depth curves are shown in Figure 2.
Retained austenite is measured by DMAX/III X-Ray diffractometer.

5. Metallographic analysis

The grown direction of a ground crack is shown in photo 3.

6. Loading examination

ND2 gears have been put into operation in Changsha railway bureau for 9000h and another type 6Y2 electric locomotive driving gears (m=12.7, z=16 p=800kw) with resemble ground cracks also have been put into use in Baoji railway bureau for 8400h. No abnormal phenomena were found on the teeth surface in examining.

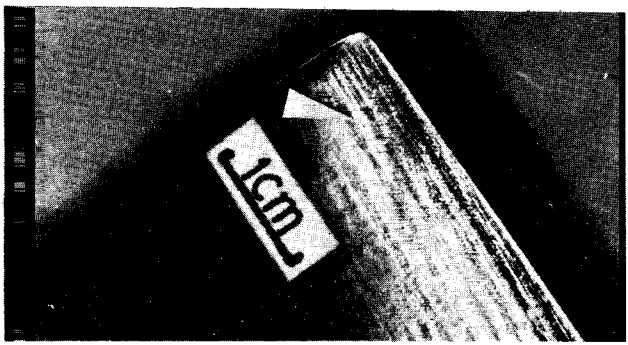


Photo 1: Macrograph of ground cracks

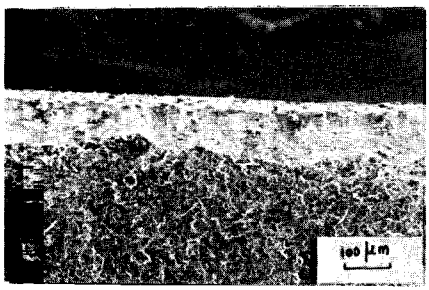


Photo 2: Profile of a ground crack. (SEM)

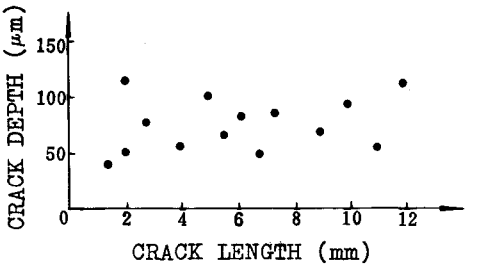
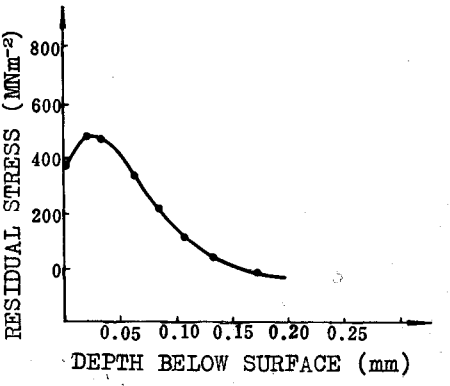
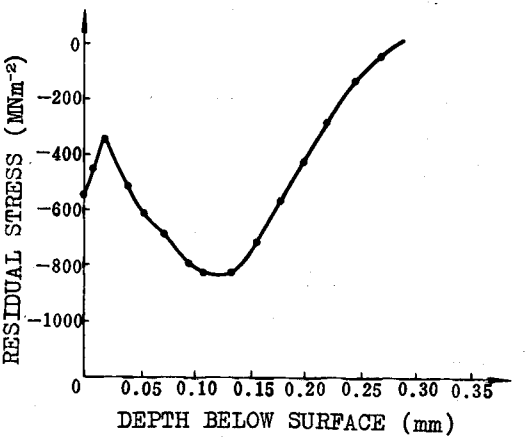


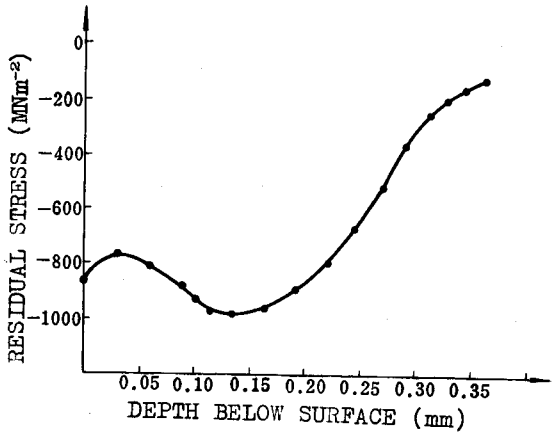
Fig. 1: Crack depth - Crack length curve



(a) Before shot peening



(b) After shot peening f=0.40A(mm)



(c) After shot peening f=0.50A(mm)

Fig. 2: Residual stress - Layer depth curves

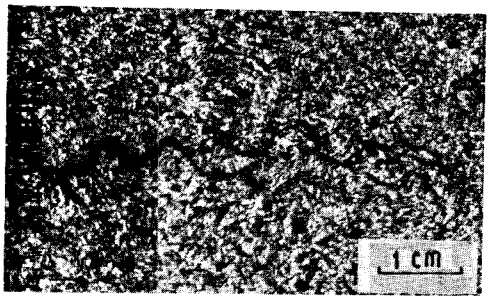


Photo 3: Optical metallograph of a ground crack

Results and Discussions

Figure 1 shows that crack depths are irrelevant to crack lengths. No matter how long the crack lengths are, the depths of cracks are always limited in the range of 0.04-0.12mm. The depths range is associate with the depth which is influenced by tensile stress, see Figure 2(a).

The results of macroanalysis and SEM analysis show that ground cracks are always longitudinal along the gear contour. In the medium part of a crack depth keeps no change on the whole (Photo 1,2). The ends of a crack turn to tooth surface. Photo 3 is a metallograph of a ground crack. The crack grows from left to right. It seems that the microstructure of carburized layer is a factor which influences the crack growth under contact fatigue process, due to the matensite

packet boundary acts as a obstacle which makes the crack turn aside from the original direction. Because the hardness of chilled iron shot is softer than that of teeth surface, the maximum value of the residual stress is located beneath the surface rather than on the very surface of the contour (1)(2). Figures 2(b)(c) show residual stress-layer depth curves. The peaks of compressive residual stress of two shot peening programmes are located in 0.10-0.15mm layer depth position. It follows that the front of ground crack is buried in compressive stress zone. Probably it might not propagate in contact fatigue process (3)(4).

After shot peening no crack was detected on the teeth surface by ultrasonic detector, but we cannot consider that ground cracks have been healed. Because the ground crack is in tight closed condition in operation, lubricating oil and pernicious mediums are not easy to penetrate to the tip of the crack.

Retained austenites in the carburized layer will transform to martensites. The amount of retained austenite decreases from 19% to 1% and hardness number increases from HRC 60 to HRC 62. When retained austenite transforms to martensite, the volume of strengthened layer will expand. Thus the tiny ground cracks are further situated in closure condition and it is beneficial to the strength of contant fatigue.

If the teeth surfaces are not treated by shot peening, the residual tensile stress will existed in the surface layer, see Figure 2(a). The tips of ground cracks are usualy situated in opened condition. Oil and mediums can penetrate to crack tip easily. Therefore the crack will propagate in lower stress, Thus the gear will not be allowed to put into use.

Conclusions

(1) Residual tensile stress exists in the layer of ground gear surface. Gears with surface ground cracks are not allowed to put into use.
(2) After shot peening residual compressive stress is located in surface strengthened layer. If tiny cracks are buried in the compressive stress area, the gear with ground cracks will be permitted to operation.
(3) Loading examinations certify the argument mentioned above.

References

(1) H.Wohlfahrt: Residual stress and stress Relaxation (1981), P.17
(2) N.S.Hu: Report of Science and Technology, Xi'an Jiaotong University, 1985-581
(3) Z.J.Deng: Proceedings of ICSP(I), P.389
(4) W.J. Zhou: J. Xi'an Jiaotong University Vol.16, (1982) P.1