The Effect of Shot Peening on Contact Fatigue Behavior of 40Cr Steel After Compound Heat Treatment

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ABSTRACT

The rolling contact fatigue specimens of 40Cr steel were treated by shot peening after the compound heat treatment of ion-nitriding and induction hardening. In order to study the effect of shot peening on contact fatigue behavior of 40Cr steel after compound heat treatment, the contact fatigue test, fractography and metallography studies, hardness measurement as well as the residual stress analysis were conducted.

KEYWORDS

Compound heat treatment (CHT); shot peening after the compound heat treatment (CHT+SP); ion-nitriding (IN); induction hardening (IH); carburizing hardening (CH); shallow spalling; deep spalling; pitting; surface crack.

INTRODUCTION

Shot peening is one of the effective processes for surface hardening and about its research for bending fatigue behavior there are already some reports[1,2] . But its effects on the contact fatigue behavior and its use in process of gear hardening have seldom been refered to. In order to provide the theoretical basis for improving the process of working gears and increasing the contact fatigue strength of materials and lifetime in employment, the affecting rules of shot peening on contact fatigue behavior of 40Cr steel after the compound heat treatment(short name of nitriding and induction hardening) have been investigated.

EXPERIMENTAL PROCEDURES

1. Material. The main specimens were prepared with 40Cr steel. The matching specimens were prepared with carburized 20CrMnTi steel. The chemical composition is shown in table 1.

TABLE 1. Chemical composition of specimens

Material	C	Cr	Mn	Ti	P	S
40Cr	0.40	1.09	0.8	-	0.02	0.008
20CrMnTi	0.21	1.08	1.0	0.03	0.02	0.009

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

3. Heat treatment and shot peening. The main specimens of 40Cr steel were treated with ionnitriding at 620°C for 7 hours then with 900°C induction hardening and tempered at 180°C for 2 hours. The matching specimens were carburized at 930°C and reheated to 840°C, quenched into oil, then tempered at 180°C for 2 hours.

The main specimens of 40Cr steel were shot peened under the following conditions:

First shot peening with steel shots, diameter: 0.8-1.2mm, time: 5 minutes, pressure of air:45N/mm^2, rotational speed of specimens:8r.p.m, Almen intensity:0.4mm(this is an arc high of Almen specimens of A type after shot peening).

The second, with iron shots, diameter: 0.2-0.4mm, time: 3 minutes, pressure of air:50N/mm^2, rotational speed of specimens:8r.p.m, Almen intensity:0.4mm.

Thereafter, the contact fatique test and analysis of fractography are made with all specimens treated.

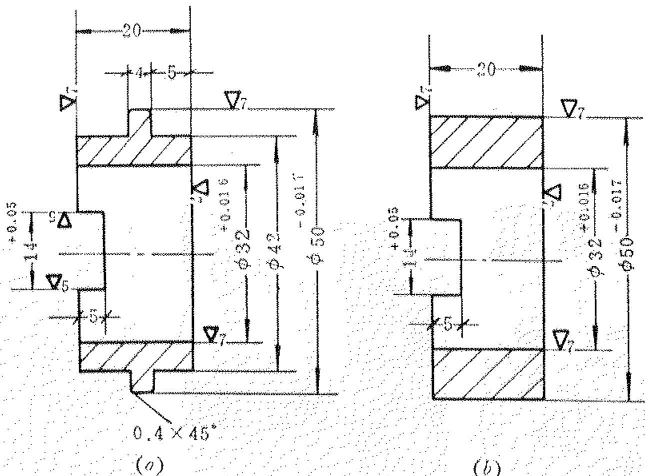
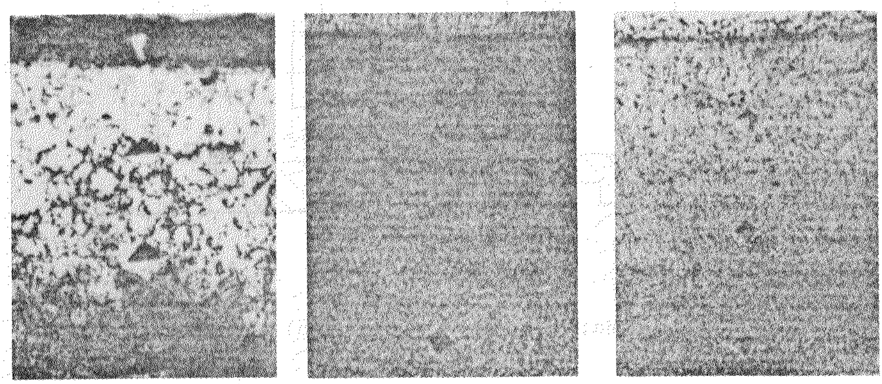


Fig.1. Main(a) and matching(b) specimens.

EXPERIMENAL RESULTS

The structure of surface layer and the distribution of hardness along depth of layer are shown in Fig.2 and Fig.3 separately after ion-nitriding(IN), compound heat treatment (CHT) and shot peening after compound heat treatment(CHT+SP), It is found by means of X-ray diffraction that the structure of surface layer of specimens is nitrogen containing martensite(α') adding retained austenite(γ) by compound heat treatment, the decrease of its hardness depends on the increase of content of γ, with Hv 300 at surface of specimens, and that the structure of surface layer is α' by shot peening, the density of dislocation and lattice distortion are increased and the subgrain size is decreased during cyclic attack of shots, as a result the hardness is increased notably, with Hv 900 at the surface layer. But the hardness gradients are similar over 0.2mm of depth from the surface by both shot peening and compound heat treatment.

The field of residual stress with compound heat treatment and shot peening is plotted in Fig.4. It may be seen that there is a zone of residual tensile stress along tangent direction of surface layer of specimen by compound heat treatment, that the position of maximum residual tensile stress corresponds with that of peak of curve of Hv with depth of 0.2-0.25 mm from surface approximately, but the state of distribution of stress in specimen with compound heat treatment is changed



(a) (b) (c)

Fig.2, Microstructure of surface layer of specimens which were IN(a), CHT(b) and CHT+SP(c).

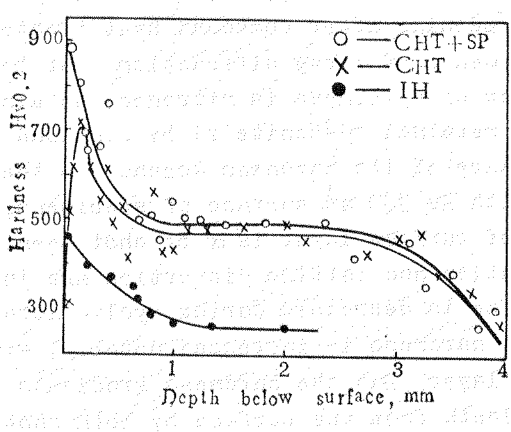


Fig.3, Hardness distribution.

into residual compression stress by shot peening, with the position of maximum value of σ_r in sublayer.

It has been proved from the results of test of contact fatigue, as shown in Fig.5, that the compound heat treatment can enhance the contact fatigue behavior markedly, approached that of 20CrMnTi steel by carburizing hardening or over, and shot peening can improve the behavior further. for instance, 2340 N/mm^2 of condition fatigue life time of specimens by induction hardening, 2800 N/mm^2 by compound heat treatment or carburizing hardening, and 2900 N/mm^2 by shot peening after compound heat treatment. The endurance limits of the latter both are increased by 19% and 24% separately as compared with that by induction hardening.

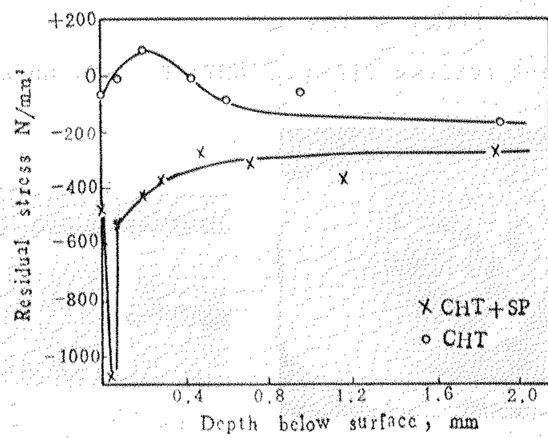


Fig.4, Distribution of residual stress after CHT and CHT+SP.

DISCUSSION

The shallow spalling and the less pittings are main types of fatigue failure in this test, but deep spalling is avoided with improving technology. The SEM photographes of morphology of contact fatigue fracture is shown in Fig.6 and Fig.7. Fig. 6(a) shaws the morphology of shallow spalling fracture, the (b), (c), the nucleation and propagation of crack of specimen by shot peening after compound heat treatment, and (d), for comparison, shaws that by compound heat treatment.

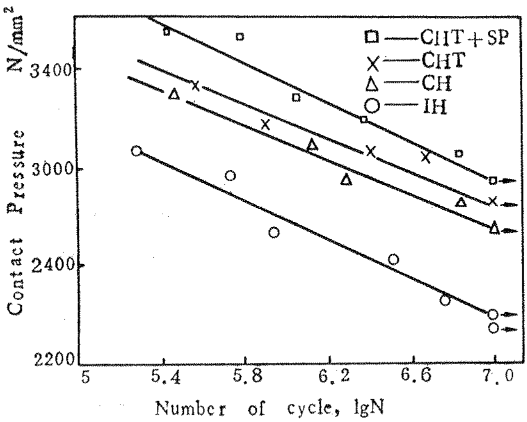
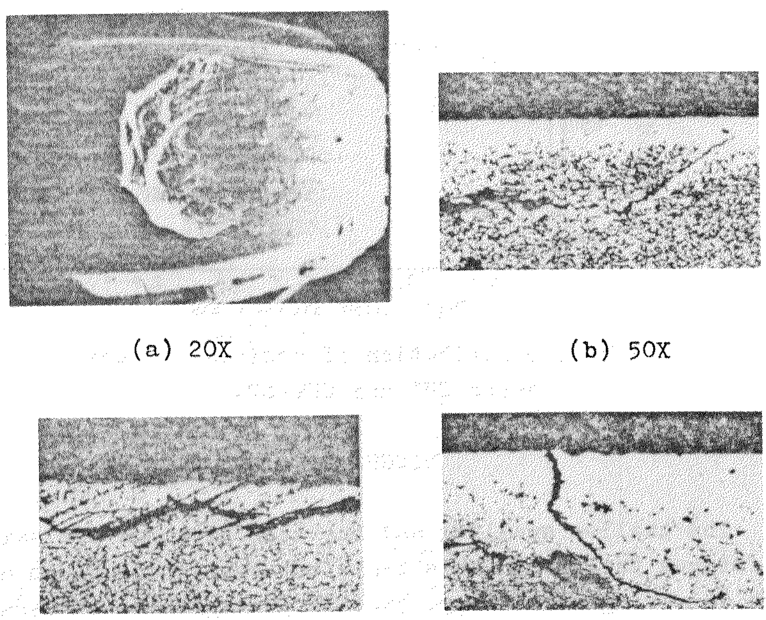


Fig.5, Contact fatigue lifes of CHT+SP. CHT. CH and IH.

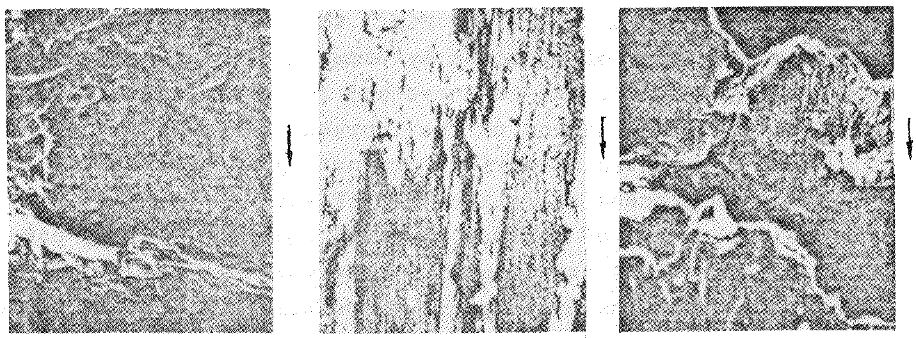


(a) 20X (b) 50X

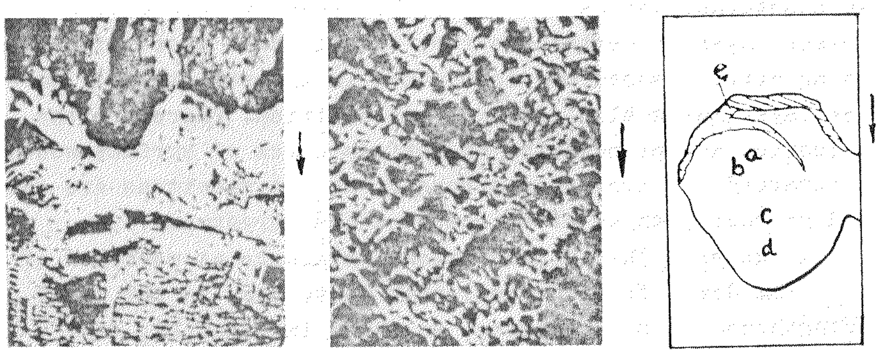
(c) 40X (d) 50X

Fig.6,Crack initiation site.

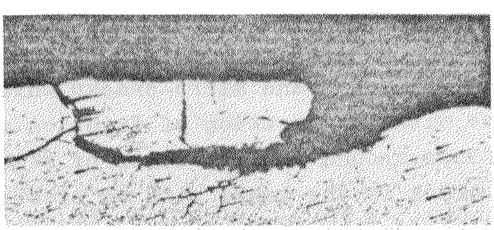
It may be seen that the process of contact fatigue failure is comprised of crack nucleation and crack propagation, the driving force of which is maximum shear stress τ_{max} , and the acting position of τ_{max} is removed to surface due to the



(a) 300X3/5 (b) 1500X1/2 (c) 500X1/2



(d) 500X1/2 (e) 1500X1/2 (g)



(f) 40X

(a). origin of crack;
(b-d). propagation of crack;
(e). root of break zone;
(f). shallow spalling;
(g). fatigue fracture.
↓ : roolling direction.

Fig.7, Fractography of contact fatigue.

friction which is caused with opposite slide between contact planes of specimens, with the value of τ_{max} increased, a cyclic shear stress is also developed at the same time. For this reason, the nucleation and the propagation of crack take place at surface easily and failure in consequence of that.

It is seen from Fig.2 and Fig.3 that owing to the fact that the structure of specimen by compound heat treatment is phased with α' and γ, its hardness and shear yield strength are decreased with dependence on the increase of amount of γ, and the crack originates at surface frequently and propagates rapidly within process of fatigue test(Fig.6.d). The hardness and yield strength of surface layer of specimen by shot peening after compound heat treatment increase markedly due to α' obtained with strain-inductive phase transformation and the effect of work hardening. Secondly, the increase of residual compression stress in the surface layer of specimen by shot peening can counteract and weaken the cyclic shear stress acting on surface layer in certain degree, the field of short distance acting stress caused by dislocation in the structure of surface layer makes slip difficult in addition. Therefore the nucleation and propagation of fatigue crack of surface would be retarded and prevented strongly, as the specimens are carried on shot peening after compound heat treatment.

In general the fatigue cracks originate at position of 0.2-0.4mm depth from surface, that is to say, in the layer strengthened by shot peening, as shown in Fig.6(b), (c).

The contact fatigue fracture, similar to other fatigue fractures, includes fatigue crack origin, propagation zone and final fracture zone.

The fractures of shallow spalling of specimen by shot peening are consisted of small holes and micro-cracks which originate at the interface with the function of friction and pressure, as the matrix flows around the particles of second phase, and the origin of crack is the small pits as eyes of fish in Fig.7(a). The smooth fracture with dark grey colour indicates that it is in the field of shear stress that the crack nucleates and propagates, and the propagation of crack is forced to parallellize the surface along the direction of circumference, followed by crack elongating to surface. In this case, the crack propagation takes place in vacuum, not developing the fatigue lines, so that direct observe of its morphology is not easy for the effect of friction as shown in Fig.7(b). When fatigue crack emerging out, lubricant oil enters the crack and oil filling forces the tip of crack propagating in direction of circumference inversely, as the crack tip is at state of plane stress of spit open type. The steps of different morphologies, as shown in Fig.7(c). (d), are observed which are resulted from the change of stress at creak tip and the difference of frequency of acting with oil pressure. At last, the crack of split open type, as a beam, can be broken off and peeled off for some time of impulse(Fig.7(f)) a pattern of small pits drawing-out is found at the root of break zone, as shown in Fig.7(e).

The reasons for improving the contact fatigue behavior by shot peening have been discussed as stated above, but the effect of roughness of surface by shot peening on the contact fatigue should be approached in the next work. It may be infered from above that the shot peening after compound heat treatment may be taken as a new technology in strengthening the surface of gears in industrial production.

CONCLUSIONS

1. The contact fatigue behavior of 40Cr steel by shot peening after the compound heat treatment is far superior to that of the induction hardening(the fatigue life has been increased 5-8 times under the same contact stress), and that of the hardening of the carburized steels, This process is noted for its time and energy saving, and less deformation than that of the carburization hardening.

2. After shot peening, the surface layer is strain hardened. There is a nitrogen containing α' in the sublayer which has a depth of 0.3mm. it is a very fine grained microstructure with the hardness Hv 750-900.

3. Shot peening enhances the residual compression stress which has already been developed by the compound heat treatment with the surface layer of shot peening formed at the same time. The work hardened surface layer thus formed has a strong ability to prevent the nucleation of the surface crack and hence increases the fatigue resistance markedly.

When the contact stress is 2800-3200 N/mm^2, the primary type of fatigue failure is shallow spalling(0.20-0.40mm of depth) and deep spalling(until transient layer) with pit etching which shows a less degree. When the whole hardening layer is 2-3mm deep or over, the shallow spalling failure is primary with deep spalling prevented.

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