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# Influence of Deep-Nitriding and Shot Peening on Rolling Contact Fatigue Performance of 32Cr3MoVA Steel

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**The effects of deep-nitriding and following shot peening on microhardness, rolling contact fatigue property of 32Cr3MoVA steel were investigated and Scanning Electron Microscope (SEM) was employed to evaluate the failure surface of rolling contact fatigue specimens. The fatigue results indicate that the depth of deep-nitrided layer is about 0.75 mm and following shot peening can improve the rolling contact fatigue life. The SEM test shows that the area of failure for nitrided and following shot-peened specimens is smaller and the depth of pit is lower compared with nitrided specimens.**

**Keywords** deep-nitriding, rolling contact fatigue, shot peening, 32Cr3MoVA steel

## 1. Introduction

Nitriding is a chemical-heat treatment to improve fatigue, wear and corrosion for metallic parts. In engineering the depth of nitriding is generally about 0.3-0.4 mm, this thin harder surface layer may cause surface layer spall from matrix because of high-applied load or great stress gradient in surface layer (Ref 1). The deep-nitiding technology, therefore, is developed in aeronautical industry to improve contact fatigue and wear properties. This paper will present the deep-nitriding process and investigate its effect on rolling contact fatigue performance.

Shot peening is a surface strain strengthening process to improve bending or torsion fatigue and have been employed to increase bending fatigue resistant of gear in engineering (Ref 1, 2). It is usually used to improve fatigue of carburized steel and less employed for nitrided steel in gear engineering. The reason why it is not used to improve fatigue for nitrided steel is that the hardness of nitrided layer is higher than that of shot and it will make shots break during peening. This paper will investigate the effect of shot peening on rolling contact fatigue of deep-nitrided steel.

32Cr3MoVA steel is employed to make gear in aeronautical industry and nitriding is often used to increase hardness and modify contact fatigue (Ref 3). Although there are many investigations on shot peening of carburized steel, there are fewer on shot peening of nitrided steel, especially there is little research on effect of deep-nitriding and following shot peening on rolling contact fatigue of 32Cr3MoVA steel. The objective of this paper is to investigate the effect of shot peening on rolling contact fatigue of deep-nitrided 32Cr3MoVA steel and clarifies whether it is necessary to employ shot peening for nitrided parts.

## 2. Experimental Procedure

### 2.1 Material and Heat Treatment

32Cr3MoVA steel is employed in this investigation. Its chemical composition and mechanical properties are listed in Tables 1 and 2, respectively. The heat-treatment processes used for 32Cr3MoVA steel were the followings:

(i) solution treatment at 950 °C for 1 h plus oil cooling;
(ii) tempering at 635 °C for 2 h plus air cooling;
(iii) nitriding at 560 °C for 72 h under $NH_3$ = 65% to get deeper nitrided layer.

Microstructures were examined by optical microscope and the microstructures of surface, center and shot-peened surface for 32Cr3MoVA steel after heat treatment are shown in Fig. 1(a), (b), and (c), respectively. In the deep-nitrided surface and following shot-peened surface, there is no wave-shape nitride shown as in Fig. 1(b), which is in the subsurface layer and along the grain boundary.

### 2.2 Shot Peening

Fifty samples from 100 nitrided specimens were properly shot-peened with shot peening intensity of 0.45 mmA (arc height of Almen strip type A) and coverage rate of 200% on a pneumatic machine. The value of the deflection of Almen strips obtained after a saturation time is considered to be characteristic of the shot peening intensity. The coverage is 200% when the shot peening time is twice as the saturation time. Ceramic beads were used and the diameter of shot was about 0.9 mm (Z850 type bead made by Saint-Gobain, Zirpro, France). The peened surfaces were fine ground out 0.01 mm to get surface roughness, *Ra*, is 0.12-0.18 μm from three specimens.

### 2.3 Microhardness Test

Vickers indentations were made on the surface of polished samples with loads $F$ equal to 49 N along the cross surface as a function of distance along depth and Vickers hardness $HV$ is calculated as

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**Table 1** **Chemical composition of 32Cr3MoVA steel (wt.%)**

| C | Mn | Si | S | Cr | Ni | Mo | V | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|
| 0.34 | 0.60 | 0.38 | 0.002 | 3.07 | 0.06 | 0.99 | 0.26 | 0.07 | Bal. |

**Table 2** **Mechanical properties of 32Cr3MoVA steel**

| Yield strength $\sigma_{0.2}$, (0.2% offset), MPa | Tensile strength $\sigma_b$, MPa | Reduction of area $\psi$, % | Elongation $\delta_5$, % |
|---|---|---|---|
| 1163 | 1340 | 68.4 | 17.2 |

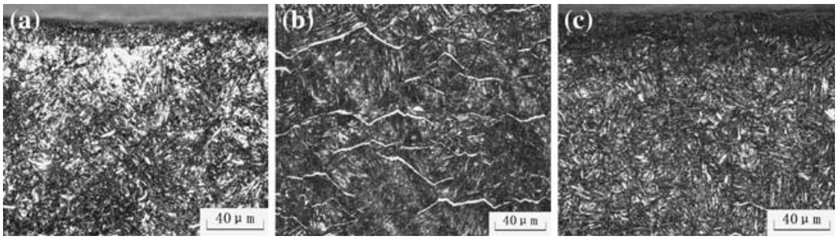


**Fig. 1** Microstructure of surface, subsurface layer and nitrided following shot-peened surface for 32Cr3MoVA steel (a) surface of nitrided specimen, (b) subsurface layer of nitride specimen, (c) surface of nitrided following peened specimen

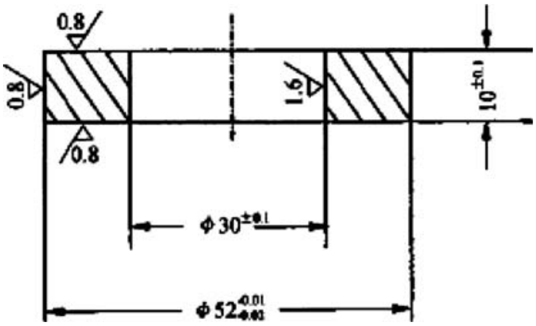


**Fig. 2** Configuration and dimension of contact fatigue specimen

$$HV = \frac{1.854F}{d^2} \qquad \text{(Eq 1)}$$

where $d$ is the length of the indent diagonal.

There are nitrided and nitrided following groups specimens to measure hardness and each group has five samples. The experimental results are the average of the measured values.

### 2.4 Rolling Contact Fatigue

Rolling contact fatigue specimens shown in Fig. 2 were nitrided or nitrided following shot peened as above described. Rolling contact fatigue was undertaken in a type of TLP contact fatigue tester as shown in Fig. 3 at room temperature according to standard (Ref 4). The specimen is placed at the sample holder and stress is applied by a load on the lever end. Contact fatigue specimen contacts with the 8107 type axletree, which is rotating and revolving by driving with a motor.

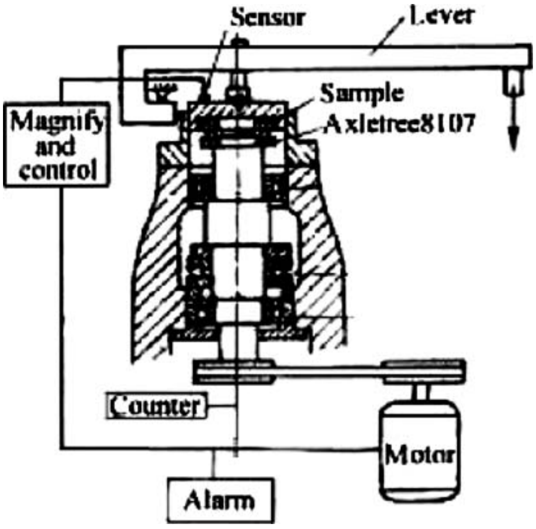


**Fig. 3** Schematic of operation of contact fatigue tester

The rotating rate of shaft is 2040 r/min. 20# machine oil was circulated to lubricate surface of specimens. The size of specimens is $\varphi$ 52 × 7.5 mm and surface roughness *Ra* is 0.12-0.18 μm. Take 25 specimens as a group and the maximum rolling contact stress is 4508 MPa, which is calculated according to

$$\sigma_{\max} = \frac{186}{\mu V} \sqrt[3]{F\left(\sum \rho\right)^2} \qquad \text{(Eq 2)}$$

where $F$ is perpendicular load at contact pot; $\sum \rho$ is sum of radius of two contact pots; $\mu V$ is an ellipse integrate function.

Rolling contact fatigue life distribution is following with two parameters Weibull distribution function:

$$P(N)s = 1 - e^{-\left(\frac{N}{Vs}\right)^b} \qquad \text{(Eq 3)}$$

where $P(N)s$ is probability of fatigue life less than $N$ when the stress level is $S$; $b$ is slope of Weibull distribution line plotted in log-log axes; $N$ is fatigue life or cycles; $Vs$ is characteristic fatigue life when the $P(N)s$ = 63.2%. When the $P(N)s$ = 10%

and 50%, the corresponding fatigue life is $L10$ and $L50$, respectively. The relationship of $Vs$, $L10$, and $L50$ are the following:

$$L10 = Vs(0.10536)^{1/b} \quad \text{(Eq 4)}$$

and

$$L50 = Vs(0.69315)^{1/b} \quad \text{(Eq 5)}$$

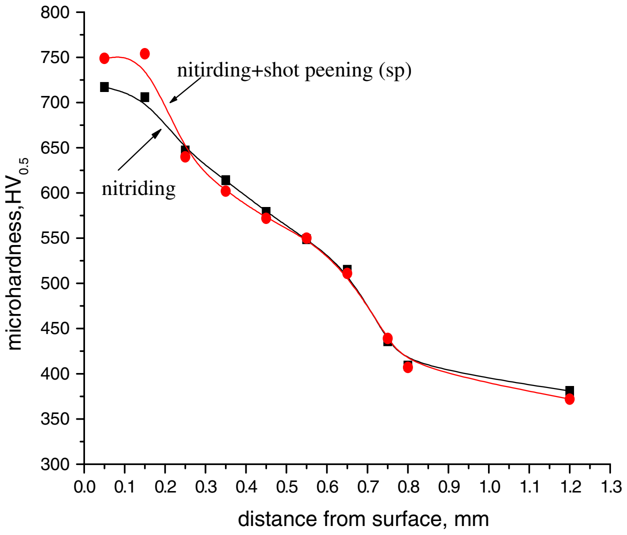


**Fig. 4** Microhardness distribution along surface layer

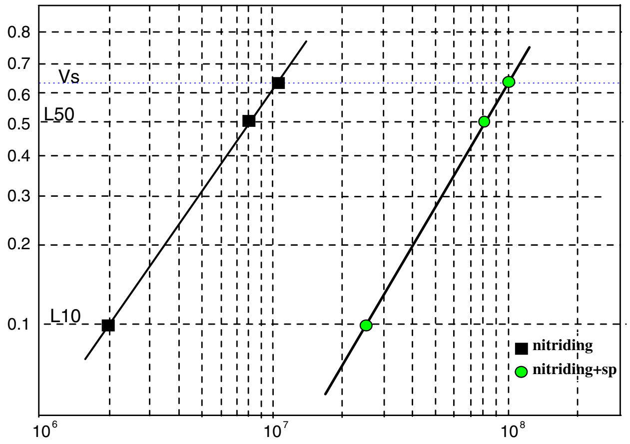


**Fig. 5** P-N curve of rolling contact fatigue

### 2.5 Failure Analysis

The failure surface was investigated in Scanning Electron Microscope (SEM) and the area and depth of spalled pit were determined and compared by SEM. The area of pit was determined in rolling contacted surface and the depth of the pit was checked in across surface.

## 3. Results and Discussion

The microhardness distribution along surface layer and curve of rolling contact fatigue failure probability $P$ to fatigue life or cycles $N$ are illustrated in Fig. 4 and 5, respectively.

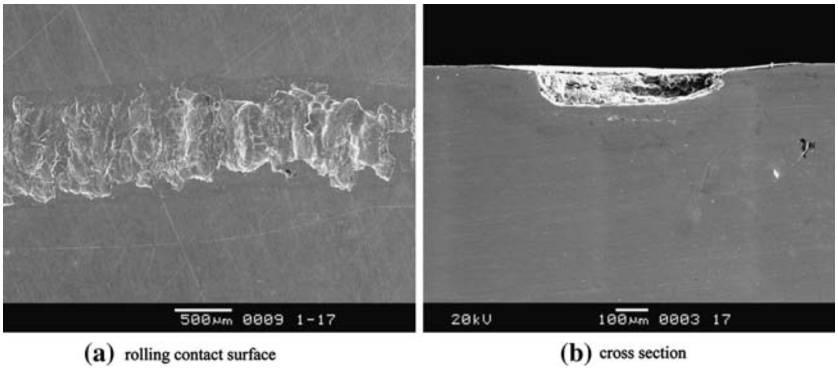
It can be known that the depth of nitrided surface layer both for deep-nitrided specimens and following shot-peened specimens is about 0.75 mm, but the microhardness of nitrided following peened specimens is higher than the nitrided specimens from surface to distance from surface about 0.2 mm as shown in Fig. 4. The harder the surface layer, the longer contact fatigue life. The increase in hardness by shot peening will improve fatigue life. The fatigue life is increased by shot peening, as shown in Fig. 5 and Table 3. The fatigue life for nitrided following shot-peened specimens is longer than the nitrided specimens.

The area and depth of spalled pit for nitrided and nitrided following shot-peened specimens are show in Fig. 6 and 7, respectively. The area of failure surface for nitrided and following shot-peened specimens is smaller and the depth of spalled pit is lower compared with the nitrided specimens.

There are few investigations on contact fatigue mechanisms for surface hardened specimens and a few of references only

**Table 3 Characteristic parameters of P-N curves for rolling contact fatigue test**

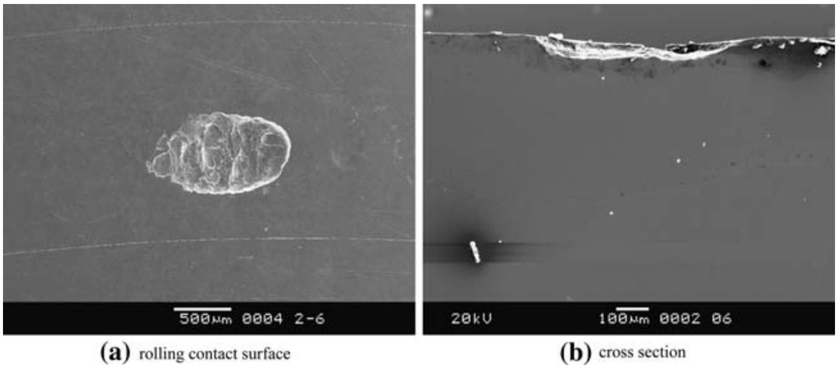
| | $L10$ | $L50$ | $Vs$ | $b$ |
|---|---|---|---|---|
| Nitrided specimens | $1.978\times10^6$ | $7.734\times10^6$ | $1.008\times10^7$ | 1.3818 |
| Nitrided + shot-peened specimens | $2.446\times10^7$ | $7.872\times10^7$ | $9.882\times10^7$ | 1.6116 |



(a) rolling contact surface

(b) cross section

**Fig. 6** Images of rolling contact fatigue failure surface for nitrided specimens (a) rolling contact surface, (b) cross section qualitatively show that the hardness and compressive residual stress are beneficial to rolling contact fatigue by shot peening (Ref 5-12). Surface work-hardened layer and compressive residual stresses increase the stress of crack initiation and propagation, the contact fatigue life of shot-peened specimens, therefore, can be increased greatly. The mechanism of contact fatigue crack initiation and propagation for both unpeened and peened specimens is schematically illustrated in Fig. 8. For



**(a)** rolling contact surface **(b)** cross section

**Fig. 7** Images of contact fatigue surface for nitrided following shot-peened specimens (a) rolling contact surface, (b) cross section

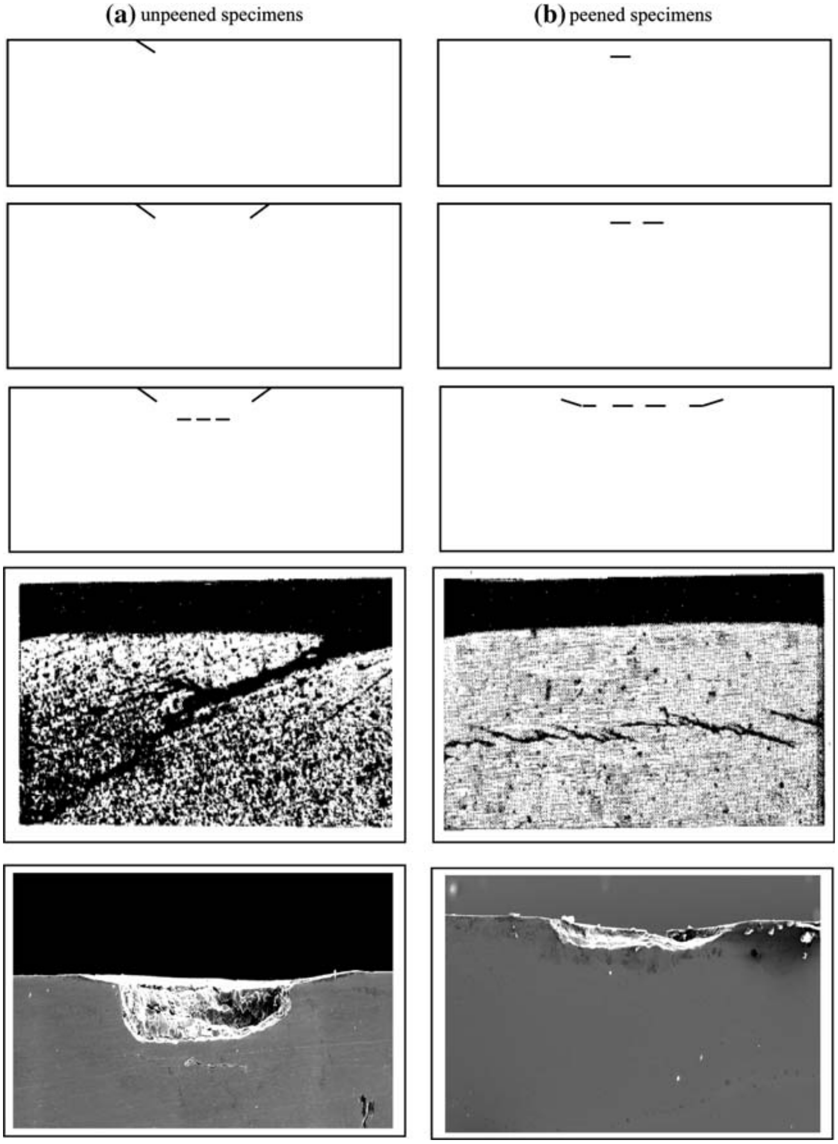


**Fig. 8** Schematic process of contact fatigue crack initiation and propagation through cross section in surface layer (a) unpeened specimens, (b) peened specimens

unpeened specimens, the fatigue cracks initiate at surface and propagate to subsurface layer; whereas, the fatigue cracks initiate at subsurface layer and propagate to surface for peened specimens due to the compressive residual stress and hardened surface layer induced during shot peening.

The residual stress is usually measured by x-ray diffraction method and is a function of depth, and the residual stress distribution can be determined with step-by-step electrolytic dissolution. In this investigation, the diffraction peaks for martensite phase and $Fe_2N$, $Fe_3N$ and $Fe_4N$ phases are overlapped, it is therefore difficult to determine residual stress distribution along surface layer for both deep nitrided and nitrided following peened specimens, but it should be compressive residual stress in surface layer for nitrided or peened specimens. The compressive residual stress is beneficial to rolling contact fatigue, and shot peening can increase the value and depth of compressive residual stress, therefore shot peening can improve rolling contact fatigue performance.

## 4. Conclusions

1. Deep nitiding process can get a depth of 0.75 mm surface strengthened nitrided layer.
2. Shot peening with proper intensity prolongs the rolling contact fatigue life and makes the spalled pit lower and smaller.

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