THE REGULARITY OF FATIGUE CRACKS INITIATION IN SURFACE HARDENED STEEL

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Surface plastic strain hardening can produce in high-strength materials residual compression stresses up to 1500-1700 MPa extending to the depth of 1-1,5 mm. It results in significant increase both in cyclic life of parts before fatigue cracks initiation and in resistance to cracks development. For calculating fatigue strength of hardened parts and developing the effective technology of surface treatment it is necessary to know regularities of location of fatigue fracture center and cracks growth.

INTRODUCTION

Shot-peening is often used for improving fatigue resistance of machine parts. Fatigue fracture of peen-hardened parts may start on the surface or beneath the surface usually at 1-2 mm depth.

It was experimentally found that the location of the crack center depends on surface layer properties, geometry of a part and the nature of applied stress. When values of residual compression stress are large and cyclic load amplitudes are small, a crack initiates beneath the surface. With the increase of cyclic load the crack initiation center displaces closer towards the surface and with large loads it appears on the surface. These results are shown in Fig.1. The electronic microscopic examination showed that inclusion in the basic material of a part is the direct source of cracks initiation beneath the surface.

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In order to identify the location of fatigue crack initiation we shall analytically compare the stress-bending load diagram described by the equation

$$\sigma_i = \sigma_{max} (1 - \bar{\delta}_i)^{\omega} \qquad (1)$$

and the diagram of peak-to-peak stress amplitudes for a hardened part, where

σ_i = stress under applied load at the depth of $\bar{\delta} = \delta_i / d_A$ (δ_i - depth of the layer; d_A - typical crosssectional area);

σ_{max} = maximum surface stress in the concentration zone;

ω = $(3\alpha_\sigma - 2)$ - parameter (here, α_σ - theoretical coefficient of stress concentration).

To describe the diagram of peak-to-peak stress amplitudes, which should be determined with regard for properties appeared as a result of surface plastic strain hardening, we shall use the fatigue fracture similarity equation

$$\sigma_{-1A} = \frac{\sigma_{-10}}{2\alpha_\sigma} \left(1 + \theta^{-\nu_\sigma}\right) \qquad (2)$$

where σ_{-1A} = average fatigue strength of the part;

σ_{-10} = average fatigue strength of a smooth test piece 7,5 mm in diameter under bending/rotation load;

$\theta = \frac{L/\bar{G}}{(L/\bar{G})_{gl.o}}$ = relative similarity criterion of fatigue fracture (here, L - perimeter or partial perimeter of the cross-sectional area in the concentration zone);

ν_σ = parameter defined by the properties of the material.

The comparison of the diagrams shows that if stresses caused by the applied load are close to the fatigue resistance limit (after 10 cyclic tests) and under the hardened surface layer they coincide with the fatigue resistance limit of the nonhardened core of the part, the fatigue fracture may equally start on the surface as well as underneath the surface of the part. For such combination of diagrams the thickness of the hardened layer may be called critical (δ_{cr}). In such a case the center of undersurface fracture will locate on the boundary between the hardened layer and the nonhardened core of the part.

The fatigue resistance limit of the core beneath the hardened layer in the vicinity of the fracture center is calculated using the relationship

$$\sigma_{-1c} = \alpha_{\sigma} \delta^{el}_{-1A} \left[1-2\left(\bar{\delta}_{cr} + \bar{\delta}_{o}\right)\right]^{\omega} \qquad (3)$$

where σ^{el}_{-1A} = fatigue resistance limit of a part with the hardened layer having thickness $\delta_{pl} = \delta_{cr}$;

$\bar{\delta}_{o}$ = the value used to take account of the fact that in the fracture area maximum stresses caused by the applied load always slightly exceed the conventional fatigue resistance limit expressed by maximum stresses

$$\bar{\delta}_{o} = 0{,}5 \left[1-\left(\frac{1+\theta_{gl}^{-\nu_{\sigma}}}{1+\theta^{-\nu_{\sigma}}}\right)^{1/\omega}\right.$$

Using the relationship (2)

$$\sigma_{-1c} = \frac{\sigma_{-10c}}{2}\left(1+\theta_{gl}^{-\nu_{\sigma}}\right) \qquad (4)$$

where σ_{-10c}= fatigue resistance limit for a smooth test piece 7,5 mm in diameter having properties typical for the nonhardened core.

Hence the fatigue resistance limit of a hardened part, in case a crack initiates on the surface, will be

$$\sigma_{-1\Delta}^{el} = K_{el} \cdot K_F \frac{\sigma_{-10c}}{2\alpha_\sigma}\left(1+\theta^{-\nu_\sigma}\right) \tag{5}$$

and in case a crack initiates beneath the surface, will be

$$\sigma_{-1\Delta}^{el} = \frac{\sigma_{-10c}}{2\alpha_\sigma}\,\frac{(1+\theta_{gl}{}^{-\nu_\sigma})}{[1-2(\bar{\delta}_{pl}+\bar{\delta}_o)]^{\omega}} \tag{6}$$

where K_{el} = coefficient of efficiency of surface hardening;

K_F = coefficient of the surface roughness effect.

Using the relationships (3)-(6)

$$\bar{\delta}_{cr}=0,5\left(\frac{1+\theta_{pl}{}^{-\nu_\sigma}}{1+\theta^{-\nu_\sigma}}\right)^{-\frac{1}{\omega}}\left[1-\left(K_{el}\cdot K_F\right)^{-1/\omega}\right]$$

K_{el} estimates the increase in the fatigue resistance limit as a result of surface plastic strain hardening due to residual compression stresses, peening, structural changes, etc. appearing in the surface layer.

The identification of the fatigue crack initiation comes to the comparison of the actual thickness of the hardened layer $\bar{\delta}_{pl}$ and $\bar{\delta}_{cr}$. If $\bar{\delta}_{pl} > \bar{\delta}_{cr}$, the fatigue fracture shall start on the surface.

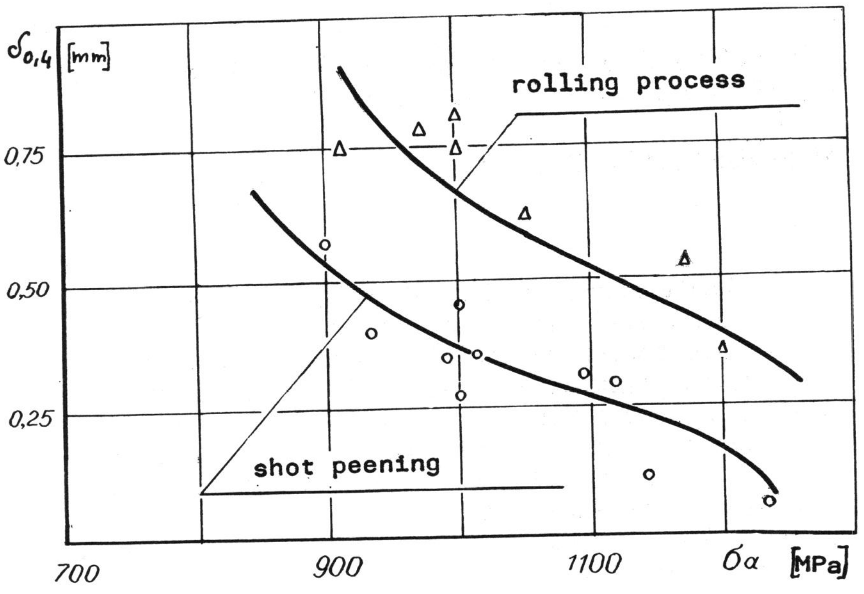

Figure 1 Dependence of $\delta_{0,4}'$ on σ_α