CRITERIA FOR THE INCREASE IN STRENGTH OF PARTS SUBJECTED TO SURFACE-DIFFUSION TREATMENT

V. I. Pokhmurskii and G. V. Karpenko


An analysis of factors determining the variation in the endurance of steels due to surface hardening by diffusing various elements is presented.

It is generally believed that treatments leading to the appearance of residual compressive stresses in metal-surface layers always produce an increase in the fatigue strength, while the appearance of residual tensile stresses leads to a considerable reduction in the cyclic strength of parts in air and especially in corrosive media. It is therefore customary to regard the appearance of residual compressive stresses in metal-surface layers as the main criterion for increase in their strength; this is correct in most cases for parts of a simple shape subjected to surface work-hardening, carburizing, nitriding, surface quench-hardening, etc.

Let us consider more complex cases when the formation of surface-diffusion layers (though accompanied by the appearance of residual compressive stresses) leads to a noticeable reduction in the fatigue limit of unnotched specimens and decreases the notch sensitivity of steel, or when a surface treatment produces residual tensile stresses and an increase in the endurance of notched specimens.

For example (Fig. 1), calorizing to a depth of about 0.1 mm decreases the fatigue limit of unnotched specimens of a medium-carbon steel by 25-30% and produces a similar increase in the fatigue limit of notched specimens ($\varepsilon_K = 3.22$); in this case the surface-diffusion treatment leads to the appearance of relatively low residual compressive stresses in the surface layers (up to $20 \text{ kg/mm}^2$) [1]. Boronizing to a depth of 0.10-0.2 mm, which increases the fatigue limit of unnotched specimens by only 10-15%, almost doubles the fatigue limit of notched specimens; the maximum compressive stresses produced in this case in the surface layers are 60-80 kg/mm$^2$ [2]. Coppering to a depth of 0.3 mm reduces the fatigue limit of unnotched specimens and increases that of notched specimens [3].

Fig. 1. Fatigue limit of St. 45 steel (a) in air, $N = 10^7$ leading cycles; b) in 3% NaCl solution, $N = 5 \cdot 10^7$ loading cycles) plotted against the diffusion layer thickness: 1, I) chromizing; 2, II) boronizing; 3, III) calorizing; 4, IV) coppering; 5, V) vanadizing (Arabic and Roman numerals relate to unnotched and notched specimens, respectively).
Chromizing (10 hrs at 1100° C), which produces compressive stresses on the order of 80 kg/mm² in steel surface layers, has no effect on the fatigue limit of unnotched specimens but increases that of notched specimens from 13 to 21 kg/mm² [4]. Decarburizing (4 hrs at 800° C) of carbon steels in a stream of hydrogen leads to the appearance of residual tensile stresses in the steel surface layers; it produces a marked reduction in the fatigue limit of unnotched specimens but increases that of notched specimens.

One could continue citing similar examples, but even those listed above are sufficient to show that not only residual stresses but also many other factors affect the notch sensitivity of steel under cyclic straining conditions.

In this work it was attempted to establish a relationship between the fatigue strength and the structural and stress state of notched medium-carbon steel specimens subjected to various surface-diffusion treatments.

First of all let us consider the process of the formation of a diffusion layer in the region of a V-shaped notch on a cylindrical specimen and the variation in the character of the layers structure. The relative quantities of phases formed as a result of surface-diffusion treatment in the notch region and the thickness of the diffusion layers in this region are as a rule different from those observed on the unnotched part of the specimen. The change in thickness both of individual regions and of the entire layer depends on the treatment applied and on the conditions of time and temperature.

Let us consider certain most typical cases.

Diffusion layers formed by elements which do not form carbides (boron, aluminum, silicon, etc.) and by carbon. In this case (Fig. 2a) the diffusion-layer thickness at the root of a V-shaped notch is smaller than that in the unnotched cylindrical part of the specimen, and the difference increases with decreasing notch-root radius; the same applies to the thickness of the carbon-enriched zone under the intermetallic layer. The main cause of this difference is the difference in the ratios of the areas of surfaces which adsorb the diffusing elements to the volumes into which this element diffuses.

When elements which do not form carbides are used to produce surface-diffusion layers, the notch sharpness is as a rule increased, i.e., \( q > q_d \), where \( q \) and \( q_d \) denote notch-root radii before and after diffusion treatment. Various structural stress raisers (boride needles, grain boundaries in diffusion layers, etc.) formed during surface treatments of this kind are usually normal to the surface treated (Fig. 2a).

Diffusion layers formed by carbide-forming elements (chromium, vanadium, etc.) In this case (Fig. 2b) the thickness of the carbide and intermediate (pearlite) zones at the notch root may be larger than the thickness of these zones on the unnotched part of the specimen. This is because the ratio of the volume of steel from which carbon diffuses outward to the area of the surface on which the diffusing element is adsorbed is larger in the notch-root region. The depth of the decarburized zone in the notch-root region should be smaller than on the unnotched part of the specimen. Surface-diffusion treatment with carbide-forming elements usually reduces the notch sharpness, i.e., \( q < q_d \). The increase in notch-root radius is observed also after coppering and after treatment with liquid media (liquid calorizing, zinc coatings, etc.).

![Fig. 2. Schematic representation of change in the diffusion-layer thickness in the notch-root region: a) treatment with elements that do not form carbides; b) treatment with carbide-forming elements.](image)

![Fig. 3. Schematic representation of stress distribution in the notch region of specimens strained in bending after surface-diffusion treatment with a) elements that do not form carbides and b) carbide-forming elements.](image)