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SOME BASIC REGULARITIES IN THE CHANGE OF STATIC STRENGTH AT STRESS-CONCENTRATION SITES

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Stress concentration, as is known, manifests itself above all in a local and, in many cases, very considerable increase in stresses. The measure of the increase of stresses at the sites of various concentrators is usually expressed by the ratio of the greatest stress $\sigma_{\max}$ to the average stress σ_n, called the concentration factor $K_t = \sigma_{\max}/\sigma_n$.

In determining dimensions from the condition of static strength of various structural elements at concentrator sites, the stresses σ_n averaged over the section are usually calculated first, and only then are concentration factors introduced in order to determine $\sigma_{\max}$. A strength calculation according to $\sigma_{\max}$ is carried out to ensure the necessary reliability, since it is precisely the value $\sigma_{\max}$ that is compared with the strength limit of the material in determining allowable stresses. However, as will be shown below, under static loading only in very rare cases can failure occur at stress-concentration sites upon $\sigma_{\max}$ reaching a value equal to the strength limit of the material. In the overwhelming majority of cases, as a rule, the limiting value of $\sigma_{\max}$ at which failure occurs greatly exceeds the strength limit of the material.

This happens because the effect of stress concentration is not limited to their local increase. The second most important feature—one still almost not taken into account in strength calculations—of the deformed state at concentrator sites consists in the fact that, simultaneously with the local increase of stresses in the vicinity of concentrators, a two- or, more often, three-dimensional stressed state arises. The level of nonuniformity depends on the intensity of the stress concentration and may vary within very broad limits—from a stressed state close to linear, to biaxial and triaxial uniform tension or compression.

A remarkable feature of the change in the intensity of stress concentration is that it may occur in two, and in some cases three, different ways: 1) the level of local increase of stresses in the vicinity of a groove depends almost exclusively on the curvature of the groove; 2) the character of the stressed state in the vicinity of a groove depends mainly on its depth, while the level of nonuniformity ($\tau_{\max}/\sigma_1$) also depends on its curvature; 3) in the vicinity of grooves on prismatic

Fig. 1 and Fig. 2: graphs showing the change in static strength at stress concentrators as a function of stress-concentration factor K_t.

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bodies, what was noted in points 1) and 2) remains valid; however, in this case the nonuniformity of the stressed state (different degree of two- and three-dimensionality of stresses) changes substantially not only with different depth and curvature of the groove, but also when the width of the section of prismatic bodies changes (for example, the thickness of sheet elements or plates).

Thus, the character of the change in the intensity of stress concentration is such that one and the same local increase of stresses (i.e., one and the same value of K_t) for different groove depths t may correspond to a great variety of stressed states—from nearly linear to close to all-round tension.

It was of considerable interest to clarify the question of the extent to which strength at concentrator sites depends on the nonuniformity of the stressed state at the same local increase of stresses, i.e., at the same K_t.

In a study undertaken to clarify this question, grooves of various sizes were made on cylindrical specimens. The depth varied from very small (surface grooves) to a depth equal to the radius of the smallest section (deep grooves), which provided the above-noted variation of the stress state over wide limits. The curvature of grooves of one and the same depth was varied so as to provide values of K_t from 1.0 to 5.0. Thus, any value of K_t within these limits corresponded to a change in the stress state from nearly linear (small values of t) to close to triaxial nonuniform tension (large values of t).

Fig. 1. Change in static strength at locations of various stress concentrators σ_{bn}, relative to the strength of the material σ_b, as a function of the stress-concentration factor K_t (steel 45). Solid lines $-d = 15$ mm, dashed lines $-$ $d = 5$ mm

Fig. 2. Same as in Fig. 1 for alloy 40Kh

Specimens with such grooves were prepared from three materials: medium-carbon steel 45 in the normalized condition, chromium steel 40Kh after quenching (870°) and tempering (200°), and aluminum alloy D-16T (as supplied).

The change in the ultimate strengths σ_{bn} of specimens with concentrators, relative to the ultimate strengths of smooth specimens σ_b, as a function of the concentration factors K_t, is presented for each of the indicated materials in Figs. 1, 2, and 3.

The results obtained indicate the presence of the following basic regularities in the change of static strength at locations of stress concentration.

Figure 3

Figure 2: Figure 3

Figure 4

Figure 3: Figure 4

1. The stress state has a very significant influence on the strength at locations of concentrators.

For identical concentration factors K_t, but with different stress states, the static strength may vary over wide limits, both in the direction of increase (almost twofold, in plastic metals of the medium-carbon-steel type) and in the direction of decrease (low-plasticity high-strength metals of the low-tempered-steel type ···).

40Kh); however, in this case as well the reduction in strength becomes noticeable only at a stress concentration of $K_t > 3.0$.

Fig. 3. Same as Fig. 1, for alloy D-16 T

2. Within a broad class of structural ductile metals (steels with low and medium carbon content, aluminum alloys, etc.), stress concentration not only does not cause a reduction in static strength but, as a rule, is accompanied by an increase in it. In this case a paradoxical change in strength is observed: it becomes greater the greater the stress concentration, i.e., K_t.
3. A substantial influence of size on static strength at points of concentration has been established. On specimens of small dimensions ($d = 5.0$ mm) no appreciable decrease occurs in the strength σ_{bn} relative to the material strength σ_b, even when the concentration is increased to $K_t = 5.0$, and even for such a low-ductility and high-strength material as low-tempered steel 40Kh.

However, when the dimensions are increased by a factor of 3 ($d = 15.0$ mm), the character of the change in strength becomes entirely different: in low-ductility steel 40Kh there is a sharp decrease in strength, especially at $K_t > 3.0$; the decrease also begins in aluminum alloy D-16T.

4. For the investigated range of variation of stress concentration within broad limits, no correspondence was found between the level of reduction in static strength and an increase in the mean stress σ_n to the value $\sigma_n K_t = \sigma_{\max}$. Thus, at the greatest of the stress concentrations investigated here, $K_t = 5.0$, in low-ductility steel 40Kh, a reduction in strength σ_{bn} relative to the material strength σ_b was found to be only a factor of two (Fig. 2), whereas if the indicated correspondence existed, a fivefold decrease in strength σ_{bn} relative to σ_b should have been observed.

Fig. 4. Change in ductility (reduction of area ψ) at different stress concentrators as a function of the stress-concentration factor K_t. Solid lines—steel 45; dashed lines—steel 40Kh

5. The stress state has a markedly smaller effect on changes in ductility in the vicinity of concentrators (Fig. 4); the character of these changes, apparently, is determined mainly by the level of the local increase in stresses, i.e., by the magnitude of K_t.

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