
CRITERIA FOR DETERMINING THE WORKING CAPACITY OF STRUCTURAL STEELS

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Structural steels are among the basic materials used in many branches of industry and therefore it is very important to establish the criteria for determining the working capacity (reliability)* of structural steels, i.e., determine the resistance to fracture.

The purpose of this work was to establish criteria for determining the structural strength (working capacity) of alloy structural steels with yield strength as high as 100 kgf/mm² and testing methods suitable for wide use that make it possible to establish the quality of the metal with extremal operating conditions of machine parts.

Various low-carbon and medium-carbon alloy structural steels were tested.

After rolling, the steel was subjected to preliminary heat treatment — quenching from a temperature of Ac+(50-80)°C and tempering at 650-670° or tempering alone (without quenching).

The basic final heat treatment is given in Table 1.

In conformity with the T–T–T diagram, 40-60% austenite remains untransformed in the process of quenching to upper and lower bainite (treatments 3–6). During subsequent cooling a large part of the retained austenite transforms to martensite.

In treatments 2, 4, 6, 7, and 8 the tempering time was regulated to obtain the same hardness as after treatment 1. Tempering at 500-525° (treatment 7) greatly embrittles the steel and has a slight effect on the hardness after tempering at 650-660°.

The austenitizing temperature was selected so that ~70% of the carbides formed in the process of preliminary heat treatment were dissolved in austenite. The austenite grain size was grade 7-9 in this case. Austenitizing at 1100-1200° induced solution of ~95% of the carbides and a grain size of grade 1-2.

The structural strength of all steels tested differed greatly after heat treatment under these conditions.

Numerous methods of testing to determine the working capacity and also other methods were used in this work.†

*The terms structural strength, reliability, and working capacity used by various investigators are synonymous.
†In particular, dynamic and static bending tests at temperatures from +150 to −196° were made with five types of samples with different notches — type I with a Messnager notch, overall cross section 10×10 mm, notch depth 2 mm, root radius r = 1 mm, net section at the notch 8×10 mm; type II samples were the same as type I but the notch had an included angle of 45°, r = 0.25 mm; samples of type III were the same as type II but with a fatigue crack 1.0-1.5 mm deep at the bottom of the notch, overall cross section 11×10 mm, net section (7.5-8)×10 mm; samples of type IV were the same as type II but with three identical notches, two of which were lateral, overall cross section 10×14 mm, net section at the notch 8×10 mm; samples of type V were the same as type I but with r = 2.5 mm.

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Fig. 1. Changes in $\alpha_1$, $\alpha_p$, $\alpha_T$, reduction in area and fracture in relation to testing temperature for steels 12KhN3A (a), 15KhN2MFA (b), and 38KhSA (c) after heat treatment. B) Brittle fracture; M) mixed fracture; D) ductile fracture.

Bending and off-centered tensile tests were also made to determine the stress intensity coefficient $K_{IC}$, static bending tests of different samples of large thickness (in the middle of the length these samples had a notch perpendicular to the lateral surface), and also axial tensile tests with smooth and notched samples.

Only typical results from a very large number of tests are given here.

Dynamic Bending Tests. Of basic importance in determining the working capacity are $\alpha_n$, the fracture toughness of notched samples; $\alpha_T$, the fracture toughness of samples with a crack; $\alpha_1$, the work of crack initiation; $\alpha_p$, the work of crack propagation; the upper and lower temperatures of brittleness; reduction in area; $T_d$, the lowest temperature of completely ductile fracture; and $T_b$, the highest temperature of completely brittle fracture.

Due to the fact that the fracture toughness $\alpha_n$ is an integral characteristic and consists of $\alpha_1$ and $\alpha_p$, several methods of determining $\alpha_1$ and $\alpha_p$ have been proposed (by L. S. Livshits and A. S. Rakhmanov, B. A. Drozdovskii, A. P. Gulyaev, Otani, et al.). In this work the methods of Drozdovskii [1, 2] and Gulyaev [3, 4] were used. It should be noted that when the steel has a fibrous fracture and high fracture toughness (>10 kgf-m/cm²), particularly when $\alpha_1$ reaches 20-30 kgf-m/cm², separation of the fracture toughness into its component parts by the Drozdovskii and Gulyaev methods gives values of $\alpha_1$ equal to 3-5 kgf-m/cm². These values of $\alpha_1$ are undoubtedly low due to the fact that both the Drozdovskii and Gulyaev methods determine not $\alpha_p$ but $\alpha_T$, which is larger than $\alpha_p$ in this case.*

The relationships between the structure of the fracture and $\alpha_n$, $\alpha_p$, and other properties were established in [4-6 etc.], and therefore major attention is given in this work to the structure of the fracture as a criterion for determining the working capacity of structural steels.

Figure 1 shows typical values for steels 12KhN3A and 38KhSA. The high fracture toughness makes it impossible to identify $\alpha_1$ with the difference between $\alpha_1$ and $\alpha_T$. The values of $\alpha_1$ are too low, since the fracture toughness of samples with a crack $\alpha_T$ is much higher than the work of crack propagation due to macroplastic deformation.

Newhouse has shown, however, that $\alpha_1$ does not change in the temperature range of the transition to brittle fracture and thus when $\alpha_p=0$ (below $T_b$) $\alpha_1=\alpha_T$ (in the given case, $\alpha_1=\alpha_p$, since notched samples with $r=1$ mm were tested).

*With low values of $\alpha_1$ (<10 kgf-m/cm²) $\alpha_T=\alpha_p$. 

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