Study of Breakdown Resistance of Machine Components at Low Temperatures

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One of the problems in designing machines for "northern" service is to confer on the components a certain cold resistance, that is, to prevent their brittle failure due to changes in the mechanical properties of the steels at low temperatures.

In selecting materials the commonest method has been to test construction steels with impact loading of the specimens at various temperatures. In this case, using the impact strength values or the form of fracture, we obtain the so-called threshold of cold fracture or the critical temperature for the various types of steel with various forms of heat working. However, the impact strength cannot be used for designing components and constructions. The cold fracture threshold determined by impact testing of specimens does not characterize the critical temperatures of actual machine components, and may be used only for a qualitative comparison in selecting the materials or heat processing method.

The Ioffe scheme for the transition of a material into the brittle state is relevant only for the change that occurs with a reduction in the temperature of the mechanical characteristics \( \sigma_{\text{av}}, \sigma_{\text{T}} \). In the scheme proposed later by Davidenkov, Uzhik, Fridman, and others, they propose a combination of mechanical characteristics and the form of the stressed state in the component.

Existing methods of evaluating the proneness of materials to brittleness cannot be used to obtain a reliable evaluation of the working capacity of various forms of machine components operating at low temperatures because of the rather complicated combinations of different embrittlement factors in real components. This meant that a series of investigations had to be carried out at low temperatures directly on the machine components.

Threaded Connections. For threaded components there is a typical relatively high concentration of stresses, the magnitude of which is variable over the length of the screw. The magnitude of the theoretical coefficient of concentrations alters from 2-3 on the free section of the thread to 8-10 in the zone of the first working turn of the nut [1].

An investigation of the strength and ductility of threaded joints was made on screws with threads M6 \( \times 1 \), M12 \( \times 1 \), M12 \( \times 1.75 \), and M24 \( \times 3 \). The screw materials were steel 35 in the state as delivered, steel 45 in the same state, also normalized and improved, steel 40Kh in the state as delivered, and improved. The threads of the screws were made by thread rolling, and cutting.

The static strength tests were made on the screws on a special rig guaranteeing the required test temperature in the range from 20 to \(-80^\circ\text{C}\). The relationships obtained for the destructive load and the test temperature [2] showed that the static strength of the screws in the sizes tested does not alter very much with a reduction in temperature. In this case up to a certain temperature level there was a slight increase in the strength, and subsequently it gradually dropped.

It was found that the nature of the relationship between the destructive load is closely connected with the nature of the change in the magnitude of the relative elongation during breakdown \( \varepsilon_{\text{P}} \). The measurements were made over a length equal to about 1.5 times the diameter of the thread. The curves for the threads of different sizes are shown in Fig. 1. From a comparison of the curves it is seen that a positive effect as regards brittle breakdown can be expected with the use of fine threads (curves 1 and 2), and also...
Fig. 1. Relationship between relative elongation during breakdown of screws and temperature for cut (1, 2, 3, 6, 7) and rolled (4, 5) threads: 1, 2) steel 45, normalized; 3) steel 40Kh, improved; 4) steel 40Kh, as delivered; 5) steel 35, delivered; 6) steel 45, delivered; 7) steel 45, improved [1) thread M12 × 1; 2-7) M12 × 1.75].

Fig. 2. Effect of scale effect as a function of temperature on the ductility of the threaded section of screws with rolled threads made from steel 45, normalized: 1) thread M6 × 1; 2) thread M12 × 1.75; 3) thread M24 × 3.

with the use of steel 40Kh for making the screws (curves 3 and 4), and the use of chilling with high annealing (improvement), as the heat processing technique. It should be mentioned that the test carried out on the screws heat processed at a relatively high hardness of 37HRC (for the threaded components) (curve 7) demonstrated that there is no reduction in ductility over the entire temperature range. However, the ductility level remained comparatively low which may be the cause of the brittle failure.

Figure 2 shows the effect of the screw diameter on the magnitude of the relative elongation $\varepsilon_p$ at different temperatures. It is seen that an increase in the screw diameter doubles the displacement of the boundary of initial sudden fall in ductility toward the higher temperature side by approximately 40°C.

Simultaneous results were obtained from a study of the effect of the loading rate on the ductility of the screws. During tests on three standard screw sizes with threads M12 × 1.75 (steel 10 and steel 35 in the state as delivered with a rolled thread, and steel 45 in the normalized state with a cut thread), an increase in the loading rate of from $3 \times 10^{-5} \text{ m/sec}$ to 10 m/sec caused a marked displacement of the initial sudden fall in ductility temperature toward the positive temperature side (by about 30-50°C). The increase in the loading rate on the screws made from steel 40Kh in the delivered state with the rolled thread, and steel 40Kh with the improved and cut thread, did not produce a marked fall in ductility in the temperature range investigated (from 20 to -80°C).

A typical feature for the breakdown of the threaded joints during static and impact loading is the inconsistency of the breakdown site. At higher temperatures breakdown occurs in the middle of the free (loaded) section of the thread, and with a reduction in temperature to a certain value, determined for each standard sized bolt, the breakdown site moves toward the zone of the first working turn on the nut, where the maximum stress concentration is observed. In connection with this, from the arrangement of the breakdown site during the test it is possible to quite reliably evaluate the tendency of the standard sized screws to embrittlement.

The investigation of the effect of temperature on the cyclic strength was made on screws produced from steel grade 40Kh in the state as delivered with a rolled thread. Tests were made at temperatures of 20 and -60°C. An analysis of the results obtained (curves) showed that with a reduction in the test temperature to -60°C the fatigue limit increases by approximately 15%. The arrangement of the sloping section of the fatigue curve is hardly affected by the fall in temperature.