for evaluating the tendency to brittle fracture of chromium—nickel steels of the austenitic—martensitic class.

LITERATURE CITED


EFFECT OF HYDROGEN ON STRENGTH OF STEEL


The purpose of this investigation is to study the effect of a hydrogen-containing atmosphere at elevated temperatures on the short-term strength and creep of steels 1Kh18N9T and 50, to establish the governing factors, and to estimate their kinetics. We also considered the effect on the strength of the steels of prior exposure in a hydrogen atmosphere under isothermal conditions. The experiments were conducted on wire (diameter 3 mm) and tubular (10 × 1.5 mm) specimens.

The tests were conducted in a flow of hydrogen containing 0.09% H2O at temperatures from 500 to 850°C. The hydrogen-containing gas was fed continuously into the reaction volume at a constant rate of 100 liters/h. The exposed wire specimens were tested for fracture to determine the tensile strength at room temperature, while the tubular specimens were tested with hydrogen being passed simultaneously inside the specimens.

The results of testing in hydrogen were compared with those for testing in argon, conducted under analogous conditions. The data obtained indicate that preliminary exposure in a hydrogen-containing atmosphere at 500 and 600°C does not affect the tensile strength of the steel being studied. At 700°C the tensile strength of the specimens is lowered after only a 5-h exposure in hydrogen. Similar results are obtained on testing 1Kh18N9T and 50 steels in argon (Fig. 1).

Studies of the dependence of the relative elongation of the specimens on exposure time under a constant load showed that the rate of creep in hydrogen at 700 and 800°C increases after 12-15-h testing (Fig. 2). For a test temperature of 500°C no substantial effect of hydrogen on creep is observed.

Metallographic analysis of specimens of steels 1Kh18N9T and 50 tested in hydrogen at 750°C showed that intensive grain growth is observed in their surface layers (Fig. 3). Spectral layer-by-layer analysis of specimens of steel 50 established that decarbonization takes place in the surface layers (Fig. 4). In steel 1Kh18N9T the redistribution of carbon was determined from the variation in the local thermoelectromotive force (thermo-emf) in the surface layers.

An estimate was also made of the effect of mechanical loading on the growth kinetics of the decarbonized zone in steel 50. To establish the time dependence of the displacement in the interphase boundary at 750°C some of the specimens were tested for creep, while others were maintained at this temperature without loading. Displacement of the interphase boundary was estimated from the distribution of the thermo-emf in the surface layers by metallographic analysis.

Fig. 1. Dependence of the tensile strength of steels on temperature and exposure period in different atmospheres. 1, 4) at 20°C after different exposure periods in hydrogen at 600°C of steels 1Kh18N9T and 50 respectively; 2, 3) temperature dependence in hydrogen and argon respectively (1Kh18N9T steel); 5, 6) temperature dependence in hydrogen and argon respectively (steel 50).

Fig. 2. Creep of specimens of 1Kh18N9T steel for $\sigma = 7.5$ kgf/mm$^2$ and different temperatures (the continuous lines represent testing in argon, the dashed lines represent testing in hydrogen).

A comparison of the data obtained indicates that no effect of stress on the diffusion of carbon in the solid phase is observed for the rates of loading studied. A comparison of the strength characteristics with the results from the metallographic investigations shows that hydrogen leads to a change in the strength characteristics, owing to the decarbonization of the surface layers and probably the mechanochemical effect from the micro-plasticization of the metal caused by the intercrystallite chemi-adsorption of hydrogen [1, 2].

Fracture of the specimens as a result of creep has an intercrystallite nature. When testing for creep there is a period of time after which the decarbonized layer reaches a value where its effect on creep commences to be revealed. A comparison of the data for the dependence of short-term strength and creep on the thickness of the decarbonized zone does not give a definite correlation between these quantities. However, we may note that if the thickness of this zone exceeds 0.1 mm the effect of decarbonization on the strength characteristics is exhibited to an appreciable extent. For a certain plastic deformation cracks are formed in the layer, which serve as stress concentrators. The reduction in strength takes place not only as a result of the growth of the decarbonized zone but also as a result of the reverse boundary diffusion of hydrogen.

The following experiments were conducted. Specimens were maintained in a hydrogen-containing atmosphere at various temperatures and for various periods. Then metallographic sections were prepared from the end of a specimen and specimens having the same depth of decarbonization were selected.

Tensile and creep tests showed that both decarbonization and hydrogen treatment affect the strength characteristics. We cannot estimate theoretically the true values for the reduction in the strength characteristics under the simultaneous action of hydrogenation and decarbonization, but the decarbonization period at which the commencement of embrittlement is probable can be established to a close approximation from the data on the decarbonization kinetics.

Let us consider the growth kinetics of the decarbonized layer. It is known that the ability of steels to undergo decarbonization arises from the reaction between the carbon contained in $\alpha$-Fe, $\gamma$-Fe and iron carbides, and gaseous atmospheres containing oxygen and hydrogen. The theoretical foundations of the decarbonization process and the nature of the layers formed during this have been studied in [3]. The kinetics of the process have been studied to a lesser extent. During the decarbonization of a subeutectoid steel ferrite is formed on its surface if the temperature of the process lies in the transformation-point range 723–910°C on the Fe–C diagram.

The experimental values for carbon concentration (Fig. 4, curve 6) through the depth of the surface layer approach the theoretical values (curve 7).

The rate of growth of the decarbonized layer of ferrite, i.e., the displacement of the $\xi$ boundary, depends on the kinetic parameters of carbon diffusion of carbon in the layer of ferrite and austenite. The diffusion of carbon in ferrite governs the progress of the $\xi$ boundary into the metal, while in austenite it governs