MECHANICAL PROPERTIES OF AUSTENITIC STAINLESS STEELS
AT −253°C

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We investigated the mechanical properties of austenitic steels under stress at the temperature of boiling liquid hydrogen (−253°C) and also the stability of austenite during low temperature deformation.

The chemical composition of the steel investigated was as follows: 0.03% C, 18% Cr, 0.16-0.12% Si, 0.03% Mn, 0.014% S, 0.015-0.02% P, and 8-20% Ni.

We used steels with an austenite structure (face-centered cubic) which remain ductile down to the temperature of boiling liquid hydrogen. Steels with a body-centered cubic structure undergo brittle rupture at low temperatures [1-3]. Apparently, this difference in the deformation capacity between austenitic and ferritic steels is due to the influence of impurities. Steels with a body-centered cubic structure are more sensitive to the influence of impurities [4-7].

Tests of uniaxial static elongation at −253°C were made by the method described in [8].

We used cylindrical samples in which the diameter of the working part was 4 mm and the calculated length 20 mm. The working part of the sample was electrolytically polished for 20 sec in a reagent consisting of 60 g of Cr2O3 and 440 g of H3PO4. The elongation rate was 2 mm/min. The samples were tested after quenching from 1050 and 1250°C in water (the average grain size corresponded to grades 7-8 and 3-4, according to GOST 5639-57).

Figure 1 shows that the deformation within the elastic-plastic region is characterized by an unstable process accompanied by the formation of necks along the working part of the sample beginning with stresses above the yield strength and continuing almost to the maximum stress. The largest number of necks is formed in samples containing 10-12% Ni.

The deformation of austenitic steels under elongation at low temperatures by jumps is due to phase transformations with the formation of martensite as the result of deformation [9], twinning, and thermal fluctuations [10]. The instability of plastic deformation in the steels investigated is probably due to martensitic transformation. Apparently at −253°C thermodynamic conditions are created in which martensite formation and plastic deformation are possible from the energy standpoint [11]. The dependence of the strength on the testing temperature indirectly confirms the presence of structural transformations. The increase of the yield strength with
temperature is much less than the increase of the ultimate strength with temperature. In studying this dependence one must take into account the irregular deformation (by jumps) in the elastic-plastic region and also the effect of thermal fluctuations. The grain size of steels containing 8 and 10% Ni has no influence on the deformation process within the elastic-plastic region. Samples with large grains in steel with 14% Ni are deformed much more regularly than samples with small grains. The amount of the α-phase in these samples is about the same. This is due to the fact that samples with large grains have fewer pulses of martensitic transformation than samples with small grains.

In the steel containing 20% Ni and consisting of small grains (quenched from 1050°C) the deformation process is unstable within the region where plastic flow is not accompanied by strengthening (Fig. 1). The reason for this phenomenon is unrelated to the presence of martensite. Magnetic analysis of this steel showed the absence of the α-phase in this steel. Apparently thermal fluctuation is the determining factor in the instability of the deformation process in the steel with 20% Ni, since thermal fluctuation develops much more easily in a small-grain structure.

Figure 2 shows that the strength increases, while the ductility decreases, with decreasing amounts of nickel in the steel. For steels containing between 20 and 14% Ni (region of stable austenite) the mechanical properties change very little. For steels containing between 14 and 10% Ni the strength of the steel increases and the ductility decreases (intense formation of martensite during cooling and deformation). When the steel contains 10% Ni and the grains are large then the ultimate strength decreases sharply. For steels with a small-grained structure the inflection point of the curves representing the variation of the ultimate strength with the nickel concentration corresponds to 8% Ni. The decrease of the ultimate strength after the maximum (10 or 8% Ni) is due to the fact that in steel with a low nickel concentration the α' martensite resulting from cooling (before deformation) is formed much more rapidly than in steel containing 8 or 10% Ni. This leads to thermodynamic conditions in which simultaneous plastic deformation and the formation of α'' during further deformation become difficult. Thus, the total amount of martensite (α' + α'') in steel with a low nickel concentration is smaller than in steel with a high nickel concentration (Fig. 3).

Figure 4 shows the microstructure of the steel with 8% Ni after deformation. The total amount of martensite is about 60%. The strength and ductility of steels with a small-grained structure are about 10% higher than those of steels with a large-grained structure.

At a testing temperature of −253°C the strength increases considerably with decreasing concentrations of nickel in the steel and the ductility remains high (δ = 25%). However, in steels containing 8% Ni the difference between the magnitudes of the uniform and local deformation (as determined by the reduction in section) decreases, indicating that the steels are considerably strengthened by deformation. The central part of the break is crystalline, which indicates that the break occurs within small volumes and may be induced by accidental defects in the structure of the metal.

To analyze more precisely the mechanical properties of the steels investigated, we recorded the variation of stress during elongation tests and during the tests made to determine the coefficient of strengthening. In the case of uniform deformation the real stresses were determined by calculation, using the experimental values of the real