Kh8 steel pipe is widely used in the petroleum and chemical industries. There are no difficulties in manufacturing hot-rolled pipe of this steel, but cold-rolled pipe tends to crack during rolling.

The pipe blanks are heat treated before cold rolling. The blanks are heat treated in chamber furnaces, in which the heating and cooling conditions vary with the position of the blank in the stack, and therefore the structure of the metal is not identical in all blanks, as the result of which the metal subjected to cold rolling differs in its resistance to deformation and brittle fracture.

The susceptibility of hot-rolled pipe blanks to fracture was compared in relation to the heat treatment conditions in order to determine the conditions ensuring the highest resistance to fracture during cold rolling.

The investigation was conducted on hot-forged pipe 50 × 5 mm of steel Kh8 with the following composition: 0.10% C, 0.45% Mn, 0.45% Si, 0.012% S, 0.013% P, 7.9% Cr. The change points of the steel were as follows: $A_c^1 = 830^\circ C$, $A_c^3 = 890^\circ C$, $A_r^3 = 820^\circ C$, $A_r^1 = 730^\circ C$.

The pipe was subjected to heat treatments selected with regard to the conditions existing in pipe plants (see Table 1).

These heat treatments made it possible to determine the effect of the austenitizing temperature (treatments 1 and 2), the rate of cooling from tempering temperature (treatments 1-4), the effect of overheating during tempering (treatment 5), and incomplete annealing (treatments 6 and 7) on the susceptibility to brittle fracture of pipe blanks of steel Kh8.

The susceptibility of the heat treated pipes to brittle fracture was determined from tests of Mesnager samples and from fractographic studies of samples tested at -196 to 400°. The critical temperature $T_{cr}$, or cold brittleness threshold, was taken as the lowest temperature at which fracture was completely fibrous. We also determined the variation of $a_p$ (work of crack propagation) at -20 to 300° by Drozdovskii's method [1] on impact test samples with a fatigue crack 1.5 mm deep. The crack was made with a vibrator on samples 5 × 10 × 55 mm with a V notch (notch depth 0.5 mm, root radius 0.1 mm, angle of 45°). The cross section was identical for samples with a started crack and Mesnager samples.

The mechanical properties of the heat treated pipe blanks were determined in tensile tests of cylindrical samples 3 mm in diameter. Electron fractographic studies were made with the UEM-100 microscope at a magnification of ×4500.

Effect of Austenitizing Temperature. After heat treatment 1 (see Table 1) the microstructure of the pipe consisted of ferrite and globular carbides. At room temperature the plastic characteristics, fracture toughness, and work of crack propagation were high (Fig. 1a). Although the cold brittleness threshold determined on Mesnager samples was $-20^\circ C$, that determined on samples with started cracks was $+20^\circ C$. These data indicate that after treatment 1 the metal is susceptible to brittle fracture at temperatures near room temperature.

Raising the austenitizing temperature to 1050° (treatment 2) has a negligible effect on the mechanical properties but a substantial effect on the ductile characteristics $a_n$ and $a_p$ (Fig. 1). The pipe overheated...
during normalization is susceptible to brittle fracture at room temperature, as indicated by the cold brittleness threshold $T_{cr}$ of 20°C.

**Effect of Cooling Rate after Tempering.** The rate of cooling after tempering (treatments 1, 3, 4) has almost no effect on the mechanical properties at positive testing temperatures (Fig. 1b). At negative temperatures the strength characteristics tend to increase and the plastic characteristics to decrease with decreasing cooling rates, the plastic characteristics decreasing faster than the strength characteristics increase.

It can be seen from the variation of the fracture toughness with the testing temperature (Fig. 1) that a decrease of the cooling rate lowers $a_p$ and raises the cold brittleness threshold from $-20^\circ$C ($T_{cr}$ of pipe cooled in water) to room temperature.

Comparison of the variation of $a_p$ with temperature at different rates of cooling after tempering showed that when the pipe is cooled in water $a_p$ remains high (about 21 kgm/cm$^2$) at temperatures from $-20$ to $300^\circ$. The values of $a_n$, $a_p$, and the ductile fracture at room temperature indicate that the metal is not susceptible to brittle fracture.

For the samples cooled in air or in the furnace after tempering (treatments 1 and 4) the values of $a_p$ decrease with the temperature below $100^\circ$. At temperatures below room temperature the rate at which $a_p$ decreases is inversely proportional to the cooling rate after tempering. The cold brittleness threshold is at room temperature.

The results obtained indicate that the resistance of Kh8 steel pipe to crack propagation at room temperature depends on the cooling rate of the pipe after tempering – increasing the cooling rate raises the resistance to fracture.

**Effect of Overheating during Tempering.** After heating of the pipe above $Ac_1$ (treatment 5) the structure contains sections of austenite, which transform to martensite during subsequent cooling in air. For this reason the strength characteristics increase by a factor of 2–2.5 and the plastic characteristics decrease by a factor of 1.5–2 at all temperatures (see Fig. 1).

Overheating during tempering also sharply reduces the work of crack propagation and the total work of fracture at all temperatures (from $-100$ to $200^\circ$) and shifts the cold brittleness threshold from $-20^\circ$ to $100^\circ$. Samples overheated during tempering have a lower resistance to brittle fracture at room temperature and are more susceptible to fracture at temperatures of $100$–$200^\circ$ than samples tempered at lower temperatures.

**Effect of Annealing.** As compared with normalization and high-temperature tempering (treatment 1), annealing (treatment 2) increases the susceptibility to brittle fracture at room temperature, the cold brittleness threshold shifting from $-20^\circ$ to $+20^\circ$.

The resistance to brittle fracture at room temperature decreases most after treatment 7. Due to the incomplete decomposition of supercooled austenite to a mixture of ferrite and carbides, the retained austenite transforms to martensite. For this reason the cold brittleness threshold rises to $100^\circ$ and the work of crack propagation at room temperature $a_p$ is one-half that resulting from normalization and tempering; the crystalline components of the fracture in the annealed samples reach 50% as compared with the completely ductile fracture after normalization and high-temperature tempering (see Fig. 1).

Thus, annealing of Kh8 steel pipe is inadvisable, since it lowers the resistance to brittle fracture at room temperature. After treatment 7 the samples are susceptible to brittle fracture not only at room temperature but also at elevated temperatures.

It has been found that the resistance of the same steel to brittle fracture may vary within wide limits, depending on the structure [2–4].

Our results (Fig. 1) concerning the effect of overheating during normalization on the shift of the cold brittleness threshold from $-20$ to $+20^\circ$ can be explained by the increase in grain size.

The increase of the cold brittleness threshold within decreasing rates of cooling after tempering (Fig. 1b) is due to embrittlement, since steel Kh8 is susceptible to reversible temper brittleness [5], which lowers the effective energy of fracture [6].

According to data in [7], reduction of the surface energy promotes nucleation and development of brittle intergranular cracks, as a consequence of which the cold brittleness threshold rises for samples cooled slowly from the tempering temperature (Fig. 1b).