The heat treatment of forgings for rolls used in hot rolling consists of normalization and prolonged soaking at 550-680°C with slow cooling at the rate of 15-40 deg/h. The treatment increases the mechanical properties of the steel due to improvement of the structure and reduction of the hydrogen content. Rolls for hot rolling are usually made of low-alloy steels 60KhN, 60KhG, and 55Kh. After the heat treatment the structure consists of sorbite and pearlite of different sizes.

The mechanical properties of the rolls, particularly the impact strength, do not always meet the specifications.

The steels used to manufacture the rolls are susceptible to temper brittleness [1], and therefore the present heat treatment often results in inconsistent and low values of the impact strength. Also, the impact strength can be affected by the austenite grain size and the phosphorus and hydrogen content of the steel. The present work concerns the effect of these factors on the impact strength of the steels.

The investigation was made with forged pieces and under laboratory conditions. Longitudinal Mesnager samples were prepared from the necks of forgings 600-700 mm in diameter; samples were taken from the surface, at a depth one-third the radius, and from the center. The heat treatment of the samples under laboratory conditions was selected on the basis of previous work [2]. Samples 12 x 12 x 60 mm were heated to normalization temperature and cooled in the furnace at the rate of 25 deg/h, and were also held at 550-680°C and cooled at the rate of 15 deg/h, which corresponds to the normal cooling rate of forgings under shop conditions. Figure 1 shows the variation of the impact strength with the testing temperature at different austenite grain sizes for steel 60KhN with the following chemical composition: 0.68% C, 0.80% Cr, 1.15% Ni, 0.72% Mn, 0.020% S, 0.022% P, 0.25% Si.

Fig. 1. Impact strength of steel 60KhN in relation to grain size and cooling rate at different testing temperatures. ——— Grain size grade 7-8; —— Grain size grade 3. 1) Cooled in water; 2) cooled in furnace.

Fig. 2. Variation of impact strength with phosphorus content of 60KhN forgings.
Grain refining from grade 3 to grade 7-8 leads to a substantial difference in the values of the impact strength after rapid and slow cooling, which is due to the greater length of the grain boundaries. The absolute value of the impact strength in the fine-grained steel is higher than in the coarse-grained steel by 140% in the rapidly cooled steel and 125% in the steel cooled in the furnace. An increase of the cooling rate raises the impact strength, particularly in the fine-grained steel.

Figure 2 shows the variation of the impact strength with the phosphorus content of steel 60KhN from forged rolls 550-700 mm in diameter. The curve was plotted after statistical treatment of the experimental data by linear correlation. The scattering of the experimental points is due to the difference in austenite grain size, the degree of forging reduction, and the variation of the chemical composition within the nominal limits. Reduction of the phosphorus content from 0.030% to 0.015% has a negligible effect on the impact strength at room temperature, while reduction of the phosphorus content from 0.015% to 0.012% sharply increases the impact strength, which conforms with the findings in [3].

The same variation of impact strength with phosphorus content was found in steels 60KhG and 55Kh.

Figures 3, 4, and 5 show the variation of the impact strength with the testing temperature for samples of 60KhN, 60KhG, and 55Kh from three places in forged rolls 550-700 mm in diameter - the surface, at a depth of one-third the radius, and from the center. The scattering of the results after mathematical treatment is shown for steel 60KhN. Even a slight increase of the phosphorus content (a few thousandths of one percent) with increasing distance from the surface of the forging increases the susceptibility of the steel to temper brittleness. Thus, in the forging of steel 60KhN the phosphorus content in the surface is 0.006% less than in the center. This raises the cold brittleness threshold 30°C in the center, and the impact strength at 20°C decreases 1.4 times by comparison with the surface.

With equal phosphorus concentrations the values of the impact strength are almost identical regardless of which section of the forging the samples are taken from. For example, the impact strength in the center and at a depth of one-third the radius in the forging of steel 60KhG is the same at all testing temperatures for equal phosphorus concentrations (0.021%).

In the forgings investigated the austenite grain size did not vary through the section and was grade 6-7. The hydrogen content varied from 1 to 2.6 cm³/100 g of metal through the section of the forgings.* Therefore changes in the austenite grain size and hydrogen content within the limits given cannot be the reason for reduction of the impact strength with increasing distance from the surface of the forging. The impact strength in the center of the forging is lower than in the surface because of phosphorus segregation (even a few thousandths of one percent).

* Our data and those from [4] indicate that the presence of less than 4 cm³ of hydrogen per 100 g of metal has no effect on the impact strength.