EFFECT OF PHOSPHORUS ON THE PROPERTIES OF STRUCTURAL STEELS

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The harmful influence of phosphorus on the properties of structural steels is well known. Nevertheless, it is of interest to determine the quantitative effect of phosphorus on the resistance of steel to brittle and ductile fracture and the susceptibility to reversible temper brittleness. This will make it possible to establish reasonable limits for the removal of phosphorus from steel and to compare the effects of phosphorus and costly alloying elements such as nickel and molybdenum on these properties.

It can be established from existing data that for quenched and tempered structural steels an increase of the nickel content by 1% (up to 3-6%) lowers the ductile-brittle transition temperature an average of 23°C, while 0.1% Mo (up to 0.4%) lowers the transition temperature by 30°C [1-3].

We investigated the effect of phosphorus on the properties of steel 35KhGSA melted in a 50-kg induction furnace. To exclude the effect of impurities of nonferrous metals [4] a high-purity charge was used, carbonyl iron, as well as ordinary Armco iron for comparison.

In steel 35KhGSA melted from Armco iron the amounts (at.%) of the most harmful impurities (antimony and tin) are three times higher than in the steel melted from carbonyl iron; in total impurities of nonferrous metals (at.%) the latter steel is more than 15 times cleaner (Table 1).

Ingots of the experimental steel weighing 20 kg were forged to bars 14 mm square and cut into test pieces.

The pieces were heat treated as follows: normalization at 950°C for 30 min, quenching in oil from 890°C with holding for 30 min, tempering at 650°C for 1.5 h, cooling in oil. Half the pieces were then tempered in the temper brittleness range at 525°C for 500 h and cooled slowly in the furnace. The hardness of all samples of the experimental steel was HRC 25-28.

With heating to 900°C the austenite grain size was fairly fine in the experimental steels, grade 9 for the steel melted from Armco iron and grade 8 for the steel melted from carbonyl iron (GOST 5639-65).

The mechanical properties were determined on samples 5 mm in diameter and impact test samples of types I and IV (GOST 9454-60).

The resistance to brittle fracture was determined from nominal ductile-brittle transition temperatures of T₉₀, T₅₀, and T₁₀ (90, 50, and 10% ductile components in the fracture).

![Fig. 1. Effect of phosphorus content on work of crack propagation in steel 35KhGSA after quenching and high-temperature tempering. Steel melted from carbonyl iron (1) and Armco iron (2).](image)

The components of the impact strength, work of crack initiation and crack propagation, were determined by the methods described in [5, 6]: the results were very similar.

The criterion of susceptibility to reversible temper brittleness was taken as the shift of the ductile–brittle transition temperature ($T_{db}$, °C) in comparison with the unembrittled steel.

With increasing phosphorus concentrations the standard strength and ductile characteristics are practically unchanged and remain the same for steels melted from carbonyl and Armco iron.

The effect of phosphorus is evident in the resistance of the steel to ductile and brittle fracture. An increase of the phosphorus content from 0.001 to 0.045% lowers the work of crack propagation by 50–100% with a completely ductile fracture (Table 2, Fig. 1). Steels melted from carbonyl iron have higher values of the work of crack propagation than steels melted from Armco iron, although the effect of phosphorus is the same; each 0.01% P lowers the work of crack propagation ~1 kg-m/cm$^2$.

![Fig. 2. Temperature dependence of impact strength and percentage of ductile components in the fracture of steel 35KhGSA with different amounts of phosphorus. a) Steel melted from Armco iron; b) melted from carbonyl iron.](image-url)