Small additions of boron to structural steels are used to improve the hardenability and obtain a more homogeneous structure. At the same time, there are data indicating that with equal hardenability the steel with boron has a lower toughness than steel of similar composition without boron.

We have found that the addition of 0.001-0.002% B to structural steel can substantially improve the notch toughness and lower the ductile-to-brittle transition temperature without changing the hardenability or austenite grain size. Boron has this effect only on condition of hot plastic deformation and large deformations. Boron can also increase the evenness of the carbon distribution [1, 2].

This work concerns the effect of boron (0.002%) on the size of martensite crystals in steel 40G (0.02% C, 0.9% Mn, 0.3% Si, 0.06% Al, 0.03% Ti, 0.03% S, 0.02% P) after quenching and low-temperature tempering, and also the relationship between the size of the structural components and the toughness of the steel. Steels 40G and 40GR were subjected to identical hot plastic deformation with ε = 1.2 and 73* (the minimum and maximum deformations used in practice). Samples of steels 40G and 40GR were then quenched from

*Deformation was taken as the ratio of the section of the original ingot to the section of the finished product.

Fig. 1. Microstructure of quenched steels 40G (a, c) and 40GR (b, d). ε = 73. a,b) 8000 ×; c,d) 28,000 ×.
Fig. 2. Microstructure (foils) of highly deformed steels ($\varepsilon = 73$).
28,000 x. a, d) Steel 40G; b, c, e) 40GR; a, b, c) tempered at 200°C; d, e) at 250°C.

<table>
<thead>
<tr>
<th>Steel</th>
<th>$\sigma_0$</th>
<th>$\sigma_0/\varepsilon$</th>
<th>$\varepsilon_{20}$</th>
<th>$\varepsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>40G</td>
<td>170</td>
<td>173</td>
<td>7.4</td>
<td>17</td>
</tr>
<tr>
<td>40GR</td>
<td>190</td>
<td>173</td>
<td>11.5</td>
<td>52</td>
</tr>
</tbody>
</table>

850°C through water into oil and then tempered at 200°C, which is commonly used in practice. We also examined the structure and properties of the steels after tempering at 250°C, i.e., in the range of irreversible temper brittleness.

In studying the effect of boron we took pains to exclude the effect of the hardenability, grain size of austenite, and other factors. Steels 40G and 40GR were treated under conditions ensuring through hardenability. Identical size of austenite grains (grade 8-9) was ensured by the addition of 0.04% Ti. The standard mechanical properties after quenching and low-temperature tempering are given in Table 1.

The toughness of the steels was determined on samples of type I (GOST 9455-60) at temperatures from 20 to -80°C, and the work of crack propagation on samples with a fatigue crack.

The microstructure was examined with light and electron microscopes (MIM-8, UÉMV-100K), with use of carbon replicas and foils (accelerating voltage 100 kV). The foils were prepared by chemical polishing in an electrolyte consisting of $H_2O_2$, $H_3PO_4$, $C_2H_2O_2$, and $H_2O$.

The average values of the notch toughness and work of crack propagation are given in Tables 2 and 3. The toughness of steel 40GR reaches 8 kg-m/cm² and remains around 3 kg-m/cm² ($a_n$ of the steel without