FEATURES OF THE FRACTURE OF CONTROLLED
ROLLED STEEL

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At present wider and wider use is being made of the process called "controlled rolling."

The essence of controlled rolling is that a low-alloy (or low-pearlitic) steel (a typical representative is 07G2FB steel containing about 0.07% C, 1.7% Mn, 0.5% Si, 0.02% P, 0.006% S, 0.08% V, 0.05% Nb, and 0.015% N) is rolled with significant degrees of reduction (not less than 30%) and rolling is completed in the two phase (γ + α)-area. The work hardening and texture caused by the deformation are partially removed, the lower the temperatures within the (γ + α)-area at which deformation is completed, the less completely. In the original condition the steel contains vanadium and niobium carbonitrides, about 0.10-0.15% of each. In heating to 1150°C the vanadium carbonitrides go into solid solution and their precipitation with the subsequent reduction in temperature, stimulated by deformation, leads to hardening while the niobium carbonitrides, which did not go into solution, hinder grain growth. The ferrite grains in the steel after controlled rolling are normally fine (No. 12-13). In order to not cause solution of the niobium carbonitrides and grain growth, the heating temperature for rolling must not exceed 1150°C. If the steel is not alloyed with niobium the vanadium carbonitrides must be kept out of solution and then the heating temperature for rolling must not exceed 1050°C.

The high strength of low-pearlitic steel in alloying with V and Nb (≈600 MPa) is obtained because of additional strengthening as the result of the fine grain, partial work hardening, and the occurrence of dispersion hardening (precipitation of vanadium nitrides). The total increase in strength (σf) is ≈100 MPa.

After controlled rolling the steel has a lower ductile-to-brittle transition temperature than normalized steel with the same strength. This had already been reported in 1967 by Irvin [1]. The ductile-to-brittle transition temperature of type 07G2B steel investigated by us after different heat treatment to the same strength (σ0,2 = 450 MPa, which corresponds to about σf = 600 MPa) is:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Transition temp., °C</th>
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<tbody>
<tr>
<td>Normalized</td>
<td>-30</td>
</tr>
<tr>
<td>Controlled rolling</td>
<td>-60</td>
</tr>
<tr>
<td>Hardened and tempered</td>
<td>-100</td>
</tr>
</tbody>
</table>

Similar data has been obtained by other investigators. For example, it has been shown [2] that with σf = 650 MPa the transition temperature of normalized 09G2 steel is -40°C but after controlled rolling it is -80°C. However, as the result of the absence of an objective criterion for determining the transition temperature of steel after controlled rolling a comparison of the results obtained is not completely valid, which will be shown below.

A characteristic feature of the structure of steel after controlled rolling is the sharply expressed "pearlitic banding" (Fig. 1), which together with the texturing of the ferritic component determines the difference in the ductile properties parallel and perpendicular to the rolling direction (x and y directions) and across the thickness of the sheet (z direction) [3] (Table 1).

The low ductility in the z direction after controlled rolling leads to the fact that plastic deformation even before the occurrence of the main crack causes separation [4], which has now obtained the designation of "cleavage" (from the proposal of M. L. Bernshtein).

An investigation of fractures of 09G2 steel (Fig. 2) [2] showed that cleavage is a breakdown in continuity of the metal. If rolling is completed at 810°C, cleavages are not observed since this temperature is above the Ar3 point, but the lower the rolling temperature the more the steel is damaged by cleavages since with a reduction in temperature of the finish of rolling "pearlitic banding" is strengthened and work hardening (texturing of

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the ferrite grains) is maintained to a greater degree. In connection with this the steel becomes more and more anisotropic. A reduction in test temperature also promotes the development of cleavages as the result of a reduction in plasticity.

Therefore at the moment of start of fracture itself the metal in the plane of the sheet is already damaged by cleavages, that is, by cracks, located perpendicular to the movement of the main crack. In this case the steel must be considered as a "natural multilayer composite" (a descriptive analogy is a "metallic mica").

The crack, breaking the continuity of the metal but moving perpendicular to these multilayer failures of continuity, for its advance must again and again originate on each new surface. Naturally this leads to an increase in the work for crack propagation (toughness), which is true only at temperatures above or within the transition temperature.

In the case of completely brittle fracture this will not have significance, since the work for origin of a crack is close to zero. Therefore, after controlled rolling the impact strength of steel at temperatures close to the upper transition temperature increases as the result of an increase in the number of cleavages (Fig. 2).

The influence of the internal surfaces (cracks) on impact strength was experimentally established by Pogodin-Alekseev [5], who compared two impact samples: "sound" and with an internal crack located parallel to the sample. The sample with a crack had a higher impact strength than the sound one.