HARDENING DURING EXPLOSIVE SHOCK LOADING
OF STEEL 110G13L ALLOYED WITH VANADIUM
AND MODIFIED WITH TITANIUM

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In recent years increasing attention has been given to hardening of steel 110G13L by explosive shock loading to increase the service life of machine parts. Opinions differ on the optimal quantity of vanadium and titanium required for hardening of the steel by shock loading.

Five heats of the steel (Table 1) were prepared and samples 11 x 11 x 56 mm and 40 x 100 x 140 mm were cut. The steel was melted in a 10 ton furnace. Ferrovanadium and ferrotitanium were added immediately before casting. Vanadium slag (heat 3) was added by the method developed at the Ural Scientific-Research Institute of Ferrous Metallurgy (UralNIIChermet) [1].

According to data from [1, 2], 70-80% of the vanadium added to high-manganese steel is found in the solid solution of austenite and the remainder in carbides and oxides. Titanium forms high-melting dispersed inclusions of the carbide and nitride types. Being artificial centers of crystallization, they favor

<table>
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<th>Heat No.</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>V</th>
<th>Ti</th>
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<td>12.5</td>
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<td>0.15</td>
<td>0.06</td>
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<td>0.083</td>
<td>0.034</td>
<td>0.25</td>
<td>0.12</td>
<td>0.20</td>
<td>0.04</td>
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<tr>
<td>3</td>
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<td>12.1</td>
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<td>0.083</td>
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<td>0.25</td>
<td>0.12</td>
<td>0.26</td>
<td>0.07</td>
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<td>0.080</td>
<td>0.039</td>
<td>0.18</td>
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<tr>
<td>5</td>
<td>1.10</td>
<td>14.0</td>
<td>1.04</td>
<td>0.084</td>
<td>0.012</td>
<td>0.26</td>
<td>0.07</td>
<td>0.71</td>
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Fig. 1. Schematic diagram of explosive shock loading (a, b) and position of samples (c). a) Set-up for generating an "oblique" shock wave; b) set-up for generating a plane shock wave; 1) explosive charge; 2) metal plate; 3) samples; 4) frame.

Fig. 2. Surface hardness of steel 110G13L in relation to applied pressure. The heat numbers are given on the curves.


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the formation of a fine-grained structure and increase the total length of grain boundaries and the density of the castings.

The hard-to-dissolve carbides, nitrides, and carbonitrides increase the number of dislocations in the process of plastic deformation, and the stresses required for their movement are higher than in standard steel 110G13L [2, 3].

Explosive shock loading was conducted under conditions shown in Fig. 1. The explosive substance was bulk Hexogen and plastic explosive.

The set-up shown in Fig. 1a more closely simulates the explosive hardening process used for full-scale parts of steel 110G13L — crusher plates and the teeth of excavator buckets, for example. Samples 40 × 100 × 140 mm were hardened by this method. The surface to be hardened was ground in a flat surfacing machine with coolant. The height of the explosive charge and the loading frequency were varied. A plane shock wave was generated by the impact of a metal plate as shown in Fig. 1b. A set of six samples 11 × 11 × 56 mm was placed in a steel frame 10 mm thick. This experiment made it possible to exclude the effect of lateral and longitudinal discharge waves. The pressure, depending on the speed of the metal plate, was varied by changing the thickness of the charge. The experiments were made in the VK-6 explosion chamber. After hardening, the surface was cleaned with emery paper and the hardness was measured. The depth of hardening was determined on samples cut as shown in Fig. 1c.

Only the surface hardness was measured on samples hardened by the method shown in Fig. 1b. The pressure of the shock wave varied from 0 to 33·10^3 kg/cm^2. The results of hardening by this method are shown in Fig. 2. The measurements of the surface hardness indicate large scattering after hardening by the method shown in Fig. 1a. The data were treated with the Mir-1 computer, using the method of least squares. A linear relationship was obtained between the hardness and the distance from the hardened surface with a correlation coefficient larger than 0.9.

It was found (Figs. 2 and 3) that the addition of vanadium and titanium favors greater hardening under all conditions. Hardening was greatest for heats 4 and 5, with an elevated vanadium content. The use of plastic explosive leads to greater hardening than the use of Hexogen.

**CONCLUSIONS**

1. The addition of vanadium and titanium favors greater explosive hardening of steel 110G13L.