For the manufacture of electrodes of various types use should be made, on economic grounds, of powders of ferroalloys (the loss through burning experienced by a ferroalloy leading element during facing is less than that suffered by an element made of a pure metal). Today sintered electrode strip produced by rolling mixtures of powders (GOST 22366-77) is finding increasing application, and it is therefore important to study all aspects of the strength of ferroalloys. It has already been established [1] that, during the rolling of composite strip, inclusions rupture in the region of deformation because there is only limited scope for relief of the stress (mainly tensile, acting at right angles to the strip axis) set up in the matrix of the composite around the inclusions. The rupture of particularly large inclusions in turn can lead, by providing crack nuclei, to the rupture of the strip as a whole during bending (coiling). There is thus interest in the investigation of the strength of ferroalloy powders of the particle sizes used in strip rolling. Information concerning this property should prove useful in the comminution of these materials. Ferroalloys rupture by a cleavage mechanism. In this connection, in the present work rupture caused by a shock load, acting in one or more stages, was employed in the determination of the strength of powdered ferroalloys (Table 1).

Analysis of data on the work done during the comminution of solid particles has led to the derivation of several formulas, two of which are particularly important [2]. On the basis of Kick's law the following expression has been proposed:

\[
A = C \cdot \log \frac{D_1}{D_2},
\]

where \(D_1/D_2\) is the particle size reduction factor; \(C\), a constant; and \(A\), work done.

Kick's law [3] has been formulated on the basis of an analysis of stresses set up during plastic deformation below the elastic limit. According to this law, the work necessary for the comminution of a given particle size reduction ratio is independent of the initial particle size.

From Rittinger's law [4] it follows that the work expended during comminution is directly proportional to the area of the newly formed surface,

\[
A = C \left( S_2 - S_1 \right);
\]

\[
A = C \left( \frac{1}{D_2} - \frac{1}{D_1} \right).
\]

Experience has shown that Rittinger's law gives the best fit with experimental results.

Thus, the theoretical premise underlying the shock method of determining the strength of ferroalloys is provided by a law according to which the amount of energy expended during the brittle rupture of a solid is directly proportional to the area of the surface formed during the rupture.

This law may be expressed in the form [5]

\[
a = W_s \cdot \Delta S.
\]

The coefficient of proportionality \(W_s\), which is the work done during the formation of unit surface, represents strength.

However, not all the shock energy is expended in rupture, and consequently
TABLE 1. Chemical Compositions of Ferroalloys, %

<table>
<thead>
<tr>
<th>Ferroalloy</th>
<th>Grade</th>
<th>GOST</th>
<th>Carbon</th>
<th>Silicon</th>
<th>Manganese</th>
<th>Chromium</th>
<th>Vanadium</th>
<th>Titanium</th>
<th>Phosphorus</th>
<th>Sulfur max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrochromium</td>
<td>FKh650</td>
<td>4757--67</td>
<td>7.8</td>
<td>0.53</td>
<td>71.3</td>
<td>—</td>
<td>—</td>
<td>0.04</td>
<td>0.04</td>
<td>—</td>
</tr>
<tr>
<td>Ferrosilicon</td>
<td>F75</td>
<td>1415--70</td>
<td>76.77</td>
<td>0.71</td>
<td>0.16</td>
<td>—</td>
<td>—</td>
<td>0.042</td>
<td>0.0015</td>
<td>—</td>
</tr>
<tr>
<td>Ferrovanadium</td>
<td>V42</td>
<td>4760--49</td>
<td>0.4</td>
<td>3.0</td>
<td>2.2</td>
<td>38.9</td>
<td>—</td>
<td>0.2</td>
<td>0.1</td>
<td>—</td>
</tr>
<tr>
<td>Ferromanganese</td>
<td>FMn1.0</td>
<td>4755--70</td>
<td>1.0</td>
<td>2.0</td>
<td>85.0</td>
<td>—</td>
<td>—</td>
<td>0.3</td>
<td>0.03</td>
<td>—</td>
</tr>
<tr>
<td>Ferrotitanium</td>
<td>Ti2</td>
<td>4761--67</td>
<td>0.2</td>
<td>9.8</td>
<td>—</td>
<td>19.0</td>
<td>35.0</td>
<td>0.07</td>
<td>0.07</td>
<td>—</td>
</tr>
</tbody>
</table>

Note. The table gives the percentages of all components, the remainder being iron.

Fig. 1. Diagrammatic representation of device for comminution of ferroalloy powders by shock load: 1) striker; 2) punch; 3) die; 4) powder.

Fig. 2. Variation of strength (energy of formation of unit surface) of ferroalloys with work of rupture: 1) ferrosilicon; 2) ferrochromium; 3) ferrotitanium; 4) ferromanganese; 5) ferrovanadium. Ferroalloy particle size 0.2-0.315 mm.

\[ W_S = \frac{\delta \cdot A}{\Delta S} \] (5)

In experiments with a falling weight the theoretical efficiency (energy expended in rupture) calculated from the change in the surface area of the material may attain 60%, although in practice it is often only 10-30% [2].

During the comminution of a powder work is expended mainly in elastically deforming the volume of the powder as it reaches its limiting state (after the rupture of particles this work is almost entirely dissipated in the form of heat) and in plastic deformation.

The work done during the elastic deformation of a volume of a powder depends on the fill thickness, the particle size of the powder, and the elastic modulus of the material of the powder particles. To obtain comparable results, it is necessary to rupture powders of the same particle size, occupying a constant volume. Comparison of strength data for powders of different particle sizes deformed under identical conditions appears to indicate that the strength of coarse fractions exceeds that of fine fractions, which is not the case. The result is a consequence of the fact that changing the particle size of a powder affects the latter's apparent density and hence the amount of material being deformed in a given volume.