A study of the rolling coefficients of metal powders was carried out in the experimental mill of the Institute of Materials Problems, Academy of Sciences, UkSSR, provided with a point dynamometer mounted in one of the rolls. The design of the point dynamometer was described in an earlier paper [1]. The characteristics of the powders used are listed in the table.

The compressibility coefficient $\varepsilon$ is given by the ratio of the thickness of the powder being rolled in the section $h_r$ to the actual thickness $h_s$ of the green strip leaving the rolls (Fig. 1)

$$\varepsilon = \frac{h_r}{h_s}. \quad (1)$$

The compressibility coefficient can be determined experimentally. For this purpose, it is necessary to measure the angle of rolling $\alpha_r$ on an oscillogram recorded by means of a point dynamometer; the arc length of the angle $\alpha_r$ is the base of the specific pressure diagram. The position and size of the sought section $h_r$ correspond to the central angle $\alpha_r$.

The densification coefficient $z_t$ may be defined as the ratio of the green strip density $\gamma_s$ to the tap density of the powder $\gamma_t$

$$z_t = \frac{\gamma_s}{\gamma_t}. \quad (2)$$

The extension coefficient $\lambda$ is given as the ratio of the compressibility coefficient to the densification coefficient

$$\lambda = \frac{\varepsilon}{z_t}. \quad (3)$$

Equation (3) follows from the condition that the weight of the material being rolled is constant

$$\frac{l_2}{l_1} = \frac{h_r \gamma_t}{h_s \gamma_s}.$$

It should be noted that the term "extension" applies not to an elongation of metal particles, but to a deformation of the volume of the powder being rolled, which is characterized by a decrease in the size of this volume in one direction (compression) and an increase in another direction (extension), at a constant size in the third direction (absence of widening). The term "extension" in the case of powder rolling does not fully describe the fundamental nature of the phenomenon, which consists basically in a rearrangement and closer packing of particles under the influence of compression from all sides.

<table>
<thead>
<tr>
<th>Powder</th>
<th>Apparent density, g/cm³</th>
<th>Tap density, g/cm³</th>
<th>Particle size, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe, APZhS grade (reduced, medium fine)</td>
<td>2.09</td>
<td>2.53</td>
<td>to GOST 9849-61 standard</td>
</tr>
<tr>
<td>Cu, obtained by reduction</td>
<td>2.61</td>
<td>2.94</td>
<td>-0.45 + 0.28</td>
</tr>
<tr>
<td>Ni, obtained by reduction</td>
<td>2.73</td>
<td>3.80</td>
<td>-0.015 + 0.005</td>
</tr>
<tr>
<td>Al, obtained by atomization of molten metal by air</td>
<td>1.01</td>
<td>1.25</td>
<td>-0.45 + 0.28</td>
</tr>
</tbody>
</table>
Figures 2-5 show the relationship between the extension coefficient and the maximum specific pressure on the examples of rolling of iron, copper, nickel, and aluminum powders. An interesting characteristic observed is that the extension coefficient for the rolling of a given powder does not depend on specific pressure.

The compressibility and densification coefficients, which reflect the capacity of a powder to undergo densification during compaction by the rolls, are affected differently by the maximum specific pressure. In the case of aluminum powder (the most ductile of the powders investigated), the compressibility and densification coefficients cease to grow at pressures of about 20-25 kN/cm², while in the rolling of nickel and iron powders this does not take place until pressures of about 100 kN/cm² are reached.

It was found that changing the rolling width, amount of powder feed into the deformation zone, strip thickness, and angle of rolling has no effect on the regularities shown in Figs. 2-5. The densification and compressibility coefficients were found to be the same at the same specific pressure, while the extension coefficient remained constant in the whole pressure range. When the coefficient of external friction was reduced by lubricating the rolls, the extension coefficient increased. This confirms that the material being rolled lags behind the neutral section.

Fig. 1. Diagram of powder rolling with hopper adjoining the rolls: \( \alpha_c \) angle of contact; \( \alpha_r \) angle of rolling; \( h_r \) powder thickness at the beginning of deformation zone; \( l_1 \) length of elementary powder volume at the beginning of deformation zone; \( l_2 \) length of elementary powder volume after passage through deformation zone; \( h_s \) strip thickness.

Fig. 2. Effect of maximum specific pressure on rolling coefficients. Iron powder: 1) compressibility coefficient; 2) densification coefficient; 3) extension coefficient.

Fig. 3. Effect of maximum specific pressure on rolling coefficients. Copper powder: 1) compressibility coefficient; 2) densification coefficient; 3) extension coefficient.