The question of industrial application of the new high-productivity hydrometallurgical process for the preparation of copper powder in autoclaves [1] is linked to a large extent with the possibilities of fabrication of semifinished powder products in the form of rolled sheet, rod, etc. It would undoubtedly be desirable that both the powder and the semifinished products should be manufactured at the same industrial undertaking. Industrial fabrication of semifinished products from hydrometallurgical copper powders has already been reported in the literature [2]. The paper in question, however, which indicates the feasibility of obtaining such semifinished products and lists some of their physicomechanical properties, must be regarded as a publicity document. To evolve the fundamental technological principles of fabrication of semifinished products from copper powders, it is necessary to investigate the characteristics of formation of green strip, as well as the sintering and densification of such strip, and to determine the physicomechanical properties of the semifinished products.

The present authors have established some of the general laws governing the rolling of fine copper powders and gave certain recommendations [3]. The work now reported was undertaken with the aim of examining the sintering aspects and studying the physicomechanical properties and microstructure of densified copper-powder strip.

Experiments were conducted on powders of hydrometallurgical copper* with a mean particle size of 10 µ and PM-2 grade electrolytic copper having the following particle-size distribution: +40 µ 2%, 20-40 µ 30%, 7-20 µ 64%, and 0-7 µ 4%, and a specific surface area of 2.18 m²/g.

Chemical analysis established that the electrolytic copper powder contained 5.2% Cu₂O and 1.5% CuO. Specimen-weight measurements performed during the additional reduction of the copper in hydrogen confirmed, with an accuracy of 10%, the chemical-analysis data (it being assumed in the calculation that the weight change was essentially due to a decrease in the oxygen content). Table 1 presents some data on the starting green strip from the electrolytic copper powder.

Porous specimens 1.1 x 20 x 70 mm in size were sintered at a temperature of 950°C in a hydrogen atmosphere, the hot-zone holding periods being 1, 2, 3, 4, 5, 10, 15, 20, 30, 60, and 120 min. Specimens obtained from copper powder moistened with water were sintered immediately after rolling. Some 30-40 sec after the charging of specimens into the furnace, the water held in the specimen pores rapidly evaporated, which could be detected from a change in the size of the hydrogen jet burning at the outlet from the furnace. The surface of sintered specimens, however, showed no signs of swelling or warping as a result of the intense vapor formation at the beginning of sintering.

The sintering of specimens was followed by rolling with an overall reduction of 75%, using intermediate annealing at a temperature of 600°C for 30 min after 25-30% reduction.

The mechanical properties of densified strip were determined, using an MR-05 tensile testing machine on proportional specimens cut out in the direction of rolling. Each plot point was obtained as a mean of results for three specimens. Figure 1 shows the influence of the duration of prior sintering on the tensile strength and percentage elongation of specimens from the electrolytic copper powder after final annealing at a temperature of 600°C for 30 min. As can be seen from this figure, the mechanical properties of densified strip are markedly affected by the initial period of prior sintering. The tensile strength of strip specimens

*The powder-production technique was developed by the Gintsvetmet Institute.
TABLE 1

<table>
<thead>
<tr>
<th>Condition of copper powder</th>
<th>Moistening agent</th>
<th>Amount of moist. agent, ml/kg</th>
<th>Strip density, g/cm^3</th>
<th>Strip thickness, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidized &quot;Add. reduced&quot;</td>
<td>Gasoline</td>
<td>30</td>
<td>6.5</td>
<td>1.1</td>
</tr>
<tr>
<td>&quot;</td>
<td>Dist. water</td>
<td>30</td>
<td>7.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Add. reduced</td>
<td>Gasoline</td>
<td>30</td>
<td>6.5</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Fig. 1. Influence of duration of prior sintering on mechanical properties (tensile strength $\sigma_B$ and elongation $\delta$) of densified copper-powder strip (final annealing at 600°C for 30 min). Copper powders: 1) additionally reduced, moistened with gasoline; 2) oxidized, moistened with gasoline; 3) oxidized, moistened with water.

from the oxidized powder sintered for 1 and 5 min differ by 3-4 kg/mm^2. This indicates that the attainment of maximum bond strength between the powder particles must be preceded by the reduction of oxides in the oxidized powder. The character of elongation variation during the initial period of sintering and the absolute magnitude of elongation for specimens from the oxidized and additionally reduced powders are virtually identical.

Figure 2 shows the microstructure of densified strip specimens from the oxidized electrolytic copper powder after annealing at a temperature of 600°C for 30 min. It will be seen from this figure that the microstructure of densified strip depends to a large extent on the duration of prior sintering. The grain size of annealed strip is the greater the longer the sinterings. A similar relationship was observed also in the study of the microstructure of densified specimens from the additionally reduced powder.

The mechanical properties of sintered copper are, of course, essentially governed by three factors: presence of pores, presence of oxides, and grain size (with block structure exerting a similar influence) [4]. For a cast material, the tensile strength is the higher the smaller the grain size. Evidently, the grain size of sintered copper would be expected to affect the mechanical properties in the same way as it does for cast copper. The dependence of the mechanical properties of densified strip on the duration of prior sintering is apparently linked with differences in the degree of deoxidation attained during the sintering of compacted copper in hydrogen.

The decreased dislocation mobility in the presence of oxides hinders the propagation of slip processes in sintered copper and would be expected to result in lower ductility characteristics. This is, in fact, observed in the case of prior sintering of rolled powder strip with a holding period of up to 5 min.

Microscopical analysis (according to GOST 635-52 standard) is the most common method of determining oxygen in copper. However, this technique is not sufficiently reliable for revealing thousandth parts