THE PROPERTIES OF FINE BERYLLIUM WIRE

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Beryllium has a unique combination of physomechanical properties and surpasses many structural materials in its strength-to-weight ratio, modulus of elasticity and shear modulus. It has a low density expansion coefficient, and electrical resistivity, and high heat resistance and thermal conductivity.

However, the low ductility and substantial anisotropy of the mechanical properties make it difficult to reduce beryllium to small sections.

We succeeded in producing fine beryllium wire with a diameter as small as 0.09 mm and investigated its physomechanical properties.

The original material was a P/M block of 99.6% Be in a steel casing subjected to hot extrusion to a rod 3 mm in diameter and 5–6 m long, with subsequent hot drawing and intermediate annealing (Table 1).

The effect of tempering temperatures from 300 to 500°C on the physomechanical properties of beryllium wire 0.09 and 0.37 mm in diameter was determined. For 0.09 mm wire an increase of the tempering temperature above 300°C is accompanied by some reduction of the ultimate strength and elongation and an increase of the proportionality limit (Fig. 1a).

Evidently the change in the strength and ductility of beryllium wire with increasing tempering temperature is due to two opposing processes – stress removal and precipitation hardening [1].

With further increase of the tempering temperature to 500°C the proportionality limit decreases and the elongation increases, which may be due to the transition to the second stage of aging – completion of precipitation from the supersaturated matrix.

The electrical resistivity decreases smoothly with increasing tempering temperature from 0.05 \( \Omega \cdot \text{mm}^2/\text{m} \) in the original condition to 0.048 \( \Omega \cdot \text{mm}^2/\text{m} \) after tempering at 500°C.

The shear modulus in torsion after tempering at 300–500°C increases about 14% as compared with the original condition.

<table>
<thead>
<tr>
<th>Diameter, mm</th>
<th>Heating temperature, °C</th>
<th>Heating temperature, °C</th>
<th>Number of passes between intermediate annealing</th>
<th>Intermediate annealing temperature, °C</th>
</tr>
</thead>
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<td>1.5</td>
<td>600–700</td>
<td>450–500</td>
<td>5–7</td>
<td>800</td>
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<tr>
<td>0.5</td>
<td>550–650</td>
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<td>750–800</td>
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<td>8–10</td>
<td>700–750</td>
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<tr>
<td>0.2–0.1</td>
<td>450–500</td>
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<td></td>
<td>650–700</td>
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</table>

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Increasing the holding time to 3 h at 300°C (Fig. 1b) induces changes in the properties characteristic of precipitation hardening – an increase of the ultimate strength and proportionality limit (around 10%). The elongation and resistivity remain unchanged within the limits of precision of the measurements.

In the given case the aging process predominates over the stress removal process, and the total effect is manifest in an increase of the strength as compared with the original condition.

The variation of the properties of 0.37 mm wire with the tempering temperature is shown in Fig. 2a. The ultimate strength and proportionality limit are highest and the elongation lowest at 400°C (300°C for 0.09 mm wire), which is explained by the small strain hardening of this wire during the preceding hot drawing. The effect of aging is stronger for 0.37 mm wire than for 0.09 mm
wire, in which greater precipitation hardening occurs during drawing. However, the strength of 0.37 mm wire after tempering is 14% below that of 0.09 mm wire. With an increase of the tempering time at 400°C to 2 h the ultimate strength and proportionality limit of 0.37 mm wire increase, with a decrease of elongation and resistivity (Fig. 2b). Further increase of the tempering time to 3 h lowers the strength and resistivity.

No differences were observed in the microstructure of the wire after drawing and after tempering at 300-500°C.

Figure 3 shows the properties of wire with different diameters after drawing. The strength of the 0.37 mm wire is 30% below that of 0.09 mm wire; the elongation is five times higher and the resistivity 35% higher. This is explained by the effect of the preceding treatment (Table 1) and the difference in the structural condition of wire with different diameters resulting from strain hardening and precipitation hardening during hot drawing.

After annealing at 700°C for 40 min the wires (all diameters) have similar structures and identical strength characteristics (Table 2).

The reduction of the strength after tempering as compared with the original condition (after drawing) is greatest for the wire 0.09 mm in diameter, which undergoes the greatest degree of deformation during drawing.

On the load-extension diagrams of the annealed wire of all diameters there is a yield point.

It was found that to obtain the maximum strength and elastic characteristics of beryllium wire with diameters of 0.1-0.4 mm it is necessary to conduct subrecrystallization tempering at 300-400°C after hot drawing.