We investigated Gagarin samples that were pressure cast in shell molds. The properties and structure of the bronze in relation to the casting conditions and chemical composition are given in Table 1.

Heats 1 and 2, obtained by pressure casting, differed in chemical composition and solidification rate (Fig. 1a, d). Heat 3 was cast in a shell mold; the cooling rate in this case was five times (40 deg/sec) lower than in the case of pressure casting (heats 1 and 2).

Heat 1 consists mainly of α phase (80-95%) with a grain size of 5.7 μm. Along with high ductility, the alloy has low strength and hardness.

Fractographic analysis (Fig. 1b) showed the ductile character of the fractures.

Axial porosity is visible in the center of the sample (Fig. 1c), which reduces the strength.

<table>
<thead>
<tr>
<th>Heat No.</th>
<th>Composition, %</th>
<th>Grain size of α phase, μm</th>
<th>Amount of α phase, %</th>
<th>σb, MPa</th>
<th>HB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.7 4.1 5.1 9.0</td>
<td>5.7 86 500 32</td>
<td>902 0026/80/1112-0902 $07.50 © 1981 Plenum Publishing Corporation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Heat 2, with a high concentration of aluminum and nickel in contrast to heat 1, consists of α phase, α + χ (β phase) eutectoid, and inclusions of χ phase. Heat 2 has fairly high strength, low relative elongation, and high hardness. However, heat 2 is characterized by ductile fracture (Fig. 1d).

The grain size of the main structural component of heat 2 is smaller than in heat 1. The difference is clearly evident on fractographs. The reduction of the grain size evidently favors a larger quantity of dispersed aluminum oxides. However, oxides of substantial size are also observed on the fracture surface along with dispersed aluminum oxides.

It should be noted that axial porosity is also observed in samples of heat 2, although the grain size is much smaller than in heat 1.

Heat 3 consists of α phase and a small quantity of χ phase (Fig. 1e). The strength of this grain size is what smaller than that of heat 2, but the relative elongation is far higher. This is also confirmed by the type of fracture (Fig. 1f, g). In the center of the sample the fracture is intergranular and one observes slight porosity. Individual grains undergo ductile fracture, as in heat 1. At the grain boundaries of heat 3 one observes precipitates of χ phase, which also leads to lower ductility.

The data obtained were subjected to computer analysis and are presented in Fig. 2. The tensile strength of the alloy increases with the concentrations of all elements tested. With increasing quantities of zinc the strength decreases and the ductility increases (Fig. 2a, b). Silicon has a similar effect on the ductility (Fig. 2b).

The ductility of the alloy also varies with the grain size and quantity of α phase. Figure 2d, e shows the effect of chemical composition on the grain size of α phase. With a high concentration of silicon and zinc the grain size of α phase and the amount of this phase increase (Fig. 2e). These elements are impurities in AZhN bronze, and thus their concentrations should be limited. The main components (aluminum, iron, nickel, manganese) raise the strength and hardness, lower the relative elongation (Fig. 2a-c), promote grain refining, and reduce the quantity of α phase. Only manganese has different effects on the properties and structure. When the manganese content is raised to 1.5% the strength and hardness decrease, the ductility increases, and the grain size and quantity of α phase increase. At larger concentrations of manganese it has the opposite effect.

CONCLUSIONS

1. A high cooling rate of bronze castings leads to a structure of refined α phase and a substantial quantity of β phase (α + χ), which reduces the ductile characteristics of the alloy.