Most joints in cryogenic equipment operating at very low temperatures are made with silver solders. The joints must have sufficient strength and cold resistance to exclude the possibility of brittle fracture during operation.

We investigated silver solders of the Ag—Cu—Zn system (PSr45, PSr25, PSr12), the Ag—Cu—Zn—Cd system (PSr40), and the Ag—Cu—Zn—Mn system (PSr37.5), the chemical composition and mechanical properties of which are given in Table 1.

According to the phase diagram [1], solders of the ternary Ag—Cu—Zn system have a single-phase structure in the equilibrium condition, although as-received they are biphase alloys.

Solder PSr40 has a heterophase structure, and PSr37.5 a biphase structure with a predominance of α phase.

Five samples cut from sheets of solder 1–2 mm thick in the original condition were subjected to tensile tests in a low-temperature attachment built at PNT INT AN Ukrainian SSR [2], permitting tests down to the temperature of liquid helium (4.2°K). The level of the cooling agent in the attachment was determined by means of an electrical level meter [3] and maintained so that the samples were constantly submerged in the liquid. The samples were successively placed in testing position automatically by means of multiposition clamps [4].

Figure 1 shows the load—extension diagrams of solders at different temperatures. All solders tested have a saw-toothed curve at 4.2°K. In our opinion, the saw-toothed pattern of silver solders at 4.2°K is mainly the result of twinning [5, 6].

With decreasing temperatures the ultimate tensile strength and yield strength of all solders increases by a factor of ~1.5, increasing at the highest rate in the range of 77–4.2°K (see Table 1).

The variation of the ductility with testing temperature differs. The relative elongation of the most ductile solder (PSr37.5) increases by a factor of ~2.2 when the temperature is changed from room temperature to 4.2°K. The change in the ductility is similar for PSr40 and PSr12, although the absolute values of their

| Table 1 |
|---|---|---|---|---|---|
| Solder No. | Sheet thickness, mm | Composition, % | σ_b, kgf/mm² | σ_0.2, kgf/mm² | δ, % |
| | Ag | Cu | Zn | at 200 K | 170 K | 90 K | 77 K | 50 K | 4.2 K | 200 K | 170 K | 90 K | 77 K | 50 K | 4.2 K |
| PSr45 | 1.5 | 44.5 | 55.1 | 95.1 | 214 | 75.0 | 95.0 | 102.0 | 102.0 | 89.0 | 86.0 | 86.0 | 83.0 | 94.0 | 3.5 | 3.1 | 4.2 | 2.8 |
| PSr60 | 1.5 | 29.3 | 17.1 | 57.6 | 184 | 54.0 | 84.0 | 98.0 | 98.0 | 86.0 | 60.0 | 60.0 | 82.0 | 85.5 | 6.0 | 14.8 | 11.4 | 11.7 |
| PSr25 | 2.0 | 55.0 | 40.0 | 84.4 | 333 | 61.0 | 88.0 | 88.0 | 88.0 | 80.0 | 94.0 | 94.0 | 92.0 | 90.0 | 7.0 | 10.8 | 9.4 | 8.5 |
| PSr12 | 2.0 | 11.6 | 29.1 | 85.0 | 221 | 76.0 | 86.0 | 94.0 | 97.0 | 85.5 | 77.0 | 86.0 | 89.0 | 94.0 | 5.1 | 6.0 | 10.8 | 11.4 |

Note. 1) PSr40 also contained 26.2% Cd and 0.31% Ni, and PSr37.5 8% Mn. 2) The values of the microhardness are averages of 10 measurements, the strength and ductility the averages of 3–5 measurements.

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relative elongation are only half that of PSr37.5. Thus, PSr40, PSr37.5, and PSr12 are not embrittled when the temperature is lowered to 4.2°K.

The ductility of the solders tested at room temperature is lowest for PSr45 (δ = 3.5%); with decreasing temperatures the ductility decreases still more.

Comparison of the temperature dependence of the strength with the chemical composition of the solders leads us to conclude that the strength is directly proportional and the ductility inversely proportional to the zinc content. In a ductile solder (of the PSr37.5 type) the silver content should evidently be five to seven times larger than the zinc content.

Fractographic analysis showed approximately the same character of fracture of each solder at all testing temperatures. Most ductile solders have fractures of the shear type, forming an angle of 45° to the rolling plane.

The fractures of solders with low ductility (PSr45, for example) occur at an angle of 90° to the rolling plane.

In some cases dimples are observed in mutually perpendicular directions at an angle of 45° to the axis of elongation and perpendicular to the rolling plane.

**CONCLUSIONS**

1. With decreasing temperatures from room temperature to 4.2°K the ultimate tensile strength and yield strength of silver solders increase by a factor of 1.5, the relative elongation of solders PSr40, PSr37.5, and PSr12 increasing by a factor greater than 2, while the ductility of PSr45 and PSr25 decreases somewhat.

2. The strain curves are sawtoothed at 4.2°K.