Measurement of mechanical properties of electronic materials at temperatures down to 4.2 K

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ABSTRACT

Operating temperatures of spacecraft components in the ‘subzero’ range are encountered during solar eclipse periods or when voyaging on deep-space missions. Moreover some spacecraft instruments or parts of them, e.g. sensors, have to be cooled to obtain an improved performance, e.g. in spacecraft missions like the infrared space observatory (ISO) and CryoSat. Materials utilized in the assembly of electronic circuits can be subjected to mechanical loading at cryogenic temperatures. [Semerad E, Scholze P, Schmidt M, Wendrlinsky W. Effect of new cleaning liquids on electronic materials and parts. ESA metallurgy report no. 3275; January 2002, [1]]. Within the present work the mechanical properties of electronic materials at cryogenic temperatures down to liquid helium temperature were analysed. Specifically the tensile properties of solders (63Sn37Pb, 62Sn36Pb2Ag, 60Sn40Pb, 96Sn4Ag, 50In50Pb, 70Pb30In, 96.8Pb1.5Ag1.7Sn, 96.5Sn3Ag0.5Cu), PCB boards (MLB polyimide glass fibre, MLB epoxy glass fibre, MLB Thermount), conformal coatings (Arathane 5750, Sylgard 184, Scotchcast 280, Solithane 113, CV-1144-0, Mapsil 213, Conathane EN4/EN11) as well as OFE Cu were characterised at room temperature, at liquid nitrogen and at liquid helium temperature by tensile tests. The fracture surface of tested samples was examined by means of optical microscope and if necessary with scanning electron microscope.

1. Introduction

The objective of the present work was to check the reliability of OFE Cu, solders, PCB boards, and conformal coatings at low operating temperatures.

Specifically the temperature dependence from room temperature (RT) down to 4.2 K (LHe) of following materials properties was characterised

- Young’s modulus.
- Proof stress.
- Elongation at rupture.
- Ultimate tensile strength.

OFE copper was delivered from Goodfellow GmbH [12] in form of an as drawn rod (diameter: 12.7 mm, length: 1000 mm, purity: better than 99.95%). The rod was cut into pieces of about 80 mm. These specimens were machined according to ASTM-E8. The round tensile specimen had a reduced length of 30 mm with a diameter of 5 mm and threaded ends of M9x1.5. The single specimens were taken arbitrarily for the tests at room temperature, at LN2- and at LHe temperature. The solders (except of 96.5Sn3Ag0.5Cu) delivered from JL Goslar GmbH had a length of about 400 mm and a triangle profile. To get samples having the same geometry like the OFE copper specimens, the raw solder bars had to be melt to a rod with a length of at least 70 mm. The raw solder materials were squeezed to a roughly round form that fits in glass tubes with an inner diameter of 10 mm and a length of 100 mm. To avoid hollows in the casted solder rods and to get comparable results with previous investigations [2,3], the melting process took place under vacuum (10E-2 mbar) at casting temperatures shown in Table 1. The melting temperatures of the solders are also given in this table. The parameters for casting were chosen in accordance to previous investigations [2], the melting process took place under vacuum (10E-2 mbar) at casting temperatures shown in Table 1. The melting temperatures of the solders are also given in this table. The parameters for casting were chosen in accordance to previous investigations [2] and [3] to ensure comparable results. In Fig. 1a typical solder rod after casting is shown.

The cast rods were cleaned, identified as well as end trimmed and machined according to ASTM-E8. The round tensile test specimens had a reduced length of 30 mm with a diameter of 5 mm and threaded ends of M9x1.5 like the OFE Cu samples. The solder 96.5Sn3Ag0.5Cu was delivered in form of a bar (48 × 4 × 2 cm³). From this bar the round tensile test samples of 5 mm and threaded ends of M9x1.5. The single specimens were taken arbitrarily for the tests at room temperature, at LN2- and at LHe temperature.

The solders (except of 96.5Sn3Ag0.5Cu) delivered from JL Goslar GmbH had a length of about 400 mm and a triangle profile. To get samples having the same geometry like the OFE copper specimens, the raw solder bars had to be melt to a rod with a length of at least 70 mm. The raw solder materials were squeezed to a roughly round form that fits in glass tubes with an inner diameter of 10 mm and a length of 100 mm. To avoid hollows in the casted solder rods and to get comparable results with previous investigations [2,3], the melting process took place under vacuum (10E-2 mbar) at casting temperatures shown in Table 1. The melting temperatures of the solders are also given in this table. The parameters for casting were chosen in accordance to previous investigations [2,3] to ensure comparable results. In Fig. 1a typical solder rod after casting is shown.

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could be cut directly. Thus, a direct comparison of the measured values of 96.5Sn3Ag0.5Cu with the other solders should be regarded carefully. In Fig. 2 a solder tensile test specimen is shown. The tensile specimens were checked by means of ultrasonic inspection. Samples with any hollows were rejected.

The PCB’s were delivered from GPV Printca A/S. The dimensions of all specimens were nearly identical, i.e. approx. 200 mm in length, 20 mm in width and 1.6 mm in thickness. The core material is 0.2 mm thick. It is pressed into a 1.6 mm sandwich (due to a real board contain several layers). For clamping in the specimen holder the thickness of the samples should be about 8 mm. Due to the thickness of the samples of 1.6 mm and to assure that they are not harmed when clamping them, their ends were taped with a 40 mm long glass fibre reinforced polymer. In Fig. 3 a sample of every PCB material prepared for tensile test is shown.

The conformal coatings consisted of three silicones, three polyurethanes and one epoxy system, which where evaluated for spacecraft applications in previous technical notes [4]. These conformal coatings have either an extensive usage in the fabrication of spacecraft or are expected to pass the ESA requirements for outgassing, offgassing, toxicity and flammability. The materials delivered from ESA had a form of 20 x 20 cm².

The samples had to be trumped by means of a special formed cutter. A photo of a Solithane 113 tensile specimen is shown in Fig. 4. Before clamping the specimens in the sample holder, they were taped with spare material of Solithane 113 to assure that they are not harmed when clamping.

### Table 1

<table>
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<tr>
<th>Solder</th>
<th>Melting range (°C)</th>
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<tr>
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<td>221</td>
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<td>209</td>
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<tr>
<td>70Pb30In</td>
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<tr>
<td>96.8Pb1.5Ag1.7Sn</td>
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<tr>
<td>96.5Sn3Ag0.5Cu</td>
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### 2. Experimental details

The tests included:

- Ultrasonic Inspection of the samples.
- Tensile tests at room temperature as well as at cryogenic temperatures down to 4.2 K.
- Visual inspection and surface analysis by optical microscope and scanning electron microscope (SEM).

Before tensile tests started, all samples were checked with ultrasonic inspection which was done by means of an automated scanning ultrasonic testing facility type panametrics multiscan with an immersion tank using a 20 MHz focused immersion transducer type: V317/188237 with a focal length of 28 mm in impulse-echo mode. For scanning the transducer was placed 23 mm above the surface of the sample – that means the focal point of the transducer was adjusted to the axis of the sample. The samples were rotated around their axis and the transducer was moved along the axis giving a rectangular winding-up c-scan of the whole cylindrical part of the sample. To prove the detectable pore size, holes of different diameters were drilled in the samples and the pre-damaged samples were inspected. Defects > 0.4 mm could be detected. Samples with any failure larger than the minimum detectable size were rejected.

The test campaigns were carried out on a class I universal testing machine. The load cells and the extensometers have been calibrated on site by the certified calibration service of Messphysik Laborgerät GmbH/Austria based on standards issued by BEF, the supreme Austrian authority for standards and calibration. The calibration certificates state accuracies of ±0.5% of the selected load.

Fig. 1. Vacuum casted solder rod.

Fig. 2. Solder tensile test specimen.

Fig. 3. Taped PCB samples.

Fig. 4. Conformal Coating tensile test specimen.
range, ±0.005 mm of the machines stroke indicator and ±0.5% of the extensometers gauge length.

Tests were performed with a constant cross-head speed of 1 mm/min and a tensile preload of 10–20 N. The extensometer was calibrated and “zeroed” at preload level prior of each test. The mechanical properties calculated after completion of each test were based on the recorded signals of the load cell, the cross-head position sensor and the extensometer. Measurements at room temperature were performed with a video extensometer.

Tensile tests at 77 K (LN2 temperature) were performed by means of a liquid nitrogen bath mounted in the tensile test machine. Measurements at cryogenic temperature were made with a special low temperature extensometer.

Tensile properties at 4.2 K (LHe temperature) were measured by means of a LHe – cryostat mounted in a mechanical testing machine (Fig. 5). The cryostat is described in detail in [5]. By means of this experimental setup tensile measurements with a maximum load of 200 kN at cryogenic temperatures down to 4.2 K can be per-

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**Fig. 5.** Arrangement for tensile testing at 4.2 K in LHe featuring the 4 column testing machine, the LHe – cryostat containing the specimen (black cylindrical object).

**Fig. 6.** Stress/strain diagram as recorded by means of a PC.

**Fig. 7.** Solder sample before and after tensile test at 4.2 K.
formed. A special top loading mechanism enables a quick change of the samples. Therefore, no heating up of the cryostat between the tests is warranted and so, the cooling down time of specimen is less than 2 h (big samples, like PCB’s) and less than 1 h (smaller samples, like OFE copper, solders and conformal coatings).

During each tensile test a stress/strain diagram is plotted, from which the tensile properties were evaluated. Fig. 6 shows a typical one.

### 3. Test results

At least 3 tensile specimens of each material and each temperature were tested. In Fig. 7 a solder sample, in Fig. 8 a PCB sample, and in Fig. 9 a conformal coating sample mounted in sample holder before and after tensile test at 4.2 K are shown.

The data are given in Tables 2–20. In Figs. 10–13 the average values of the temperature dependence of Young’s modulus E, ultimate tensile strength Rm, proof stress Rp0.2, and elongation at rupture A are plotted. An exception is the elongation at rupture of OFE Cu at room temperature (Fig. 13). Due to fracture outside of the extensometer of Test Nos. 24 and 26, it is expected that only the elongation of test 147 is a valid factor. So, this value is shown in Fig. 13. For this reason the A-values of Test Nos. 24 and 26 in Table 2 are marked with a red exclamation mark.

Before each tensile test, the samples were measured by means of a micrometer screw (accuracy: +/-0.01 mm). Applying the low

### Table 2

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<th>Test no.</th>
<th>Ch-No</th>
<th>E (kN/mm²)</th>
<th>Fmax (N)</th>
<th>Rm (N/mm²)</th>
<th>Rp0.2 (N/mm²)</th>
<th>A (%)</th>
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### Table 3

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<th>Test no.</th>
<th>Ch-No</th>
<th>E (kN/mm²)</th>
<th>Fmax (N)</th>
<th>Rm (N/mm²)</th>
<th>Rp0.2 (N/mm²)</th>
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of error propagation a deviation of the measurements of +/– 5% is roughly estimated.

The Young’s modulus of OFE Cu is superior to other tested materials. For the conformal coatings the lowest values were found. The temperature dependence of the elastic modulus is for all materials. For the conformal coatings the lowest values were found. The temperature dependence of the elastic modulus is for all materials. For the conformal coatings the lowest values were found. The temperature dependence of the elastic modulus is for all materials. For the conformal coatings the lowest values were found. The temperature dependence of the elastic modulus is for all materials. For the conformal coatings the lowest values were found. The temperature dependence of the elastic modulus is for all materials. For the conformal coatings the lowest values were found. The temperature dependence of the elastic modulus is for all materials. For the conformal coatings the lowest values were found. The temperature dependence of the elastic modulus is for all materials. For the conformal coatings the lowest values were found. The temperature dependence of the elastic modulus is for all materials. For the conformal coatings the lowest values were found. The temperature dependence of the elastic modulus is for all materials. For the conformal coatings the lowest values were found. The temperature dependence of the elastic modulus is for all materials. For the conformal coatings the lowest values were found. The temperature dependence of the elastic modulus is for all materials. For the conformal coatings the lowest values were found. The temperature dependence of the elastic modulus is for all materials. For the conformal coatings the lowest values were found.

### Table 4

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Ch No.</th>
<th>$E$ (kN/mm²)</th>
<th>$F_{\text{max}}$ (N)</th>
<th>$R_m$ (N/mm²)</th>
<th>$R_p2$ (N/mm²)</th>
<th>A (%)</th>
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### Table 5

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### Table 6

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### Table 7

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<td>0.822</td>
<td>1.670</td>
<td>7.994</td>
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OFE Cu- and PCB-values of the ultimate tensile strength are superior to all tested solders and conformal coatings. The Sn-based solders show relative high Rm-values, accept of the Ag-doted materials, their strength is in the range of 50In50Pb. 96.5Sn3Ag0.5-Cu is an exception, probably due to the Cu-content.

At RT and at 77 K (~LN2) the strength of PCB 2301 MLB epoxy glass fibre is the highest one of the tested PC boards, at 4.2 K PCB 2302 MLB polyimide glass fibre shows the highest ultimate tensile strength of the 3 PCB's. The tensile strength of PCB Thermount is at all temperatures investigated the lowest one compared with the other 2 PCB's.

The temperature dependence of the tensile strength of Arathane 5750, Sylgard 284, Scotchcast 280, Solithane 113 and Conathe N4/EN11 is shown in high gear with Conathane N4/EN11 and not so strong with Sylgard 184. The strength of CV-1144-0 and Mapsis 213 increases clearly at 4.2 K. For low temperatures the strength
of Solithane 113 is superior to the other conformal coatings and it is in the range of the values found for most solders.

The proof stress of OFE Cu is superior to all other materials tested. The Sn-based solders show similar temperature dependence. The proof stress of 96.5Sn3Ag0.5Cu is at 4.2 K is in between. At 4.2 K the proof stress of Solithane 113 is superior to the rest of the tested conformal coatings.

The elongation at rupture of all Sn-based solders is at low temperatures very low. OFE Cu and the Pb-based solders show a higher elongation at rupture at cryogenic temperatures.

For the PC boards the elongation is in the range of a few p.c. At room temperature the elongation of PCB 2301 MLB epoxy glass fibre is superior to the rest of the PC's. At low temperatures the elongation of PCB 2302 MLB polyimide glass fibre is the highest one of all tested PC boards.

The conformal coatings show very high elongations at RT, at low temperatures the elongation decreases rapidly. At 77 K Mapsil 213 has the highest elongation, at 4.2 K the elongation of Arathane 5750 is superior to the rest of the conformal coatings.

---

### Table 8

<table>
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<tr>
<th>No.</th>
<th>Ch- No.</th>
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<th>Fmax (N)</th>
<th>Rm (N/mm²)</th>
<th>Rp0.2 (N/mm²)</th>
<th>A (%)</th>
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<tr>
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### Table 9

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<th>Rm (N/mm²)</th>
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### Table 10

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<tr>
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<th>Rm (N/mm²)</th>
<th>Rp0.2 (N/mm²)</th>
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<td>148</td>
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### Table 11

<table>
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<th>Fmax (N)</th>
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<td>93</td>
<td>15.110</td>
<td>604.837</td>
<td>27.623</td>
<td>26.593</td>
<td>45.797</td>
</tr>
</tbody>
</table>
For PCB bare materials and conformal coatings we found the following:

In Fig. 14 the decomposition of the PCB 2302 MLB polyimide glass fibre-sandwich in its single layers after tensile test particularly at cryogenic temperatures is shown.

PCB 2301 MLB epoxy glass fibre is by far not so decomposed, but several cracks are found after tensile tests (Fig. 15). The fracture surface is smooth compared to PCB Thermount and looks similar at all temperatures investigated (Fig. 16).

The specimens of PCB Thermount looks similar to those of PCB 2301 MLB epoxy glass fibre after tensile tests but fewer cracks were found. At room temperature and at 77 K the singular strings can be seen in the fracture surfaces. At 4.2 K the fracture is a little bit smoother, comparable with the fracture surfaces of PCB 2301 MLB epoxy glass fibre. The reason could be that the Young’s modulus of PCB Thermount is at 4.2 K in the range of PCB 2301 MLB epoxy glass fibre, at RT and 77 K it is clearly lower.

At room temperature the fracture surface of all conformal coatings investigated is very smooth; at low temperatures it is more and more brittle. In Fig. 17 photos taken with optical microscope and in Fig. 18a–c SEM pictures of the fracture surface of Solithion 113 after tensile tests performed at room temperature, at 77 K and at 4.2 K are shown.

For all comparison with data from literature it should be considered that the grain size of the solder influences the flow stress as outlined in [6].

For OFE Cu and the solders investigated we found in detail:

3.1. OFE copper (after [12]; CV007960)

No thermal treatment was applied, but the variety of the mechanical properties of drawn wires, rolled foils or galvanic films should be considered. Aloud [12] the used Cu was delivered in form of a drawn rod and has a purity of better than 99.95%.
The ultimate tensile strength continually increases at lower temperature which is in good comparison with [13]; the proof stress remains approximately constant with temperature with a maximum value at 77 K. The values of the proof stress measured at room temperature and at 77 K are in good comparison with [13]; the Young's modulus and the stress at the limit of proportionality at low temperatures. The temperature dependence of these values is in good comparison with pure Cu a continuous increase of the Young's Modulus with decreasing temperature is expected. The strength and elasticity is superior to all solders at all temperatures. The material shows ductile behaviour down to 4.2 K, the measured elongation even increases at low temperatures.

3.2. 63Sn37Pb (inspection certificate: DIN 50049/EN 10204-3.1)

There is an increase of the ultimate tensile strength, the Young's modulus and the stress at the limit of proportionality at low temperatures. The temperature dependence of these values is in good comparison with previous investigations [2,3].

At 4.2 K and 77 K the solder is brittle, with low elongation. For high temperatures the highest ductility of all tested solders was found. Also a large reduction in the cross sectional area was found at RT.

<table>
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<td>48</td>
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<table>
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<td>Average</td>
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<tr>
<td>Standard deviation</td>
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</tbody>
</table>

3.2. 63Sn37Pb (inspection certificate: DIN 50049/EN 10204-3.1)
3.3. 62Sn36Pb2Ag (inspection certificate: DIN 50049/EN 10204-3.1)

The silver content improves the strength of the solder with respect to 63Sn37Pb for a little bit. The temperature dependence is similar to 63Sn37Pb. Also for 4.2 K and 77 K a brittle fracture with low elongation and for RT dimple fracture with higher elongation was found.

Compared with data of [3] the values of Young's modulus are about the same. Those of the ultimate tensile strength, the proof stress as well as the total elongation are a little bit lower.

3.4. 60Sn40Pb (inspection certificate: DIN 50049/EN 10204-3.1)

Generally the tensile properties are similar to those of the eutectic composition 63Sn37Pb. Small elongations and brittle fractures are obtained at 4.2 K and 77 K. At higher temperatures the solder is ductile with high elongation ratios.

Compared with [7] the proof stress, the ultimate tensile strength and the elongation at rupture are somewhat lower at cryogenic temperature. Compared with [8] and [9] the ultimate tensile strength is somewhat lower at room temperature and same at cryogenic temperatures. The elongation is lower at cryogenic temperature; nevertheless this is in good comparison with previous investigations [2,3].

3.5. 96Sn4Ag (inspection certificate: DIN 50049/EN 10204-3.1)

At room temperature the modulus of elasticity is superior to the rest of the solders. The proof stress is at RT and at 77 K somewhat lower than the values found for the rest of the Sn-based solders. At 4.2 K no proof stress could be found because of its peculiar stress/strain diagram.

The fracture of the solder is brittle at low temperatures with low elongations. At RT the solder is ductile and the fracture shows a high reduction in area.

3.6. 50In50Pb (inspection certificate: DIN 50049/EN 10204-3.1)

At 4.2 K the solder remains extremely soft with a very low Young's modulus and high ductility compared with the other solders. The fracture surfaces of this ductile solder are shown in Fig. 19 (photos taken after tensile test at different temperatures).

3.7. 70Pb30In (inspection certificate: DIN 50049/EN 10204-3.1)

Generally, this solder shows similar strength and elastic properties as the 50Pb 50In solder. The elongation is somewhat lower compared with the 50Pb 50In solder. The fracture shows a little reduction area at RT, at low temperatures the fracture is not so brittle compared with the other tested solders.
Beside the high melting point which makes the solder suitable for sequential soldering the solder shows interesting mechanical properties. The stiffness lies in between the Sn-based and In/Pb solders. The ultimate tensile strength is in the area of the In/Pb solders, at 4.2 K somewhat higher. Compared with [10,11] the measured values are lower. The proof stress is the lowest one of all solders investigated at all temperatures. The elongation is the highest one beside 50In50Pb at low temperatures. It is in good comparison with [10,11] at room temperature, at cryogenic temperature the elongation is lower. The fracture shows a high reduction area at RT and at 77 K, at 4.2 K the fracture shows also a reduction.
3.9. 96.5Sn3Ag0.5Cu (inspection certificate: DIN 50049/EN 10204-3.1)

The temperature dependence of the ultimate tensile strength is similar to the other Sn-based solders, except of 96Sn4Ag. The stress at the limit of proportionality is superior to the rest of the solders at 4.2 K. The temperature dependence of the Young’s modulus as well as of the elongation is similar to 63Sn37Pb. In the cross sectional area a reduction was found. For 4.2 K and 77 K brittle fracture with low elongation were found. The fracture surfaces of this brittle solder are shown in Fig. 20 (photos taken after tensile test at different temperatures).

As mentioned above, this solder could be tested in the as-received condition. Thus, a direct comparison of the measured values with the other solders should be regarded carefully.

4. Conclusions

4.1. Solder alloys

The measurements of the tensile properties of bulk solder depend greatly on conditions of casting (getting pore-free samples). With decreasing temperature, Sn-based solders show a strong increase in tensile strength (Rm = 135–149 MPa) and proof stress (Rp0.2 = 112–142 MPa), they are brittle with small elongations. Among them 96.5Sn3Ag0.5Cu shows the highest proof stress. For 77 K and 4.2 K this solders are brittle with small elongations (A ≈ 0.2–1.5 p.c.).

Comparing the Cu-content solder with 96Sn4Ag, for room temperature nearly the same tensile strength and proof stress are found. The elongation is clearly higher; the Young’s modulus is clearly lower. For low temperatures the elongation is nearly the same. The values found for the tensile strength and
the proof stress are clearly higher. The proof stress of 96Sn4Ag at 4.2 K could not be investigated. The Young's modulus is somewhat lower.

In/Pb solders remain soft ($E \approx 12$–14 GPa) and ductile ($A \approx 4.5$–20 p.c.) at 4.2 K, but they have low strength ($R_m \approx 29$–76 MPa) and low proof stress ($R_{p0.2} \approx 33$ MPa).

The Pb-based solder combines medium strength with good stiffness at superior ductility, but low proof stress.

4.2. PCB–bare materials

At 4.2 K the elasticity ($E \approx 33$ GPa) and the proof stress ($R_{p0.2} \approx 317$ MPa) of PCB 2301 MLB epoxy glass fibre are superior to the other tested PCB's. PCB Thermount has the lowest elasticity and strength, its elongation is at low temperatures the smallest one of the tested PCB's.

4.3. Conformal coatings

At cryogenic temperatures all tested conformal coatings show a strong increase of strength, proof stress and elasticity, their elongation decreases very strong. An exception is Arathane 5750 which has a high elasticity at all temperatures. The Young's modulus, the strength and the proof stress of Solithane 113 is superior to the other tested conformal coatings.

At room temperature the fracture surface of all investigated conformal coatings is very smooth with extremely high elongation (up to 200 p.c. for Conathane EN4/EN11), at low temperatures it is brittle, the elongation decreases to less than 10 p.c. At 4.2 K the elongation of Arathane 5750 (8.3 p.c.) is superior to the rest of the conformal coatings.

4.4. OFE copper

At cryogenic temperatures the proof stress, the elasticity and the ductility of OFE Cu is superior to all other materials tested.

4.5. Overall findings

The selection of a solder for use at cryogenic temperatures will depend on its mechanical properties, fatigue and the specific application like soldering temperature, possible dissolution of Au or Ag from plated components or wires, etc. The mechanical properties of the tested solders offer a wide range from stiff and brittle to soft and ductile materials. The differences in the strength and stiffness of the solders increase at low temperatures so the mechanical properties should be considered carefully for the selection of one material.

The elasticity of all PCB materials is for all temperatures from the same order of magnitude like the values found for the solders.
Strength and proof stress of the PCB materials is always higher than those of the solders. Generally, at room temperature the elongation of solders is higher than the elongation of PCB boards, at 4.2 K only the elongation of the In/Pb as well as the Pb-based solders is higher.

For all temperatures the modulus of elasticity, the strength and the proof stress of PCB materials is higher compared with the values found for conformal coatings. At all temperatures the elongation of the conformal coatings is superior to the elongation of the PCB's, but the relative differences diminish with respect to 4.2 K.

At 77 K the tensile strength of Solithane 113 exceeds those of the solders; at 4.2 K it is lower. The stiffness of most conformal coatings increases relatively to the solders (typically 1/20 at 4.2 K, 1/5000 at room temperature). In combination with the large thermal expansion of the conformal coating the coating will impose considerable loads to the solder joints and have to be avoided at cryogenic temperatures. An exception is Arathane 5750, its stiffness is at all temperatures investigated in the same order of magnitude (1.9–4 GPa).

Fig. 18. Solithane 113 fracture surfaces (SEM).

Fig. 19. Fracture surfaces of ductile solder (50In50Pb) performed with optical microscope.
References


Fig. 20. Fracture surfaces of brittle solder (96.5Sn3Ag0.5Cu) performed with optical microscope.