P1.20

Solder assembly of cantilever bar force or displacement sensors

Maeder, Thomas* and Genoud, Dominique**
* Sensile Technologies SA, PSE-B, CH-1015 Ecublens
** Ecole Polytechnique Fédérale de Lausanne, Institut de Production Microtechnique, CH-1015 Ecublens

Abstract

In this paper, we compared the stability of a displacement sensor assembled with Sn96 (tin-silver) solder, Sn62 (tin-lead-silver) solder or conductive silver-loaded epoxy glue. In the absence of humidity or thermal cycling, the glue was found to be much better than both solders. This is ascribed to better creep behaviour combined with lower elastic modulus and much smaller bond thickness. However, the glue underwent severe degradation in hot, humid air, and is therefore not suitable for all applications. Among the solder alloys, high-temperature Sn96 exhibited higher stability than the standard Sn62, in accordance with expectations.

Introduction

For small force ranges (ca. 10 mN to 100 N, 1 g to 10 kg), force sensors using a ceramic cantilever bar, with piezoresistive thick film resistor sensing elements, can easily be applied. This technique may also be used for displacement sensors up to ca. 1 mm. In this sensor design (figures 1–2), the cantilever bar is attached to the sensor base by either gluing, soldering or glass bonding. Assembling the cantilever bar onto the base using solder or conductive glue allows both electrical connections and mechanical mounting to be achieved in a single and easy process; the cantilever bar is mounted in a similar way to an electronic component.

While this type of assembly allows inexpensive force and displacement sensors, there are issues regarding the stability over time and loading of the output signal.

- Changes in the internal stress distribution in the solder or glue bond give rise to parasitic signals in the sensing resistors, and hence to an offset drift of the output signal.
- Creep of the solder[1,2] or glue gives rise to an offset in displacement, which is especially a problem for displacement sensors. In case of strong creep, force sensors will also be affected, because the cantilever beam will eventually rest against the sensor base.

This paper presents results on the stability of a displacement sensor, assembled using different solder materials and conductive glue.

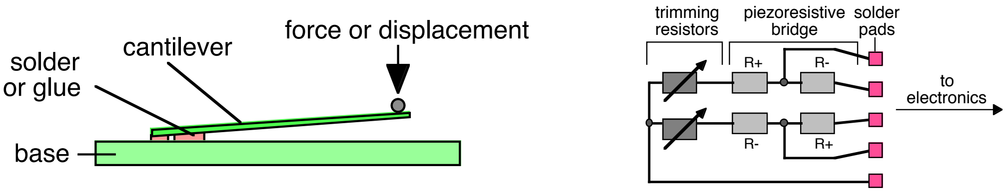

Figure 1. Sensor schematic (left) and electrical diagram (right).

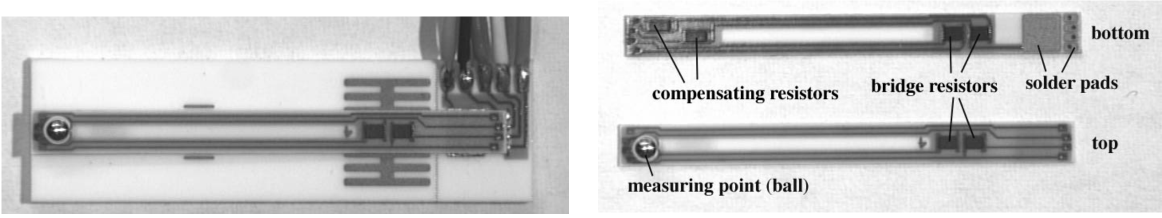

Figure 2. The sensor studied in this paper (left), and its cantilever beam (right).

Experiments

The studied sensors, pictured in fig. 2, feature a 96% alumina cantilever bar, 0.25 mm thick, assembled onto a base out of the same material, 1 mm thick. Cantilever width is 3 mm and effective length (between end of bond and force centring ball) is 21.5 mm. About 70 of these sensors were assembled using 6 different variants, labeled "Sn62", "Sn62*", "Sn96", "Sn96*", "Sn96**" and "E212". The corresponding parameters are given in table I. Three parameters were varied : bonding material, soldering procedure and bond thickness.

- Three bonding material were examined : Sn62 or Sn96 solder paste (Microbond) or E212 (Epotechny) conductive glue.
- Soldered cantilevers were either assembled using the standard method (applying the cantilever over the base covered with solder paste and then melting the solder, "Sn62" and "Sn96") or by first pre-melting the solder paste on the base ("Sn62*", "Sn96*" and "Sn96**"), and then applying the cantilever in a second melting step. Pre-melting of the solder before applying the cantilever bar is thought to decrease its porosity, by allowing the flux to escape to the surface.
- In one case, the thickness of the solder was increased (Sn96**).

Designation	**Bonding material (solder or glue)**	**solder pre-melting**	**Bond thickness**
Sn62	62% Sn + 36% Pb + 2% Ag solder	no	ca. 120 μm
Sn62*	62% Sn + 36% Pb + 2% Ag solder	yes	ca. 80 μm
Sn96	96.5% Sn + 3.5% Ag solder	no	ca. 120 μm
Sn96*	96.5% Sn + 3.5% Ag solder	yes	ca. 80 μm
Sn96**	96.5% Sn + 3.5% Ag solder	yes	ca. 200 μm
E212	Epotechny E212 conductive glue (silver-loaded epoxy)	-	ca. 25 μm

Table I. The 6 assembly variants for the displacement sensors.

The sensors were loaded by placing them in a jig schematised in fig. 3, and subjected to a battery of 5 different tests listed below. The decrease of the deflection of the cantilever beam caused by creep in the solder or glue was monitored electrically by measuring the output of the resistor bridge, which was supplied with a constant 5 VDC during all the tests.

1) 1 week at 25°C (room temperature).
2) 1 week at 50°C.
3) 1 week at 100°C.
4) Thermal cycling, 8 cycles : 6h at –25°C, then 6h at +25°C, then 6h at +100°C. Total cycle time was ca. 21 h, including the time required for temperature change.
5) Humidity testing : 1 week at 85°C and 85% RH (relative humidity).

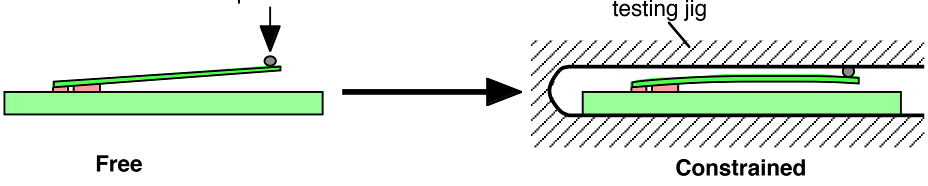

Figure 3. Schematic of the testing jig.

Results and discussions

The results of the constant temperature creep tests (25°C, 50°C and 100°C) are given for all samples in fig. 4. The E212 conductive glue clearly stands out and exhibits the lowest signal relaxation of all variants. Among the solder materials, Sn96 is more stable than Sn62.

Pre-melting the solder was slightly beneficial for Sn62, but slightly detrimental for Sn96. Normally, one would expect the denser solder achieved by pre-melting to be more stable in all cases. However, the flux in Sn96 tended to degrade more rapidly, mainly because of the higher temperature required to melt this solder (melting points are 221°C for Sn96 and 179°C for Sn62). This could have slightly impaired wetting of the cantilever soldering pads by pre-melted Sn96 solder. Moreover, Sn96 is very fluid in the molten state, and therefore the density difference between pre-molten and normal is not as great as for Sn62.

The effect of bond thickness for pre-melted Sn96 cannot be judged, as the sensors with thick solder bonds were inadvertently much less loaded than the other ones. However, the much smaller thickness of the glued bonds compared to the soldered ones is a probable cause for their better creep behaviour.

At constant temperature, the signal relaxation rate decreases strongly over time, as clearly evidenced from fig. 5. Two factors may account for this : 1) stabilisation by annealing of the solder or glue, and 2) local creep of the end of the bond, which eases stress concentrations. This latter hypothesis gives another cause for the superiority of glue over solder in these tests : its lower elastic modulus is thought to allow, at the same bond thickness, stress distribution over a much greater length and therefore to considerably lower the stress concentration at the end of the bond, as schematised in fig. 6. This will be tested in future experiments by using stiffer (i.e. thicker) cantilever beams to increase the stressed length in the solder bond.

While glue was superior to solder in constant temperature "dry" tests, it gave comparable results to solder during thermal cycling tests (fig. 7) and fared much worse than solder in humidity testing (fig. 8). Although the humidity test data presented here is deemed inaccurate due to electromigration phenomena (and hence apparent negative creep in some soldered samples), the glued samples performed clearly worse, exhibiting severe corrosion problems. In one case, the cantilever bar even became unglued from the base. On the other hand, soldered samples did not show any visible sign of corrosion.

Conclusions and outlook

In this study, the conductive epoxy glue appeared clearly superior to both types of solder in dry atmospheres, be it at room or elevated temperature (100°C). Among solders the high-temperature Sn96 type performed better than the standard Sn62 alloy. However, conductive epoxy is sensitive to humidity, and therefore not suitable in all cases. For both glue and solder assembly, burn-in of sensors is advisable, as the signal relaxation rates drop considerably over time.

Rather than involving the whole bond area, creep in this study was probably concentrated at the end of it. Future studies will concentrate on understanding and modelling these local stresses. Thicker, stiffer cantilever beams will also be studied, as they impart stress on a larger area of the bond. Also, more systematic studies of the influence of bond thickness will be made.

Solder or glue is only suitable in applications where a slight creep of the joint is acceptable, such as displacement sensors whose offset can be zeroed from time to time. Force sensors are another possible application, because a slight amount of creep does not (in principle) affect the output signal.

References

[1] J.S. Hwang, "Modern solder technology for competitive electronics manufacturing", McGraw Hill, 1996.

[2] D.R. Frear, W.B. Jones, and K.R. Kinsman-KR (Editors), "Solder mechanics", McGraw Hill, 1992.

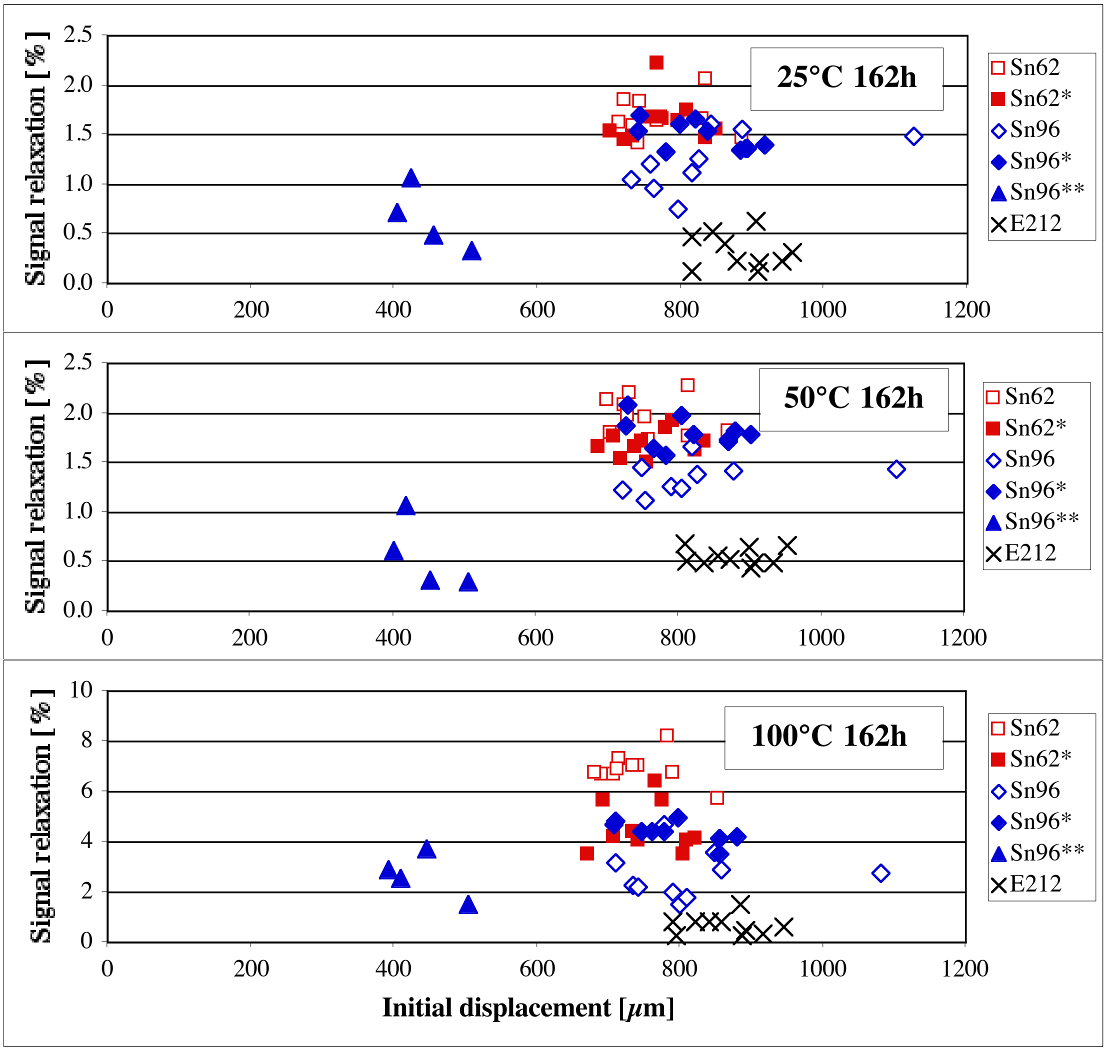

Figure 4. Signal relaxation after 162h at 25°C, 50°C and 100°C as a function of initial displacement.

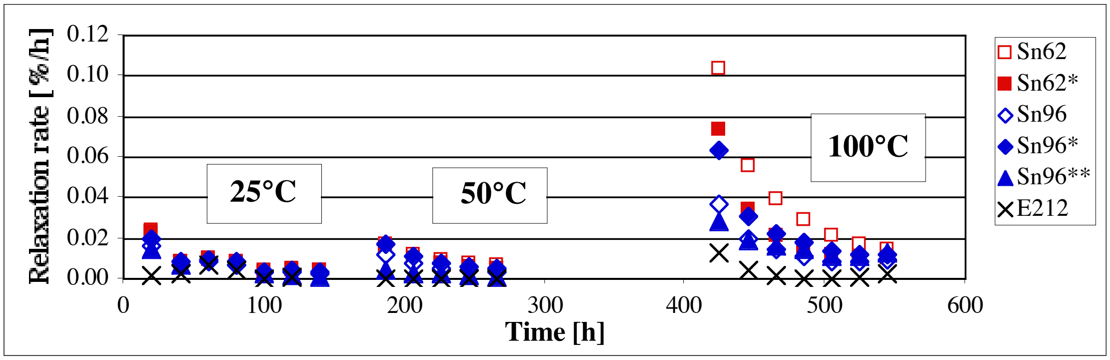

Figure 5. Signal relaxation rate as a function of time, at different temperatures.

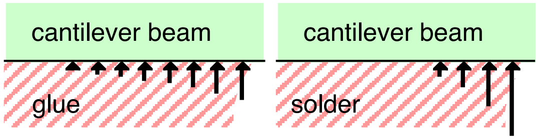

Figure 6. Purported stress distribution at the end of the glue or solder joint. The higher elastic modulus of solder entails higher stress concentration.

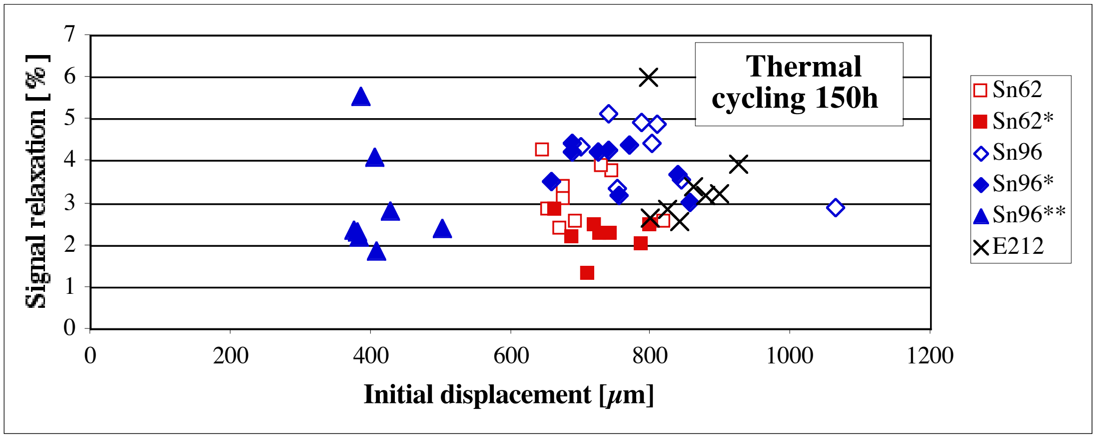

Figure 7. Signal relaxation after thermal cycling.

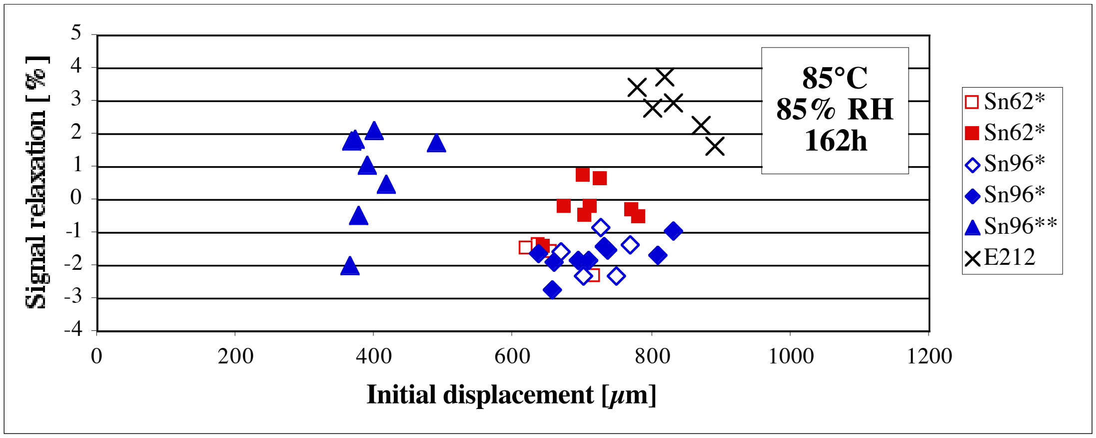

Figure 8. Apparent signal relaxation after humidity testing. The data here are deemed relatively inaccurate, due to the presence of electromigration phenomena.