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Measurement of Mechanical Properties of Lead Free Solder

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Abstract. This paper describes main results of research focused on mechanical testing of Sn-3.5Ag-0.75Cu solder. Creep, tensile and torsional properties were investigated. The plastic behavior of the material can be studied in the most effective way under pure torsion. The viscoplastic behavior with high sensitivity on strain rate as well as temperature was observed. The results will be subsequently used for the calibration of appropriate constitutive law of the lead free solder.

Introduction

Nowadays almost everyone on the planet Earth daily uses highly advanced and complex electronics such as smart phones, smart televisions, computers etc. These electronics would not work without its intelligent core – printed circuit boards. The board consists of electrically conductive copper traces and non-conductive substrate. Copper traces are sophistically laid on this board in order to connect various components such as resistors, capacitors, semiconductors, etc. In order to ensure right electrical and also mechanical connection between components and copper traces on printed circuit board, the solder joint connection is widely used.

Soldering process dates back to the 5000 years when tin combined with lead was used. Several years ago it was found that lead highly pollute the ground water, which may cause environmental problems and therefore its use was forbidden. From that time, the lead free solder alloys are used for soldering. These solder pastes consist mainly from tin, silver and other chemical elements such as copper, nickel or antimony [1]. In minor representation there are also fluxes and rosin.

Failure usually occur in this tiny solder joint connection when printed circuit board is exposed either to high temperatures or to the alternating temperatures which result in malfunction of electronic device itself. During that, solder joints are usually exposed to multiaxial loading. Finding the cause or even predict malfunction using the finite element method is highly demanded from customers. To be able to do that we firstly need to know material properties of these solder joints.

Design of specimen

Because of the size of the real product, where some components could have less than 5mm, it is really difficult to prepare specimens for measurement of mechanical properties. Also for the right properties of the soldered joint, the temperature time during soldering in solder reflow oven must be respected, see figure 1 [2]. For measurement of mechanical properties of solder joints special samples have to be prepared.

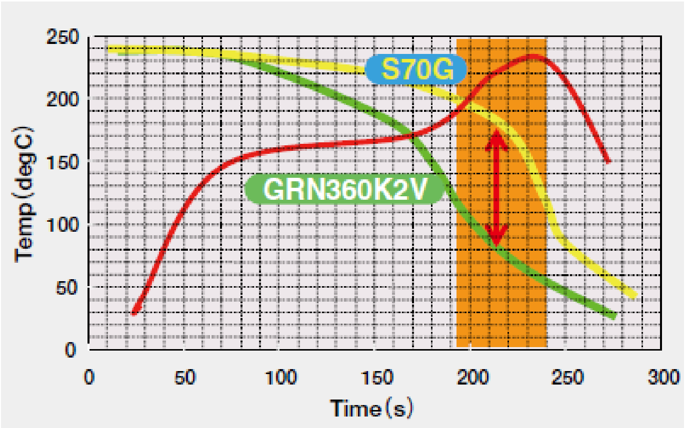

Fig.1 Soldering temperature profile [2]

During our investigations we studied several articles about mechanical properties of solder joints and its measurement ([1], [3], [4], [5]). Interesting and inspired study was the report made by engineers from Royal Instate of Technology KTG, Stockholm [6]. They measured tensile test using the special specimen, which consists of two copper flat bars between which small amounts of solder paste was applied. Because our aim was to measure not only tensile properties but also torsion or even multiaxial mechanical properties, we need to use axisymmetric shape of final specimen. On other hand engineers from Akita Prefectural University used for their testing round shape specimen prepared from ingot casting [7]. This kind of specimen is not suitable for our measurements, because it does not have fluxes and rosin, which are in real solder paste and influence behavior of solder joint. Therefore, we need to use real solder paste and create a special specimen from it. Finally, we combine these two approaches [6], [7].

Our measurement sample consists of copper dog bone round cross-section separated into two pieces between which small amount of solder paste Sn-3.5Ag-0.75Cu is applied. Thickness of solder paste was setup to 0.5mm with diameter of 7mm, see figure 2.

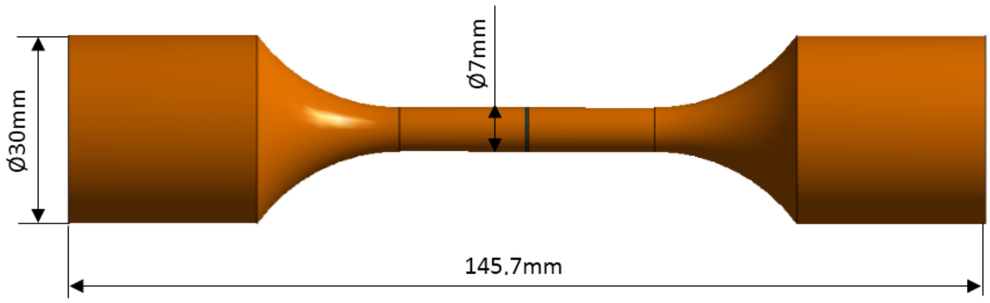

Fig.2 Solder paste specimen

To ensure right dimension of applied solder and also cohesiveness, special soldering tool needed to be designed and manufactured. Important thing was to choose right material for soldering tool with resisting adhesion for applied solder paste. For this purpose, we used S235 steel. Ready-made soldering tool can be seen in the figure 3.

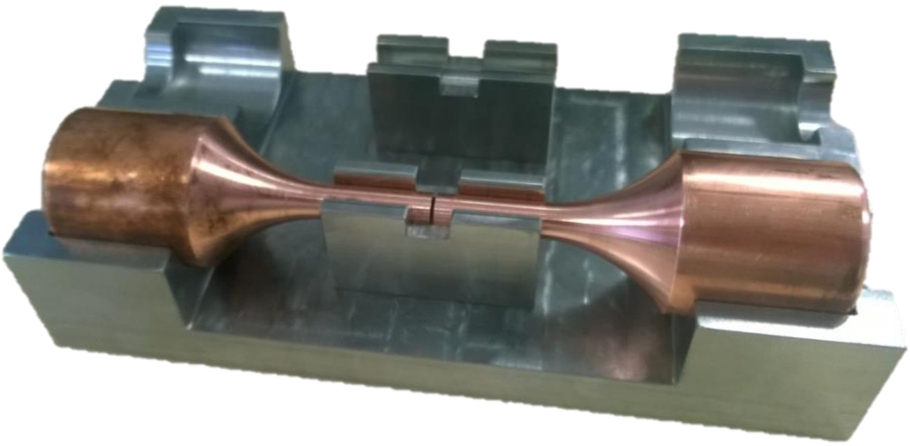

Fig.3 Soldering tool with copper parts of final specimen

Production of specimen

Soldering was done as follows. Firstly, the copper parts of the specimen were placed into soldering tool. Into the created gap, the solder paste was applied. Then such prepared soldering tool was placed into the temperature chamber and heated up to 250°C, which is soldering temperature. After the soldering temperature was reached, the soldering tool was withdrawn from temperature chamber and cooled down to room temperature, see figure 4. Then the specimen was taken out from the soldering tool. Solder area need to be machined to have ideally rounded shape, see figure 5. Such sample was then used for mechanical testing.

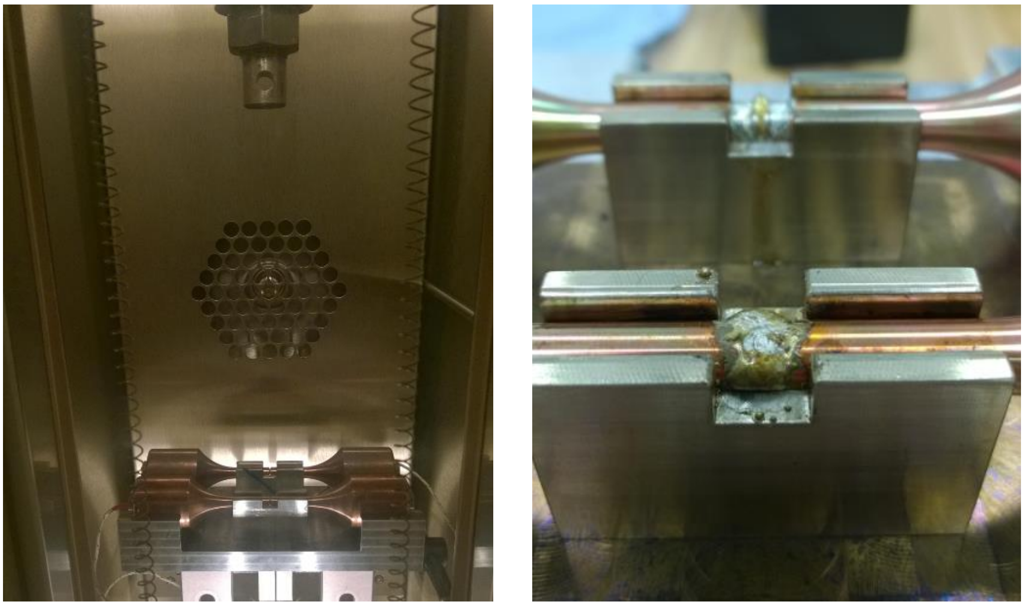

Fig.4 Soldering at temperature chamber on the left
and cooling after soldering on the right

Fig.5 Specimen before and after machining

During specimen creation, a problem with bubbles inside soldering area raised, see figure 6. It is most probable, that these bubbles are either air bubbles trapped inside the solder paste due to imperfect application between copper parts or vacuum bubbles caused by evaporation of fluxes or rosin, which are inside solder paste. Either way after long examination we discovered that bubbles inside solder area are caused by soldering process and non-observance of soldering time. Heating of soldering tool with copper parts and applied solder paste takes more than one hour before soldering temperature was achieved. This approach may also cause degradation of solder paste material. In order to obey the soldering time, firstly the soldering tool with copper parts was pre-heated to soldering temperature. After soldering temperature was reached on copper parts soldering tool was taken out from temperature chamber and solder paste was quickly applied into the gap between copper parts. By this the presence of big bubbles was eliminated. Some amount of tiny bubbles are still present even after soldering process was changed. But these bubbles are also in solder joint area of real product, see figure 7.

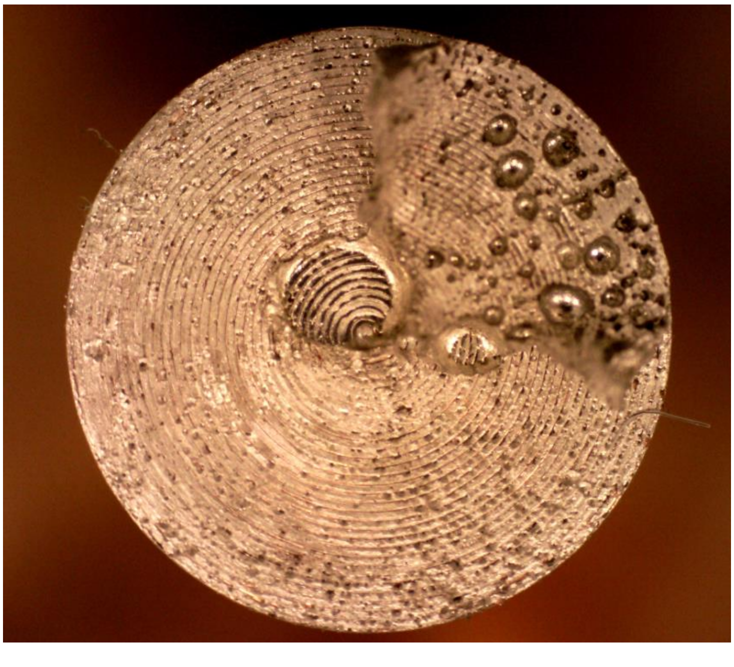

Fig.6 Bubbles inside solder area

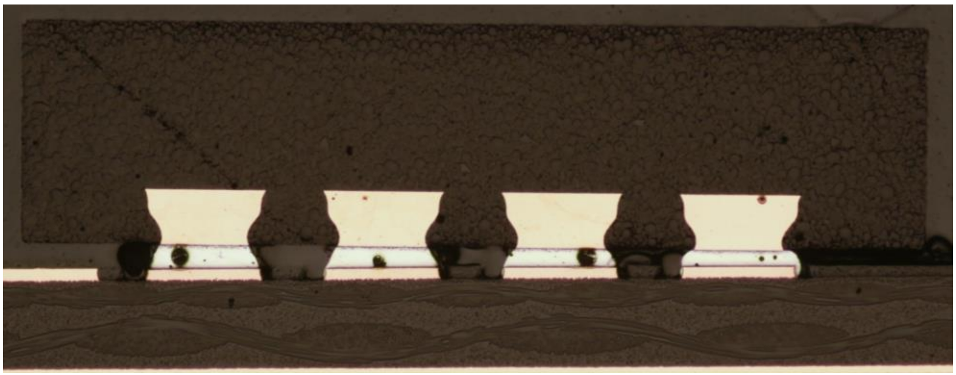

Fig.7 Bubbles inside solder joint

Experimental Results

Soldered and machined specimens were then used for tensile, torsion and also creep tests. Different temperatures and strain rates were applied during measurements. Due to the small thickness of solder area, the only results from the tests are elongation and force from jaws. Mechanical extensometer does not have such small grip and optical extensometer was not able to catch whole test due to the low resolution. Therefore the measurements are effected by presence of copper parts. Also elongation before failure is very small and presence of micro residual bubbles could influence measurement. Mechanical properties of solder joint need to be reverse engineered by using finite element method analyses.

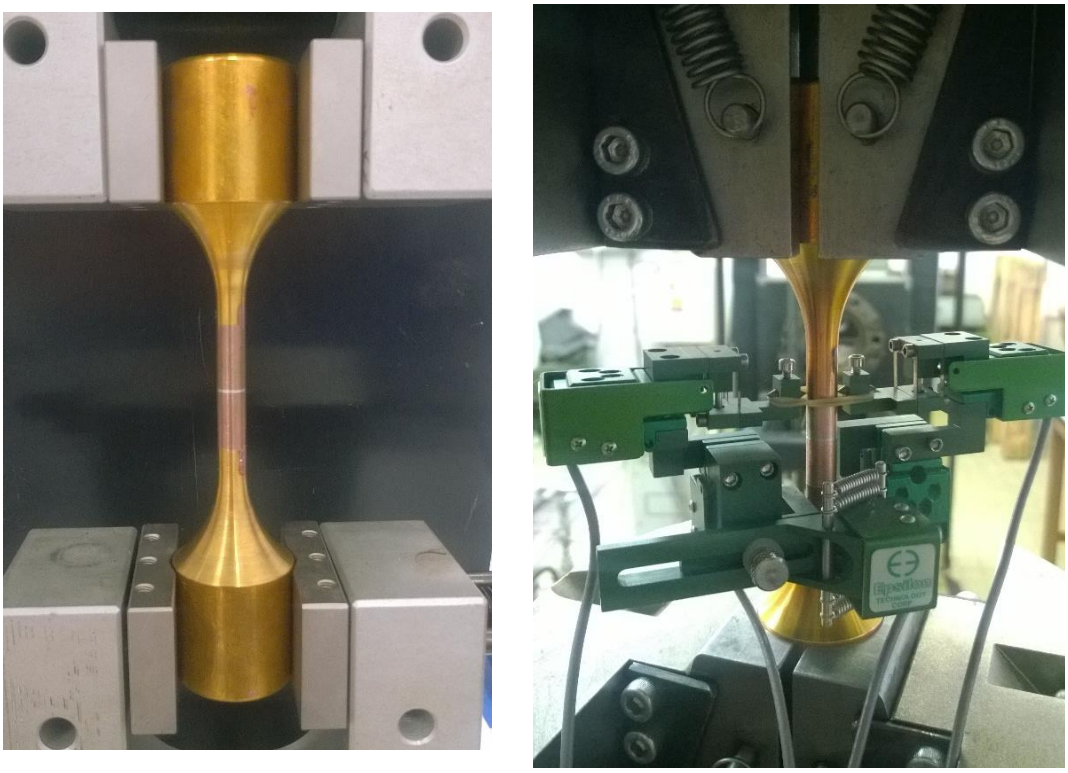

Fig.8 Fixture of specimen during tension test (left) and torsion test (right)

Uniaxial tensile tests were driven by deformation. Tests were done for crosshead speed 0.1mm/min, 1mm/min and 10mm/min and for room temperature, 80 °C and 125 °C. Results are presented in the figure 9.

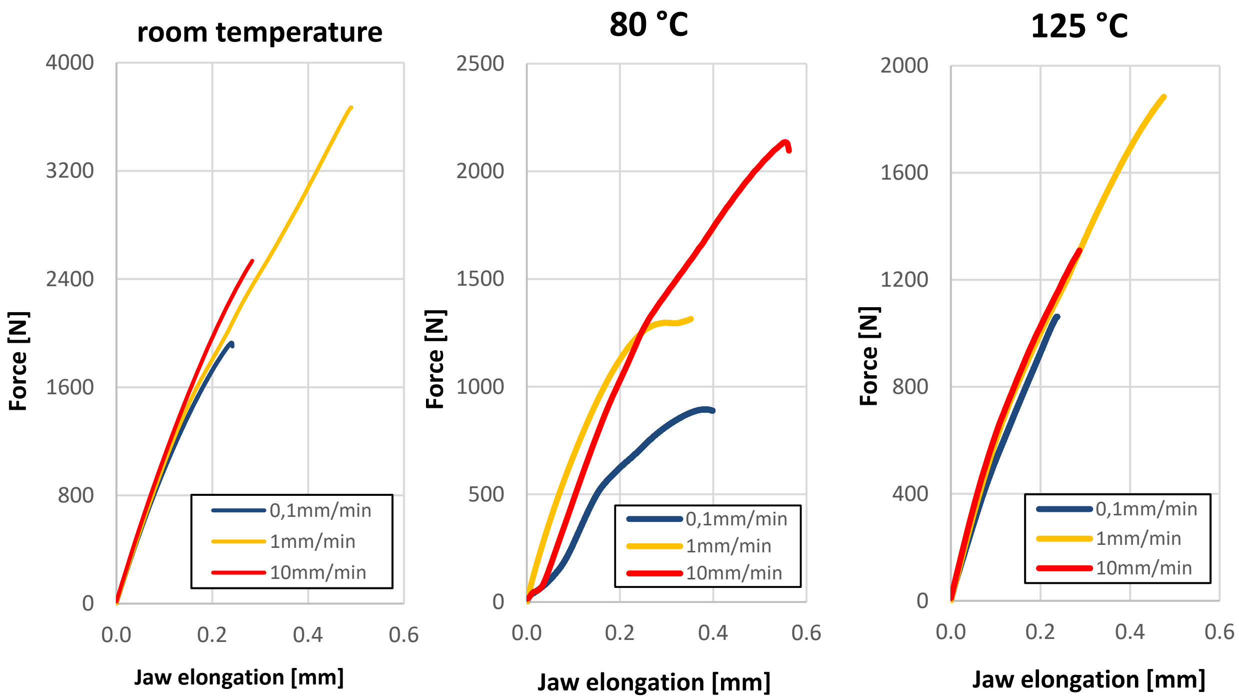

Fig.9 tensile tests records

Torsion tests were driven by shear deformation. These tests were done only for room temperature and for three crosshead speeds: 0.1°/s, 0.5°/s and 1°/s. Records from these tests are presented in the figure 10.

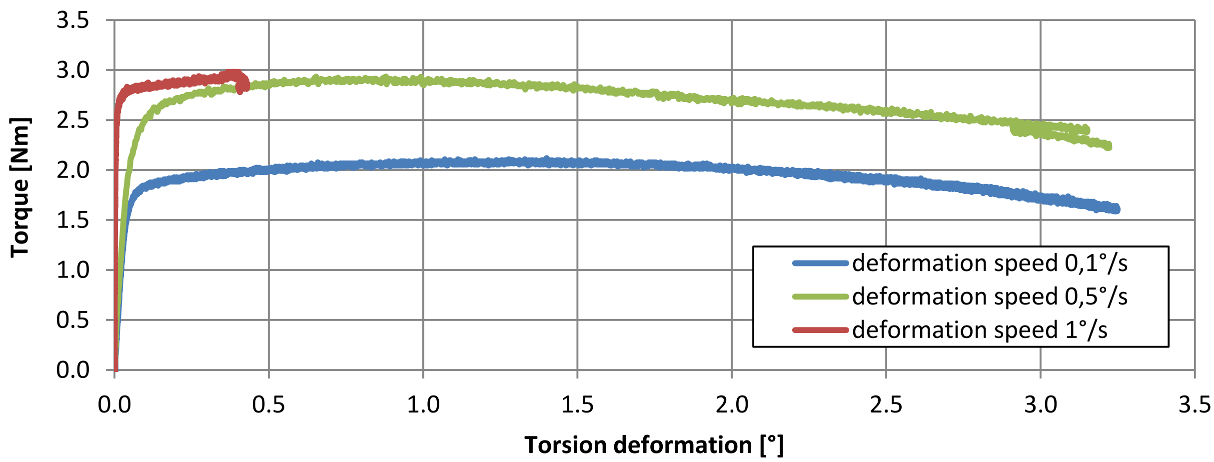

Fig.10 torsion tests records

In the case of creep testing, the loading force was set to 700N. This test was performed for two different temperatures 80°C and 125°C, see figure 11.

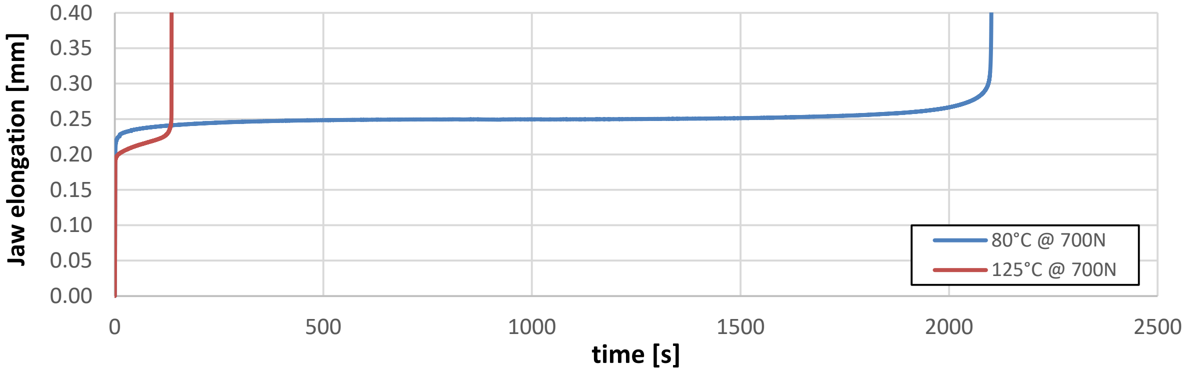

Fig.11 creep tests records

Conclusions

Measurements in tension, torsion and creep shows that behaviour of Sn-3.5Ag-0.75Cu solder joint is rate and temperature dependent. In case of tension tests rate dependency has much smaller effect than the temperature influence. On the other hand, torsion tests show us great influence on crosshead speed, mainly between 0.1°/s and 0.5°/s. During creep, the solder joint behavior is again temperature dependent. These measurements are effected by presence of copper parts and also could be effected by micro bubbles inside of the solder joint. These bubbles are natural and influence the both material strength and number of cycles to failure in the case of cyclic loading. Study of cyclic loading will be published later after deep investigations. Data from these measurements will be used for calibration of a visco-plastic material model, which has been implemented into a finite element code covering strain rate influence as well as creep behaviour of lead free solder pastes.

Acknowledgement

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