

Creep Rates and Stress Relaxation for Micro-sized Lead-free Solder Joints

Summary

This Note describes a new method for the measurement of some materials properties of lead-free solders, in particular the creep rates and stress relaxation. Such data are essential for credible FEA modelling of the behaviour of the solder joint. A major concern is that lead-free solders do not behave in the same way as lead-containing solder under accelerated thermocycling testing conditions. In addition, the joint is in shear whereas creep data have traditionally been obtained under tensile conditions. The new test method overcomes these concerns, and is particularly relevant to the assessment of micro-sized solder joints assembled using new lead-free solders currently being widely introduced into the electronics manufacturing industry. Details of the test requirements, procedures and analysis are provided. The work previously reported (1) has been used as the basis for the comments and discussion, especially regarding understanding the relative importance of the primary, secondary and tertiary stages in the creep in lead-free solder joints.

Milos Dusek and Christopher Hunt

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1 Introduction

With the arrival of legislative restriction on the use of lead solders there is a need to be able to predict the performance of solder joints made using lead-free solders (note: solder joints are commonly found to be the weakest links in electronic assemblies) and this is often achieved using FEA techniques. In turn these predictive techniques demand a credible knowledge of the materials properties of the lead-free solders, and/or suitable test procedures for obtaining them. Indeed the biggest factor in determining an FEA model's accuracy is the quality of the materials data it uses.

A major concern is that lead-free solder does not behave in the same way as lead-containing solder under accelerated thermocycling test conditions. This is complicated by the ever decreasing volume of solder used in electronics interconnection, for which materials data obtained on bulk samples are inappropriate or even misleading (2). Therefore, any test procedure must reflect the size of solder joints used in modern assemblies. The geometrical

orientation of the component and substrate mean that these strains (due to localised CTE mismatches – Figure 1) are essentially acting in shear, and this must also be reflected in any test procedure. Consequently, recent work has focused on designing a test method suitable for generating the required materials data on lead-free solder joints with geometries and dimensions mirroring those used in current assembly technology.

This Note describes a new method for the measurement of some of these materials properties of lead-free solders, in particular the creep rates and stress relaxation. The method is particularly relevant to the assessment of micro-sized solder joints assembled using new lead-free solders currently being widely introduced into the electronics manufacturing industry, and the test procedures and test requirements are detailed. The previous work (1) has been used as the basis for the comments and discussion, especially regarding understanding the relative importance of the primary, secondary and tertiary stages in the creep in lead-free solder joints.

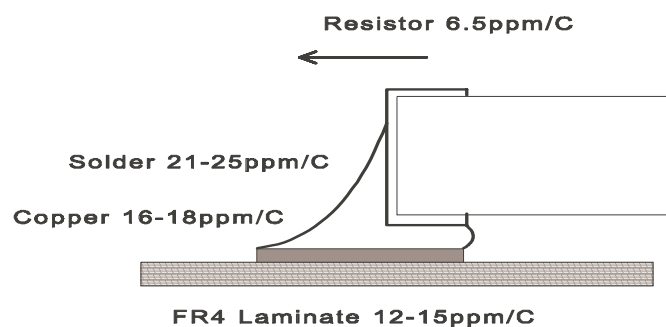


Figure 1: Schematic cross-section of a SM assembly highlighting the CTE mismatches

2 Test Procedures

The test procedure to generate the required materials data on micro-sized joints is essentially straight forward, using a purpose-designed test specimen, mounted in suitable force test equipment. The test specimen is then extended in a simple displacement mode to assess the short-term strength stress of the solder. It is subjected to increasing strain and the resultant stress is monitored via a load cell at various temperatures. The results are analysed in terms of the stress-strain curves, to provide the required material data for both lead-free and lead-containing solder joints.

Metallographic micro-sectioning can readily be undertaken to provide complementary data regarding the microstructure etc. The micro-sections can be conveniently examined optically and/or in a scanning electron microscope.

3 Test Requirements

Test Equipment: the equipment should be capable of applying a wide range of thermal and mechanical loading to the test specimen and monitoring the creep performance of the solder by measuring the resultant strain. One force machine suitable as test equipment is

the ETMT (electro-thermo-mechanical tester) designed at NPL and marketed by Instron Corp. as ETMT Mark 2.

Test Specimen: a purpose-designed test piece is required that can be loaded in tension on the axis of a force machine, such that the solder joint within the specimen (see Figure 2) experiences essentially shear forces. A test piece can be fabricated from a copper bar of dimensions length 43 mm, height 6 mm and thickness 2 mm. The bar should be wire eroded (spark eroded) down the middle of the 6 mm side to within the final 3 mm and then cut using a diamond saw for the final 3 mm. The gap width being determined by the thickness of the diamond blade (typically ~0.21 mm wide). The final cut is made with a slow speed diamond saw to avoid impregnating any carbonaceous material that occurs with wire erosion. The gap should be filled with a solder paste, which may be either lead-free or lead-containing, and reflowed using a gas torch capable of fully reflowing the paste. Cutting the bar in this way ensures not only alignment of the solder joint, but also parallelism of the two copper halves of the joint. Other advantages are that the solder can be readily changed, and that the copper bar can be plated using conventional PCB fabrication processes.

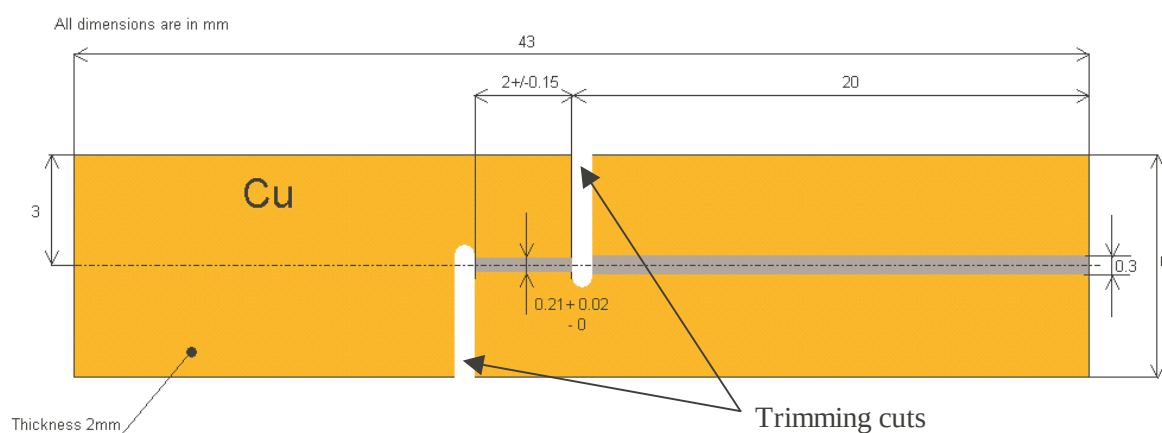


Figure 2. Test specimen for creep and stress relaxation testing

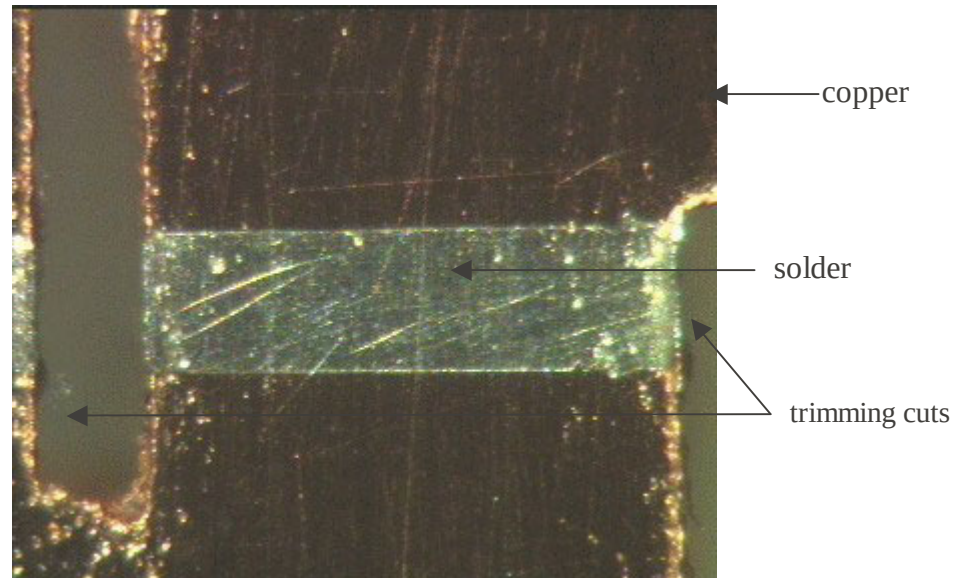


Figure 3. Detail of test specimen solder joint for mechanical testing in shear

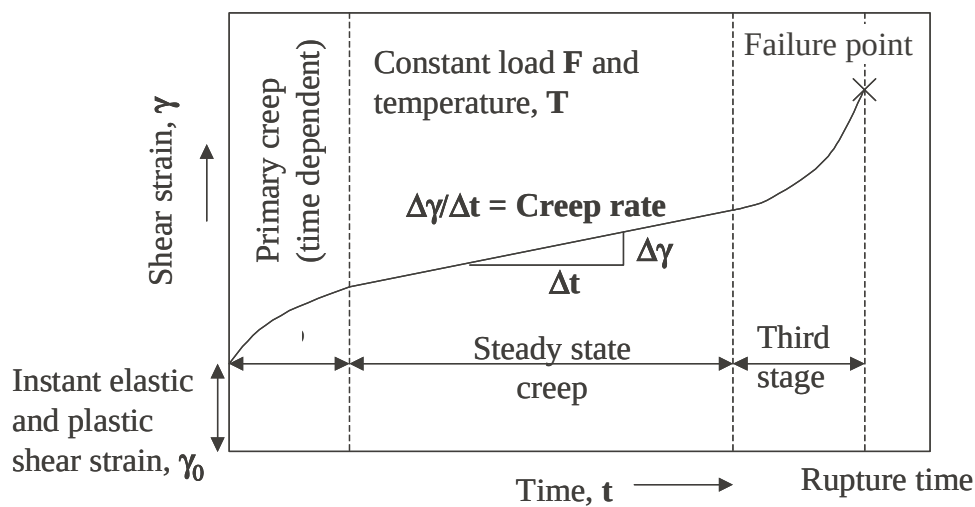


Figure 4. An idealised creep curve.

The size of the solder section to be tested is defined by two additional trimming cuts (see Figure 3). Thinner joints are possible using thinner diamond blades, or alternatively using thinner copper bars (e.g. as small as $1 \times 1 \times 0.15$ mm). That shear is the dominant mode in the solder joint of these test pieces, and that the resultant strain is uniformly distributed through the solder and not in the copper, have

been confirmed using FEA analyses (1). If required, the test specimen should be kept at constant temperature to stop thermal expansion of Cu. In addition, if appropriate, the joint face can be appropriately polished, permitting observation of the developing microstructure using a microscope and camera system, as the test proceeds.

4 Creep Testing

Creep is a time-dependent plastic deformation measured as a function of applied load and temperature. The load can be applied either by simply hanging weights on a specimen or by a force machine with a load cell. The resulting strain can be measured locally (camera + image correlation) or by displacement sensors (3). The output of a creep test is a strain or strain rate (first time derivative) plotted as a function of time or load.

Creep tests are usually long-term experiments that may include all three stages of creep - primary, secondary (steady) and tertiary (third) creep – see Figure 4 – and creep data have been the corner stone of FEA modelling in the past with SnPb solder. However, traditionally, primary creep has played only a very minor role, and creep data have specifically referred to secondary creep, in which the creep rate is constant at fixed temperature and stress, and primary creep is essentially overlooked. But recent work (1) has demonstrated that lead-free solders reveal differences in primary creep to that of SnPb, which typically has negligible primary creep. In the case of SnAgCu alloys at shear stresses of larger than 20MPa, there is significant primary creep, which must be taken into account in any modelling of lead-free solder fatigue. Hence the full isothermal creep rate characteristic is unknown in lead-free solders and constitutes a significant gap in our knowledge of lead-free material properties.

Moreover, which alloy creeps faster depends on the applied stress (1), indicating different deformation processes are operative in lead-free and lead-containing solders. Below 20MPa of shear stress SnPb solder creeps faster than lead-free counterparts, but above this stress SnPb creeps slower than SnAg or SnAgCu at room temperature.

It follows that isothermal creep testing is not wholly an appropriate method of generating lead-free solder material data from micro-sized joints. In addition, the previous work (1)

has demonstrated that stress relaxation measurement after reaching a certain strain (instantaneously applied) gives a better estimate of solder resistance against a load.

5 Stress Relaxation

During accelerated testing low cycle fatigue of solder takes place. An accelerated testing regime is typically thermocycling (4) or power cycling, during which stress is accumulated due to localised CTE material mismatches. The relatively weak solder joints are the most compliant materials in the assembly, and hence stresses accumulated due to the localised CTE mismatches (i.e. between components and substrate) are relieved by the solder. This scenario is different to that in creep testing where a constant load is applied. In this case an instantaneous and fixed strain is applied, which is more representative of thermal cycling in which the CTE mismatch applies a fixed elongation.

To measure the stress relaxation rate, a nominal stress is applied to a test piece by displacing it a certain distance in a force machine. This displacement is then maintained while monitoring the load. The previous work (1) illustrated that the relaxation rate depends on the initial strain and is different for each alloy type. Example comparative room temperature data are recorded in Figure 5 for the stress relaxation of three solder materials for a displacement of 0.06 shear strain, typical of that for 2512-type resistor joints. A shear strain of 0.03 would be typical of that for 1206-type resistor components. The stress relaxation is expressed as normalised stress (%) equal to the actual stress as a ratio of the nominal stress, and any differences in the behaviours of the three solders can be readily highlighted.

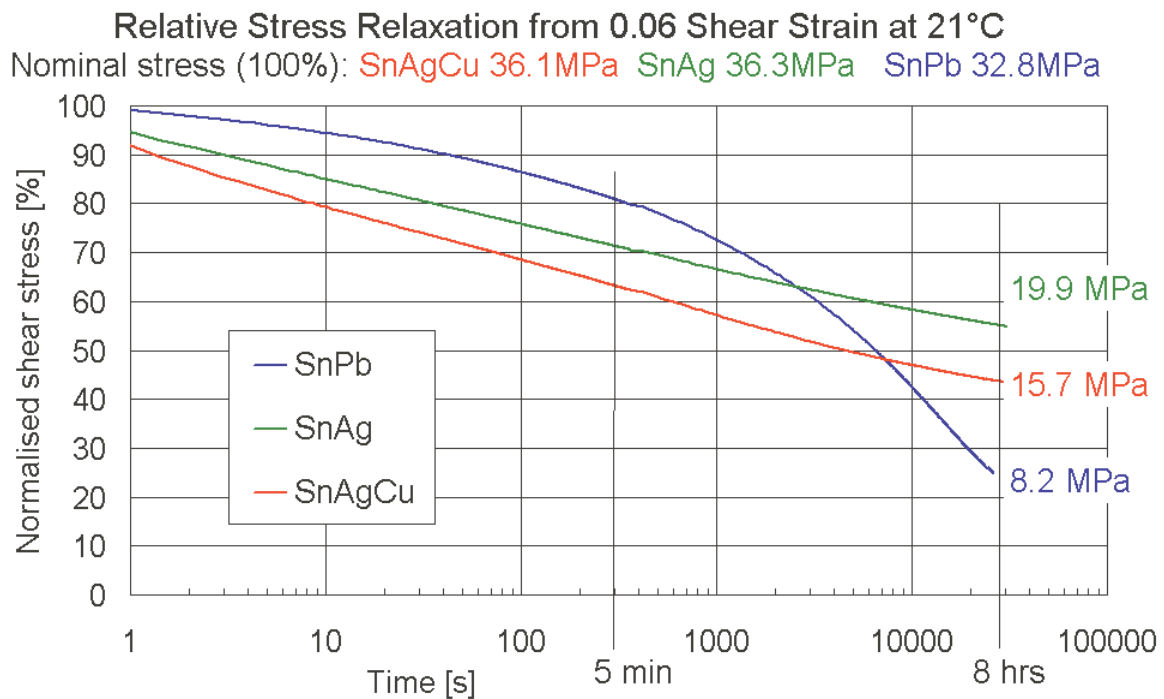


Figure 5. Stress relaxation from 0.06 shear strain for 3 alloys

SnAgCu	Initial nominal stress	36.1 MPa	Actual stress after 8 hrs	15.7 MPa
SnAg	" " "	36.6 MPa	" " " "	19.9 MPa
SnPb	" " "	32.8 MPa	" " " "	8.2 MPa

Hence measurement of stress relaxation offers an attractive technique not only for acquiring relevant materials data that are sensitive to primary creep, but also of highlighting differences in behaviour between different solder materials. Moreover, measuring the stress after the instant application, and maintenance, of a constant strain does provide data relevant to

the scenario of thermal cycling. The relaxation test has the added advantage that the test time is relatively short when compared to creep testing, and hence mimics more closely the excursions occurring in a thermal cycle. ***Stress relaxation data are therefore key to future FEA modelling of lead-free solders.***

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For further information contact:

Milos Dusek
 Engineering and Process Control Division
 National Physical Laboratory
 Hampton Road, Teddington, Middlesex, TW11 0LW
 Telephone: 020 8977 3222 (switchboard)
 Direct Line: 020 8943 6263
 Facsimile: 020 8943 6453
 E-mail: milos.dusek@npl.co.uk

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