

**A Review of Mechanical
Test Method Standards
for Lead-Free Solders**

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and Christopher Hunt**

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by

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ABSTRACT

Reviews have been undertaken of mechanical test standards appropriate for electronic solders, and of the credibility of available materials properties of lead-free solders. No test methods specific to solders were located. Moreover, the test methods identified were applicable to bulk samples, not to small solder joints. Further, they were conducted under conditions of tension or compression, but not under shear as would be the case in actual solder joints. The review also highlighted the difficulty of comparing mechanical properties data quoted in the literature. This difficulty stems from the lack of information given on test methods used, and on the experimental conditions employed (strain rates, sample size, sample geometry, test temperatures etc). A number of alternative mechanical test methods have been identified. It is recommended that materials property data acquired using these alternatives test methods should be benchmarked against those from standard thermal cycling tests. Such a benchmarking would provide the industry with a definitive test method with the twin advantages of being directly applicable to small solder joints and of enabling credible materials properties data to be generated for lead-free solders.

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Approved on behalf of Managing Director, NPL, by Dr C Lea,
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1. Introduction

The electronics industry worldwide has begun the move to eliminate lead from its manufacturing processes. Many Japanese companies, such as Fujitsu, Hitachi, Matsushita, Mitusbishi, NEC, NTT, Sony and Toshiba have active Pb reduction programmes, many with the aim on being Pb-free by 2002. These policies are being driven largely by consumer preferences for environmentally friendly products in their home markets. End-users also have an eye to their European markets where impending European legislation in the form of the WEEE (Waste of Electronic and Electrical Equipment) Directive and the ROHS (Restrictions On the Use of Certain Hazardous Substances in Electronic and Electrical Equipment) Directive is leading Europe into a complete ban on the use or disposal of lead in most electronics manufacturing industries by 2007 (currently). Many observers would not be surprised to see this timescale foreshortened.

The industry has already made great strides towards finding alternative alloys for conventional solder (SnPb) and for Pb-containing printed circuit boards finishes, and is beginning to address alternative component finishes. The alternatives proposed to replace SnPb solders, are generally new alloys, which have not previously been widely used within the electronics industry or any other industry. Hence, little knowledge is available on their performance as engineering materials. This concerns many users who consider that 60 years of experience of using solder to make electrical interconnections and 2000 years experience of using it as a joining material, are being consigned to the waste bin. It cannot be said they are being consigned to the recycle bin, as the use of lead-containing solders is unlikely to be sanctioned in many mass markets for the foreseeable future, and therefore widespread reuse of this valuable information resource is not currently anticipated in the electronics industry.

Although high reliability electronic markets such as military and aerospace are not currently mentioned in WEEE or ROHS Directives, the loss of the majority of the manufacturing marketplace to lead-containing products will lead to a dearth of product development for lead-containing interconnection materials. Many high reliability users may feel forced to change to lead-free materials to ensure continuity of supply and up-to-date materials development. They, along with manufacturers of equipment listed under these Directives, are now concerned whether these new alloys are as reliable as the baseline SnPb alloys. Until such data are widely available and understood, the introduction of many products incorporating these alloys will be delayed with the corresponding economic impact on UK industry, particularly if industries in other parts of the globe gain commercial advantage through earlier introduction of lead-free products.

To address these concerns many research projects are now underway to determine the mechanical properties and potential field reliability of these new solders. Many suppliers of these materials quote materials properties such as shear strength, tensile strength and Young's modulus, but the test methods are rarely if ever quoted. In a review of the materials data published by six manufacturers on the internet, none of them quoted the test methods utilised to obtain the data.

Many researchers have already shown that manufacturing of assemblies using new lead-free alloys is perfectly feasible although the cost of introducing such alternatives will not be negligible (Ref 1) and the long term effects on both component and solder joint reliability are

still debated. It is this latter concern, which is exercising many within the industry at present and initiated this review of mechanical test methods.

2. Review of Test Standards

A search of National and International standards (ASTM, ISO, IEC, & BSI) relating to measurement of the mechanical properties of non-ferrous materials was undertaken. No specific standards relating to solder were located. The only standards located were general standards appropriate to all non-ferrous metals.

2.1. Bulk Material Test Standards

The standards located refer mostly to tensile testing of bulk material samples in the form of cast or machined test pieces (ref 2, 3, 16 & 19). These samples are typically "dumbbell" type specimens (as shown in Figure 1) with a diameter in the range of 4 to 15mm and gauge lengths (L_o in Figure 1) in the order of 20 to 70 mm. The cross-section of the specimens can be circular or rectangular and tolerances are typically given for both. Samples may be machined, cast or prepared from tubes, wire, rod, sheet or strip.

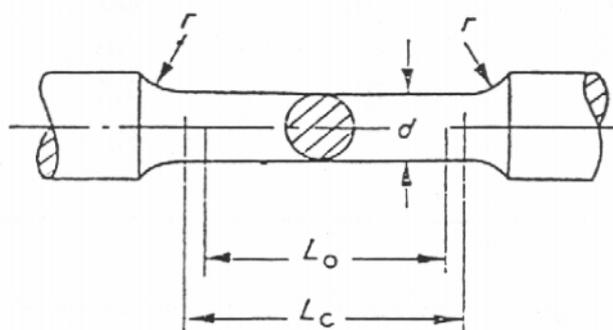


Figure 1: Typical "dumbbell" test specimen (from BS4 A4)

Similar standards are available for compression testing (Ref. 17 & 18). Here the samples generally have a simple cylindrical shape, or rectangular cross-section. Typical diameters of samples are in the range 13 to 30mm.

It should be born in mind that bulk materials properties generated by these specimens may be used in analysis of solder joints. However, such joints can be as small as 0.5 x 0.5mm, a cross section approximately 1000 times smaller than that of a typical cross-section from a dumbbell test specimen.

Being general standards appropriate to testing of any non-ferrous metal, recommendations on measuring and controlling such aspects of the test as strain rate, temperature, sample attachment etc, are given, but no suitable values for solders are recommended.

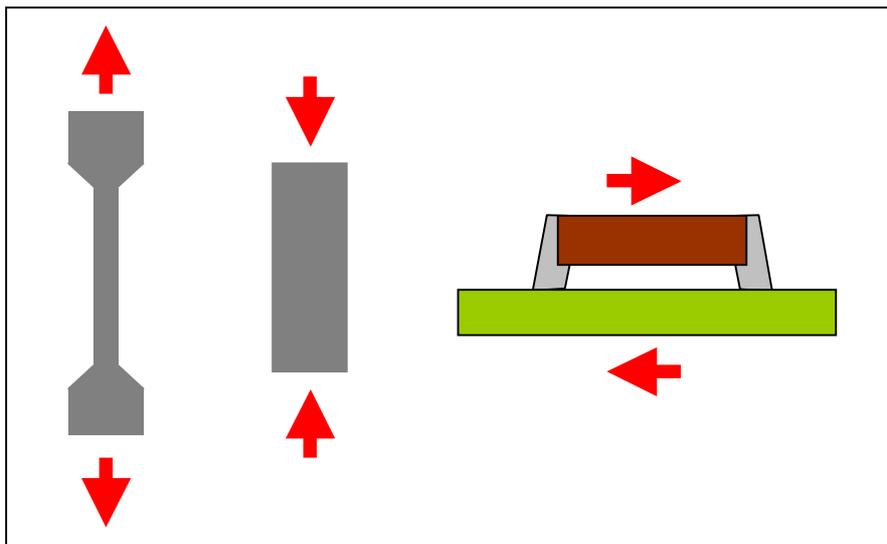


Figure 2: Typical stresses on (from left to right) tensile test specimen, compressive test specimen and SM solder joint in shear

It should also be noted that the stresses acting on these bulk test samples are significantly different from those experienced by a typical surface mount solder joint, which are normally single lap joints with an associated fillet. Figure 2 shows the typical stresses acting on a tensile test specimen, a compressive test specimen and a surface mount solder joint. The forces on the solder joint are predominantly in shear and can be caused by differential thermal expansion (see section 4.2 below), PCB flexure or mechanical shock due to drops etc.

The standards located are generally designed for use with materials that are used at a temperature significantly below their melting points. This is not the case with solder, which at room temperature is already very close to its melting point. The effects of this are described in Section 4.0 below. Standards are available which are designed to measure higher temperature performance which are perhaps more appropriate to the use of solder at or around room temperature (Ref 6). However, again no specific standards or recommended test parameters for solder were found and the standards were for bulk materials samples similar to those described above. Again, recommendations on measuring and controlling such aspects of the test as strain rate, temperature, sample attachment etc are given but no suitable values for solders are recommended.

2.2. *Joint Test Structure Standards*

No standards relevant to the mechanical testing of soldered joints or other non-ferrous metal joints were identified.

3. **Review of Pb-free Materials Properties Data**

In 1999, NPL undertook a brief review of materials property data available in the public domain. Five lead-free solder alloys were chosen (Sn3.5Ag, Sn0.7Cu, Sn3.8Ag0.7Cu, SnAgCuSb and Sn9Zn). All were potential SnPb replacements at the time. Similar data was

also collected for Sn40Pb and Sn37Pb. A synopsis of these data were subsequently published on the NPL web site and is reproduced here as Table 1 below.

Table 1: Historical Comparison of Materials Property Data for Lead-free Solders, 1999

Physical Properties	Sn63/Pb37 60Sn/40Pb	Sn96.5/ Ag3.5	Sn99.3/ Cu0.7	95.5Sn/ 3.8Ag/ 0.7Cu	Sn/Ag/ Cu/Sb	Sn91/ Zn9
Melting Point [°C]	183 (Ref.8) 183-188 (Ref.10)	221 (Ref.8) (Ref.12)	227 (Ref.8) (Ref.10)	217 (Ref.8)		199 (Ref.12)
Electrical Conductivity %IACS	11.9 (Ref.8) 11.5 (Ref.13)	14 (Ref.8) (Ref.13)	13 (Ref.10) (Ref.13)	13 (Ref.8)		
Electrical Conductivity [MS/m]					8.25 (Ref.11)	
Electrical Resistivity [μΩ.cm]	14.5 (Ref.8) 14.5 (Ref.11)	12.3 (Ref.8)		13 (Ref.8)	12.1 (Ref.11)	
Brinell Hardness HB	17 (Ref.8)	15 (Ref.8)		15 (Ref.8)		
Rockwell Hardness	10.08(Ref.11)	12.2 (Ref.11)			18.28(Ref.11)	
Vickers Hardness [HV]	12.8 (Ref.12)	16.5 (Ref.12)				
Density [g/mm ³]	8.4 (Ref.8) 8.52 (Ref.10)	7.5 (Ref.8) 7.29 (Ref.13)	7.3 (Ref.8) (Ref.10)	7.5 (Ref.8)		
Tensile Strength [N/mm ² at 0.004/s strain rate, 20°C]	40 (Ref.8)	58 (Ref.8)		48 (Ref.8)		
Tensile UTS [ksi]	4.92 (Ref.9)	5.91 (Ref.11)			5.73 (Ref.9) 5.56 (Ref.11)	
Tensile Strength [MPa]	45.1 (Ref.12)	61.4 (Ref.12)				21.3 (Ref.12)
Tensile Yield Strength [ksi]	4.38 (Ref.9)	4.07 (Ref.11)			4.86 (Ref.9) 4.03 (Ref.11)	
Shear Strength [MPa]	48.4 (Ref.12)	37.8 (Ref.12)				48.8 (Ref.12)
Joint shear strength [N/mm ² at 0.1mm/min, 20°C]	23 (Ref.8)	27 (Ref.8)	23 (Ref.8)	27 (Ref.8)		
Joint shear strength [N/mm ² at 0.1mm/min, 100°C]	14 (Ref.8)	17 (Ref.8)	16(Ref.8)	17 (Ref.8)		
Cu TH joint shear strength [N/mm ² , 20°C]	37(Ref.10)		28(Ref.10)			
Cu TH joint shear strength [N/mm ² , 100°C]	21(Ref.10)		22(Ref.10)			
Cu TH joint stress to rupture at 5N/mm ² , 20°C [hours]	4300(Ref.10)		500(Ref.10)			
Cu TH joint stress to rupture at 2N/mm ² , 100°C [hours]	1460(Ref.10)		<50 (Ref.10)			
Cu TH joint mechanical fatigue cycles (est.) [+/- 15N/mm ² , 20°C]	1100 (Ref.10)		1500 (Ref.10)			
Cu TH joint mechanical fatigue, cycles (est.) [+/- 10N/mm ² , 100°C]	900 (Ref.10)		1350 (Ref.10)			
Creep Strength (Shear)	3.3 (Ref.8)	13.7 (Ref.8)	8.6 (Ref.8)	13.0 (Ref.8)		

Physical Properties	Sn63/Pb37 60Sn/40Pb	Sn96.5/ Ag3.5	Sn99.3/ Cu0.7	95.5Sn/ 3.8Ag/ 0.7Cu	Sn/Ag/ Cu/Sb	Sn91/ Zn9
stress for 1000 hours to failure) [N/mm ² , 20°C]						
Creep Strength (Shear stress for 1000 hours to failure) [N/mm ² , 100°C]	1.0 (Ref.8)	5.0 (Ref.8)	2.1 (Ref.8)	5.0 (Ref.8)		
Tensile Youngs Modulus E [msi]	4.87 (Ref.9)	5.74 (Ref.11)			7.42 (Ref.9) 4.30 (Ref.11)	
Elastic Modulus [ksi]	3.99 (Ref.9)				4.26 (Ref.9)	
Compressive Yield Strength [ksi]	4.52 (Ref.9)				4.33 (Ref.9)	
Compressive Yield Stress 0.2% strain [ksi]		4.84 (Ref.11)			4.53 (Ref.11)	
Compressive Stress [ksi]	7.17 (Ref.9)				8.54 (Ref.9)	
Compressive Stress @25% strain []		9.88 (Ref.11)			10.07 (Ref.11)	
Thermal Coefficient of Expansion [ppm/K]	16.8 (Ref.12)	30.2 (Ref.12)				23.9 (Ref.12)
Thermal Conductivity [W/mK]	57.9 (Ref.13)	55.3 (Ref.13)				
Surface Tension [N/m]	0.49 (Ref.13)	0.48 (Ref.13)				

3.1. Discussion of Pb-free Materials Properties Data Collected

Even in the limited number of references reviewed, 27 different physical properties were identified. Many of these properties were only quoted by a single source and no standard test methods were quoted. Materials data were quoted in both metric and imperial units and usually no strain rates, size or geometry of samples, types of sample pre-conditioning or test temperatures were given for any of the quoted values. Also some quoted properties such as hardness that are of little use to engineers working in this field, as they have little bearing on the performance of solders in field reliability.

The diverse nature of the properties quoted, the lack of information about the conditions under which the tests were undertaken and the complete absence of any quoted standards makes any comparison of data at best problematic and at worst misleading.

4. Review of Commercially Quoted Mechanical Properties Data on Lead-Free Solders :

A brief review of current commercial suppliers' web sites was undertaken. Of the six major suppliers reviewed, four provided some mechanical properties data on the lead-free solder alloys they offered. However, none of these described the test methods by which the data were collected. Also the type of data quoted varied considerably between suppliers. A summary of the data reviewed is given in Table 2.

Of the 21 quoted examples of materials property data in Table 2, only one example (% Elongation) was quoted by more than one manufacturer. In addition, no standard test methods were quoted, and materials data were again provided in both metric and imperial units. Once again, no strain rates, types of sample pre-conditioning, or sample size or geometry were given for any of the quoted values.

Again, the diverse nature of the properties quoted, the lack of information about the conditions under which the tests were undertaken and the complete absence of any quoted standards makes any comparison of data at best problematic.

Table 2: Comparison of Materials Property Data Quoted by Solder Suppliers

Materials Properties	AIM	Almit	Alpha	Indium	Kester	Multicore
Tensile UTS (ksi)	<input checked="" type="checkbox"/>					
Tensile Strength (PSI)				<input checked="" type="checkbox"/>		
Tensile Strength (Nmm ⁻²)		<input checked="" type="checkbox"/>				
Tensile Strength, 20°C Nmm ⁻² at 0.004s ⁻¹ strain rate						<input checked="" type="checkbox"/>
Tensile Yield Strength (ksi)	<input checked="" type="checkbox"/>					
Young's Module (sic) (GPa)		<input checked="" type="checkbox"/>				
Tensile Young's Modulus E (msi)	<input checked="" type="checkbox"/>					
Tensile % Elongation	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>				
Compressive Elastic Modulus (msi)	<input checked="" type="checkbox"/>					
Compressive Yield Strength (ksi)	<input checked="" type="checkbox"/>					
Compressive Stress @ 25% Strain (ksi)	<input checked="" type="checkbox"/>					
Shear Bond Holding Strength (PSI)				<input checked="" type="checkbox"/>		
Joint Shear Strength Nmm ⁻² at 0.1mm min ⁻¹ , 20°C						<input checked="" type="checkbox"/>
Joint Shear Strength Nmm ⁻² at 0.1mm min ⁻¹ , 20°C						<input checked="" type="checkbox"/>
Creep Strength Nmm ⁻² 20°C (shear stress for 10 ³ hours to failure)						<input checked="" type="checkbox"/>
Creep Strength Nmm ⁻² 100°C (shear stress for 10 ³ hours to failure)						<input checked="" type="checkbox"/>
Rockwell Hardness 15w	<input checked="" type="checkbox"/>					
Brinell Hardness (HB)						<input checked="" type="checkbox"/>
Hardness (HV)		<input checked="" type="checkbox"/>				

5. Concerns in Measuring Bulk Mechanical Properties of Tin-based Solders

The current favourites to replace SnPb solders in a lead-free electronics manufacturing process are all Sn-based alloys. The main contenders are ternary alloys with a composition around Sn3.5Ag0.7Cu or the binary alloys of Sn0.7Cu or Sn3.5Ag. Sn3.0Bi alloys are also being considered. All of these alloys have melting points below 250°C. In this respect the alternatives differ little from their predecessors and it is the proximity of these melting points to the working temperature of the alloys, which has a dominant effect on their mechanical characteristics.

This is because creep, the plastic deformation of a material that is subjected to a stress below its yield stress, can occur in materials which are about or above 2/3 their homologous temperature. The homologous temperature of a material is the ratio of its absolute temperature to its absolute melting temperature i.e. $T_h = T/T_m$, where temperatures are measured in Kelvin. Therefore a SnAgCu alloy melting at 217°C (490°K), already has an homologous temperature of 0.6 at normal room temperature, and any mechanical behaviour at elevated temperatures will be influenced significantly by creep behaviour. As many companies expect their products to withstand temperatures up to 100°C (and some companies even higher temperatures perhaps as high as 150°C), an homologous temperature of 2/3 can easily be achieved. Indeed, this has led one researcher in this area to coin the phrase “gas turbine laptop” (Ref 7) to indicate the elevated nature of the temperatures at which the solder is expected to perform even in the most benign of applications. Indeed, increasing the test temperature for SnAgCu from 25 to 150°C has been shown to reduce the ultimate tensile strength (UTS) by 50% (Ref 5).

In addition, the strain rate (the rate at which a sample's length is increased with time) at which tests are conducted can have a substantial effect on the solder's mechanical properties. Solders generally produce higher values for mechanical properties at faster strain rates, with SnPb being reported as usually more sensitive than the Pb-free alternatives (Ref 4). A decrease in strain rate from 10^{-3} to 10^{-5} s^{-1} has been shown to produce a 40% reduction in UTS (Ref 5).

Conditioning of the sample also has a significant effect on the mechanical performance of solders. Again because solders are so close to their melting points when used at or around room temperature, they will readily anneal, with microstructures recrystallising and coarsening. In addition, the cooling rate of the sample during casting will significantly affect microstructure with slow cooling rates generally producing finer grain structures and stronger specimens.

Thus if one wishes to acquire mechanical properties data for solders that are relevant for solder joints, one needs *to ensure that the specimen is manufactured and conditioned to produce a specimen as close to that of a typical solder joint as possible*. None of the standards located highlighted this and much of the data quoted in the open literature do not include information on these parameters. This makes comparison of apparently similar data from different sources very difficult.

Therefore, any standards appropriate to solder should reflect the fact that solder is being used at such a high homologous temperature, or at least the industry should decide on a set of suitable tests with appropriate parameter guidelines to enable inter-comparison of data.

5.1. *Relevance of Tests to Reliability Modelling*

The shortening of the required time-to-market of most electronics-based product in recent years, has led to the increased popularity of software reliability models based on finite element analysis. These models are usually a mixture of mathematical models with empirical adjustments based on experimental results. The models enable changes to be made in such parameters as joint geometry, alloy composition, thermal cycling temperature limits and hold

durations. By running the models with the changed parameters, the effect on the fatigue life of a product can be estimated.

However, some of these models are based on single values of such temperature dependent properties such as thermal coefficient of expansion (TCE) and elastic modulus. With the significant variation of these properties with temperature, many tests would be required to assemble a full matrix of the properties with changing external effects. Thus the accuracy of the models is highly dependent on the materials data and the validity of those data for the joint conditions to be modelled. If the preconditioning of the bulk sample is different to that which would be experienced in practice by the solder joint to be modelled, then the usefulness of the results from the model could be significantly compromised.

Many researchers are also unhappy about the use of bulk materials properties in models for systems which are designed to model data on the scale of solder joints. Such models using bulk materials properties do not take into account the effect of intermetallic layers at the interfaces of the joint, or any effects associated with stressing a joint, which may be only a limited number of grains in size.

5.2. *Relevance of Tests to Field Failure Modes*

The normal method of determining reliability of electronics solder joints is to thermally cycle assemblies between high temperatures (typically in the 100 to 125°C range) and sub-ambient temperatures (in the range -55 to 0°C). This test method is designed to put strain on solder joints because of the different thermal expansion coefficients (TCE) of the materials used in the manufacture of the assembly. A typical worst case is that of ceramic chip resistors on epoxy-glass printed circuit boards, as shown in Figure 3. The ceramic has a low TCE of around 6 ppm/°C whilst the substrate's TCE is considerably higher at around 16-20 ppm. The result is that the solder joints between the two materials are strained when the ambient temperature is increased since the PCB expands more than the component for a given temperature rise (Figure 4). This is particularly critical in surface mount assembly where the component is usually only connected to the substrate via a solder lap joint.

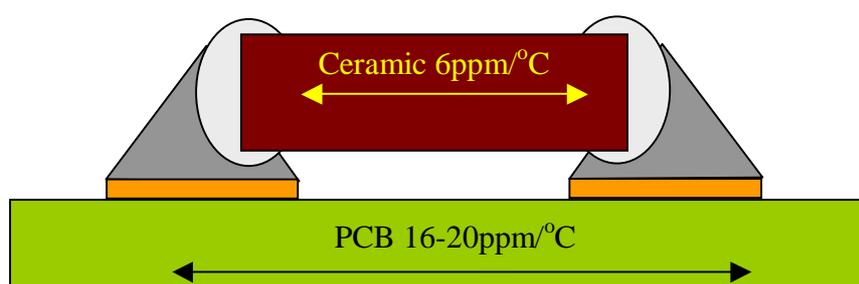


Figure 3: Differential expansion in surface mount assembly

As noted previously, strain rates can have a significant effect on the mechanical properties of solder. A typical strain rate encountered during thermal cycling of ceramic device on epoxy-glass substrate with a TCE mismatch of 14ppm, would be $4 \times 10^{-6} \text{ s}^{-1}$. This assumes a thermal cycle from -55°C to 125°C at a rate of change of temperature of 10°C/min, ($180 \times 14 \text{ ppm} / 10 \times 60 \text{ sec}$). To achieve this strain rate with a dumbbell test specimen with a gauge length of

50mm, would require a tensile testing machine with a crosshead movement rate of 0.00021mm/s and a test time to failure of around 115,000 seconds or 31 hours (based on Sn37Pb). Clearly multiple testing of different alloys would take considerable man-hours.



Resistor at zero strain (typically room temp.)



Resistor at positive temp. excursion



Resistor at negative temp. excursion

Figure 4: Effect of thermal excursion on solder joint strain

6. Alternative Mechanical Test Methods

The lack of relevance of bulk materials testing to the performance of electronics solder joints, has encouraged a number of end-users to develop tests to compare the mechanical performances of electronics assemblies.

6.1. *Lead Pull Testing*

Mechanical testing of leaded components can be undertaken using conventional tensile testing systems or specific pull testing equipment, often wire bond test systems with additional attachments. To undertake the tests, the body of the component has to be removed. This is generally undertaken by cutting through the lead below the knee with a miniature saw but has to be done with care to avoid damage to the lead or corresponding solder joint. The cut lead is then pulled upwards with the sample free to move in the horizontal axis to allow the pull force to remain along the axis of the lead. This is shown in Figure 5. The technique is

useful in comparing the relative strengths of different joint types, different alloys or different process parameters.

It should be noted that once again the stress acting on the solder joint is in tension and that generally failures of the joint result from tearing of the solder joint. Neither of these conditions are generally found in field failures. Additionally, the authors are unaware of any work which has linked lead pull strengths to field reliability or thermal cycling performance.

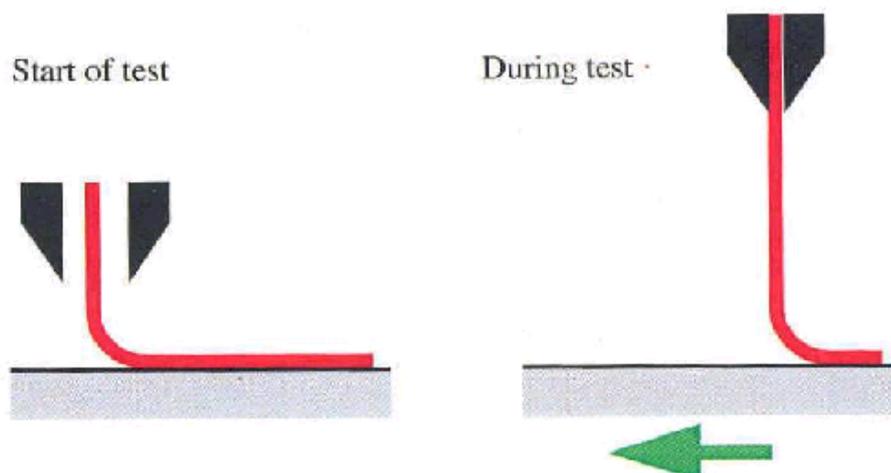


Figure 5: Shear testing of leaded components (source : Dage)

6.2. *Shear Testing*

Pull testing of leadless components is difficult because of the problems of gripping such components. Therefore shear testing is often undertaken by placing a tool along the long edge of a chip component and applying a force in a horizontal direction, parallel to the soldered ends of the component. Specialist equipment is available to undertake such tests. Shear testing of chip resistors is shown in Figure 6. As with pull testing, the technique is useful in comparing the relative strengths of different joint types, different alloys or different process parameters.

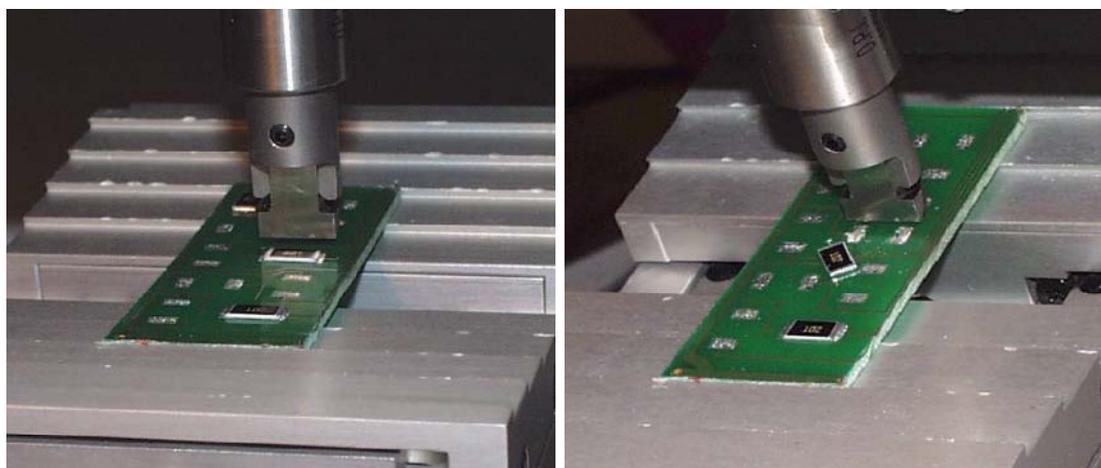


Figure 6: Shear testing of chip resistors

With this technique the stress acting on the solder joint is in shear, the same direction as that generally experienced in field failures of solder joints. However, the authors are unaware of any work which has linked shear strengths to field reliability or thermal cycling performance.

6.3. *Area Array Bend Testing*

Flexure, both to failure and to produce fatigue, has been used by some workers to stress both BGAs and flip chips (Ref 14 & 20). Generally single components are mounted onto PCBs or cut from production assemblies. In the case of 3-point bend testing, these components are then placed between three bars, two above the board on each side and one below the assembly in the centre beneath the component, as shown in Figure 7. The twin bars are then forced downwards to flex the PCB and stress the area array solder joints. With 4-point bending testing a mandrel is placed over the component and forced downwards against two support bars (Figure 8), producing a bend in the opposite direction to the 3-point bend test.

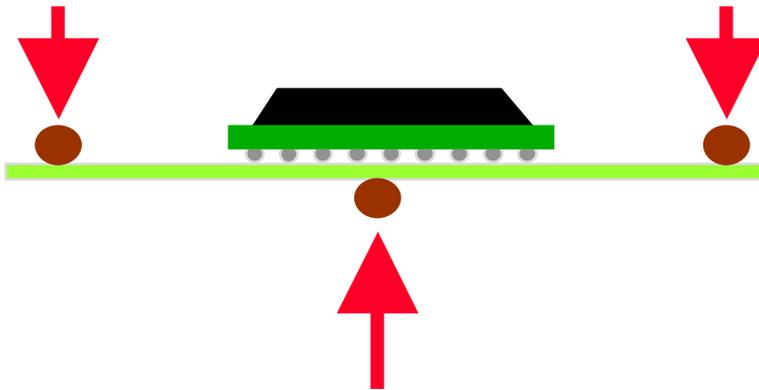


Figure 7: 3-point bend testing of area arrays

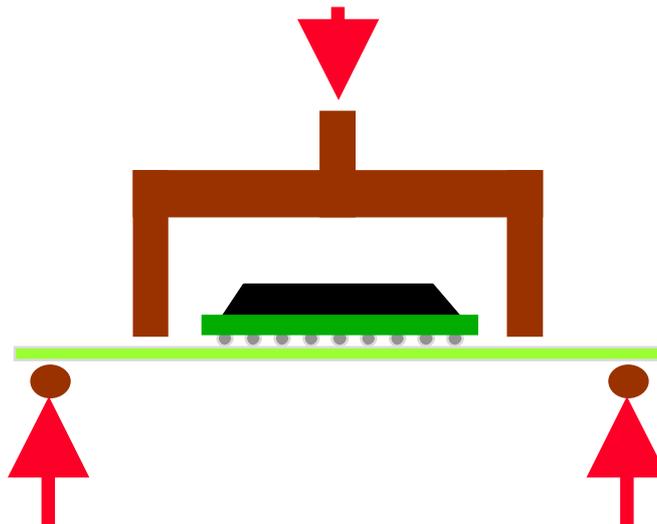


Figure 8: 4-point bend testing of area arrays

Either of these types of test can be undertaken repeatedly to generate fatigue type failures or undertaken once to the point of failure. Failure can be detected by monitoring the resistance of a daisy-chain incorporating the solder joints.

6.4. *Micro-Mechanical Joint Testing*

Work has been undertaken at the National Physical Laboratory to test small scale solder joint systems (Ref 15). In the tests, a specimen consisting of four lap joints is tested in shear. The specimen is manufactured from four small PCBs by placing solder paste onto copper pads on the PCB and reflowing in a conventional reflow oven. The test specimen is shown schematically in Figure 9. With this double lap joint arrangement, the deformation of the bonding material or solder follows relative-in-plane displacement of the bonded strip, which is comparable to that in real solder joints. This type of test specimen produces solder joints that are very similar in shape and size to real-life surface mount joints.



Figure 9: ETMT test specimen

The samples were tested in a small instrument: the Electro-Thermal Mechanical Test system (ETMT), which has been developed at NPL and is now commercially available. The ETMT machine comprises a mechanical loading assembly with a grip system suitable for small-scale samples and includes a load cell and linear displacement transducers (located either side of the sample). A computer controlled motor system is used for load application in the horizontal plane. Various types of tests can be conducted including strength tests, creep tests and thermo-mechanical fatigue (TMF) tests. A specimen, partially loaded into the equipment, is shown in Figure 10.

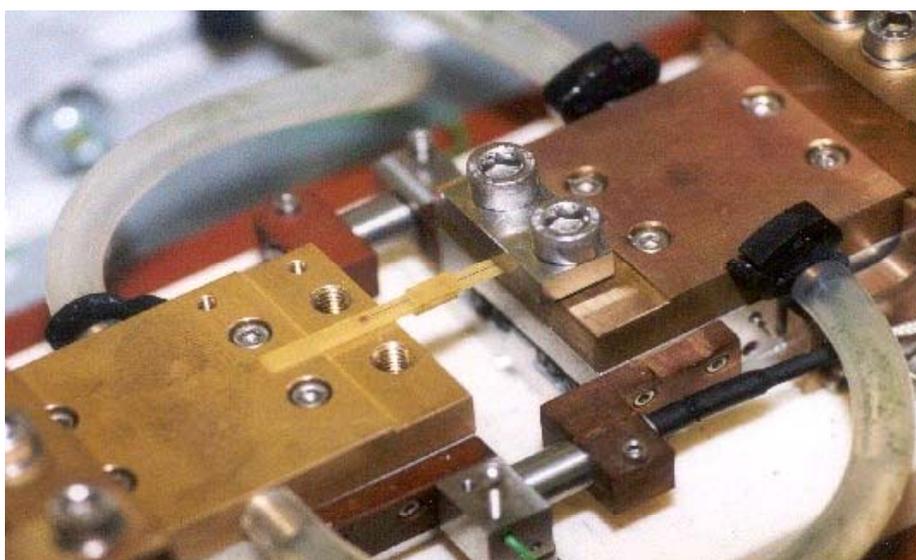


Figure 10: Test specimen partially loaded into ETMT equipment

Creep experiments at different temperatures and constant stresses have been carried out using this equipment. From the results obtained, displacement-time curves were plotted and analysed to calculate the creep properties. These data have been compared to literature data for bulk solder specimens, specifically, SnPb and SnAg. The comparison showed that measurable differences did exist between the alloys when measured by these different methods, and these differences have been directly attributed to the geometry of the different samples.

7. Discussion

This review has highlighted a number of critical areas associated with the mechanical properties of lead-free solder alloys. Considerable work, both practical and mathematical is currently being carried out to assess the suitability of these new alloys for their intended purpose in electronics manufacture. However, lack of standardisation is hampering cross community work.

The majority of currently available data is based on the testing of large samples of the alloys, predominantly in tension. Of the published data, there is very little information on the types of test used, strain rates utilised, size of sample, amount and type of preconditioning etc. Standards are rarely quoted. With solder so close to its melting point in everyday use, these parameters are critical to understanding and utilising the data. Additionally, the use of these data for modelling can lead to inaccuracies as the properties used in the modelling, can often be inappropriate to the task being modelled (i.e. tensile properties of bulk solder specimen for the reliability modelling of small chip resistor joints in shear during thermal cycling).

The lack of standards and the lack of a common set of test methods across the industry means that the comparison of data from alternative sources is, at best, very problematic and at worst impossible. Hence there are very few reference data for the industry to work on. It is true that this has always been the case, but for SnPb solders field experience has been built up with these alloys over sixty years. The industry is expected to archive all these data and build up a comparable set of data for Pb-free solders in less than a tenth that time. If the industry is to get anywhere close to achieving this, ***a set of industry standard test methods are required to generate a set of meaningful data, that can be utilised by the industry as a whole.*** If the industry continues to work on the problem in isolated groups, with little hope of inter-comparison of data, the task may prove impossible and large sections of industry may have to rely on “pot-luck” to choose an alloy that is fit for purpose for their products.

There are a number of test methods being explored which it is hoped will yield data that will enable meaningful comparisons of Pb-free alloys to be undertaken. The most promising of these is a test system developed by NPL utilising a set of symmetrical SM sized solder lap joints tested in shear and now commercially available. However, there is a need to generate much more data with this method and also with other appropriate methods. These data need to be compared with thermal cycling test results to enable a definitive test method (or methods) to be agreed that will give the industry confidence in implementing Pb-free technology.

8. Conclusions

- No test standards specific to solders were located
- There is significant difficulty in comparing quoted values of a variety of materials properties for a number of reasons
 - Test methods are not generally quoted
 - No strain rates are given
 - Sample size and geometry vary or are not quoted
 - Temperatures at which tests are conducted are not given
 - The lack of test methods and credible materials data are restricting useful modelling of solder joints.
- A number of alternative mechanical test methods are being investigated
- These alternative test methods should be benchmarked against thermal cycling to decide on a definitive test method that the industry can use to develop alternative Pb-free solder alloys.
- Suitable methods and credible materials property data will facilitate the modelling of solder joints to progress in a more meaningful way.

9. Acknowledgements

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