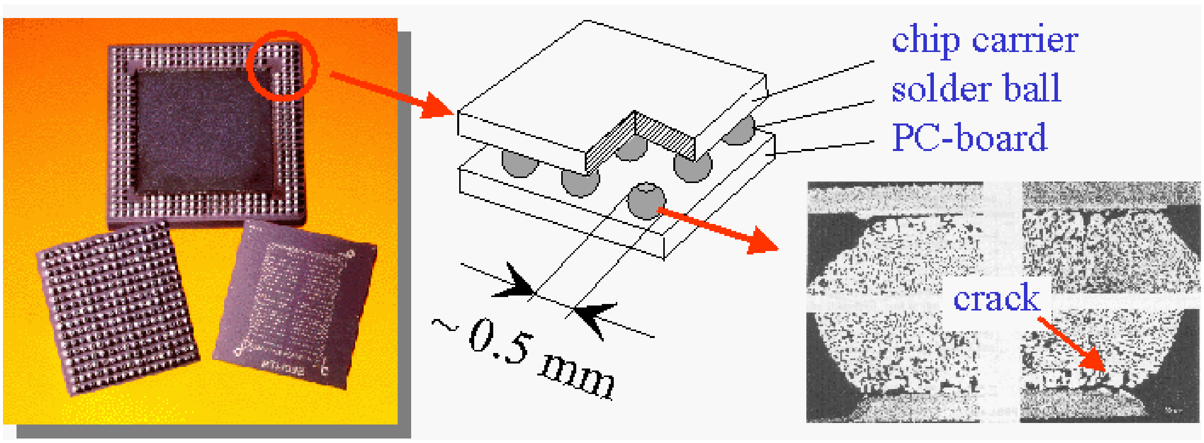
Miniature Specimen Testing

The Small Punch Test (SPT) has successfully been used in the US and in Japan to assess the material behavior of steels in nuclear reactor and pressure vessels as well as for in-service turbines. It is an efficient method to determine current mechanical properties if only small amounts of material are available. In fact, SPT miniature specimens are usually obtained by removing a small amount of material directly from the surface of in-service machinery, which leads to shorter outage times.

We use the SPT to determine the material properties of solders used for Surface Mount Technology applications both lead containing and lead free. SMT applications usually produce a considerable amount of heat, which leads to the development of thermal stresses within the whole package. The material behavior changes under these strong temperature loads. In particular, the solder used for joining the SMT package is critically affected under the combined action of advanced temperatures and thermo-mechanical loads. This will eventually result in damage of the solder joints:



SMT applications and the solder joints used therein

Conventional tensile tests, shear tests as well as thermal cycle tests are used to determine the critical stresses, strains and the number of load cycles necessary to initiate cracks within the solder balls. However, these methods do not provide detailed information regarding the change of crucial material parameters, which, for example, are necessary to know in order to perform computer simulations of the fatigue behavior of SMT structures. In order to assess the reliability and lifetime of a certain SMT design that involves solder materials the empirical equations such as the ones below are frequently used. Here σ_y denotes the yield stress, E is Young's modulus, ε_{pl} is the plastic strain and T is the temperature:

$$\sigma(T) = \sigma_y(T) + 0.05 \cdot E(T) \cdot \varepsilon_{pl}$$

,

$$\sigma_y(T) = (101.6 - 0.227 \cdot T) \cdot \frac{N}{mm^2}$$

,

$$E(T) = (61.1 - 0.04508 \cdot T) \cdot 10^3 \cdot \frac{N}{mm^2}$$

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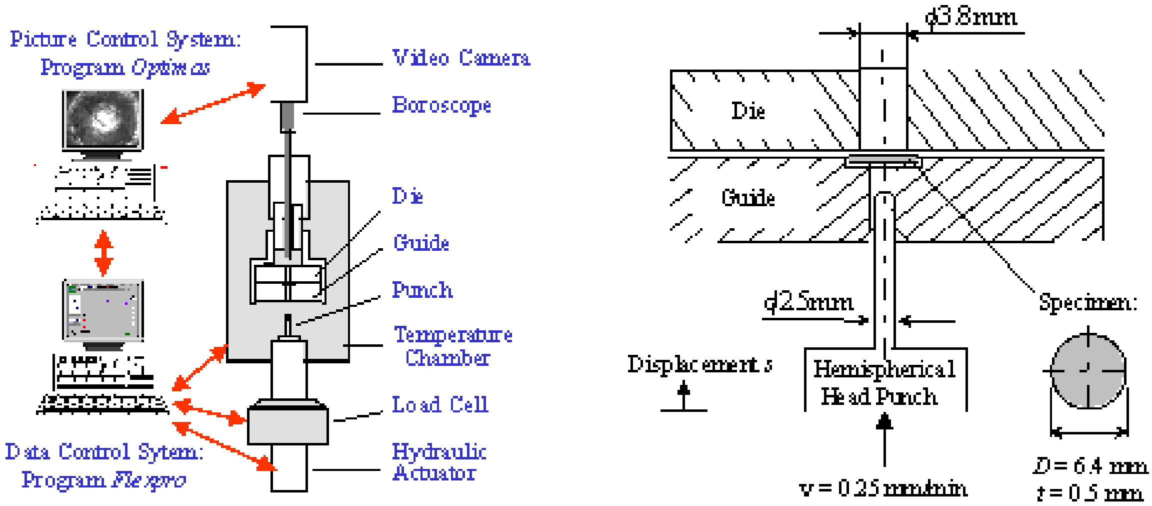
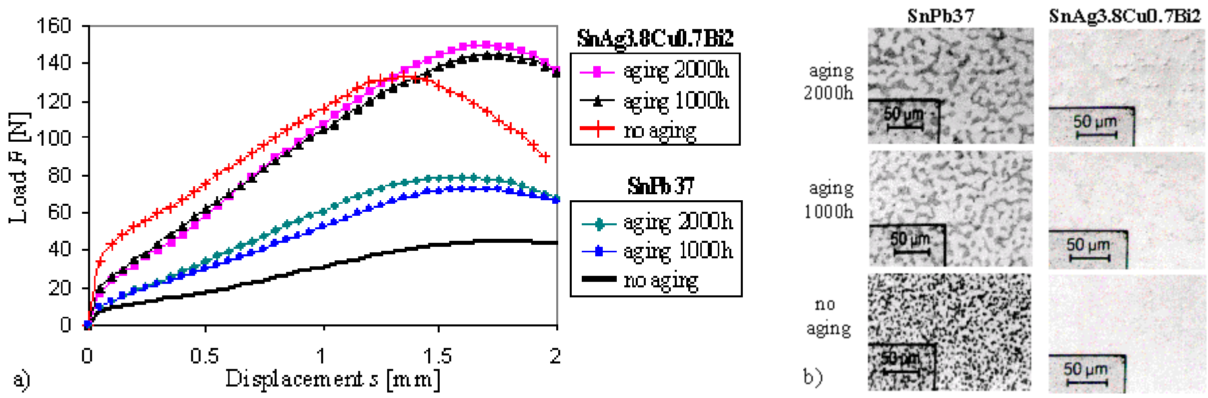
Calculated results are comparatively inaccurate as they refer to measurements obtained from bulk specimens and do not meet the specific requirements of small amounts of material. For a more accurate estimation of material properties of small volumes of testing material the small punch test is used.



SMT apparatus set-up

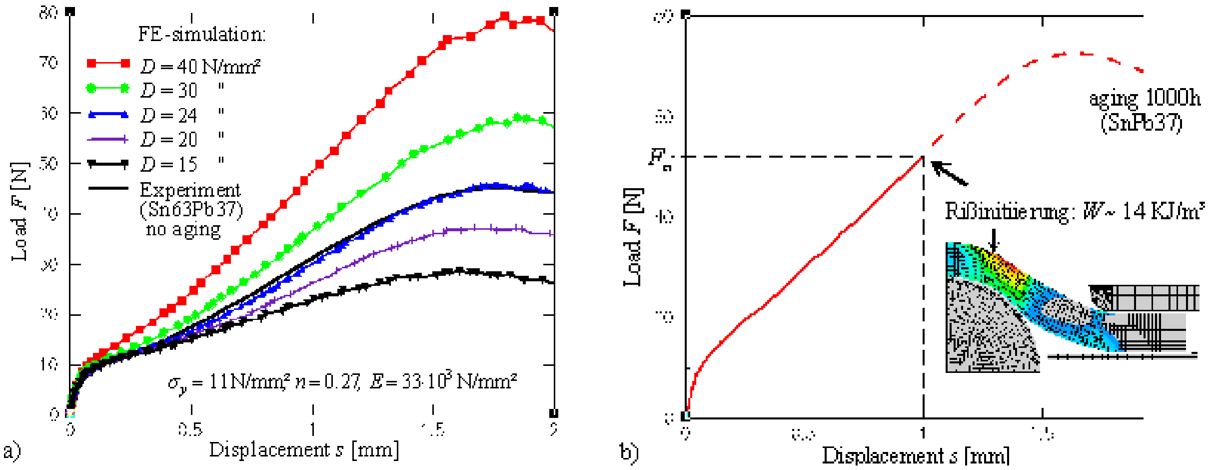


Typical load-displacement curve obtained and corresponding solder microstructures

The figure above presents the SPT apparatus. The specimen, the set of dies as well as the punch are located inside of a temperature chamber. A servo-hydraulic machine MTS203 is used for loading. Punch forces are measured by means of a 500 N load cell. A boroscope with a video camera positioned on the top enables monitoring of the upper surface of the specimen as well as allows detection of the position of the first crack initiation.

The experiment is then simulated on a workstation by means of the finite element program ABAQUS. An axi-symmetric model with four-node elements is used. Contact boundaries with a friction coefficient $\mu = 0.1$ are taken into account. The constitutive stress-strain model used is a Ramberg-Osgood power law. The behavior of the load-displacement curve is determined by four material parameters, Young´s modulus, E, the yield stress, σ_y, a reference stress, D, and the hardening coefficient, n:

$$\varepsilon = \frac{\sigma_y}{E} + \left(\frac{\sigma_y}{D}\right)^{\frac{1}{n}}$$



The procedure is iterative. The computation is repeated until the parameters provide the closest match to the experimental load-displacement curve. The table provides data for several tested solders.

In this field of research we collaborate with Dr. Albrecht from Siemens AG in Berlin, Professor K.P. Herrmann’s group at the Laboratorium für Technische Mechanik at the University of Paderborn in Paderborn/Germany, and Dr. J. Foulds, E^{x}ponent^{TM}, San Francisco.

Material parameter	No Ageing		High Temperature Storage 150°C			
			1000h		2000h	
	SnPb37	SnAg3.8Cu0.7Bi2	SnPb37	SnAg3.8Cu0.7Bi2	SnPb37	SnAg3.8u0.7Bi2
n	0.27	0.1	0.155	0.165	0.13	0.18
σ_y [N/mm²]	11	53	12	18	11	18
D [N/mm²]	24	67	35	69.5	38	73
E [N/mm²]	33×10^3	50×10^3	33×10^3	50×10^3	33×10^3	50×10^3

Determined parameters for SnPb37 and SnAg3.8Cu0.7