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Weibull Analysis of Soldered MLC under Bending Load Stress

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Abstract

A two-dimensional numerical model of MLCs is used to calculate the overall stress distribution of soldered and bent MLCs. Together with bending measurements the stress distribution leads to the Weibull parameters of three different MLC sizes. The material dependent Weibull parameters have been found to be different for each size. One possible reason under investigation are size related residual stresses due to manufacturing which are neglected in the simulation. Residual stress measurements have been carried out at the surface of three different MLC sizes near their terminations. Compressive stresses with high stress gradients were found near the terminations. These gradients may influence the accuracy of the measurement. The measured stresses are not constant from MLC size to MLC size and influences the determination of the Weibull parameters. The residual stresses influence the reliability of MLCs and should therefore be considered in future simulations. © 1999 Elsevier Science Limited. All rights reserved

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1 Introduction

Almost every electronic circuit makes use of capacitors. Ceramic multilayer capacitors (MLC) are very often used as surface mount devices. These devices are soldered leadless to the board. This advantage of compact circuits is paid for with relatively stiffly joined components. Therefore components may fail mechanically in case of board bending due to circuit integration or operation. A so called ‘flex test’ is often used to test the reliability of soldered capacitors under bending loads.[1] Other authors,[2,3] perform three point bending tests directly on MLCs to get the mean Modulus of Rupture (MOR) of different MLC types or sizes. These investigations lead to different mean strength values of MLCs depending on the internal structure, the microstructure, the size of the MLCs and on the dielectric type. Empirical models are introduced to predict the MOR of different MLCs based on the assumption of different microstructures and component size related flaw distribution. The influence of residual stresses on the component reliability is very often neglected or not discussed separately. Especially the superposition of residual and load stresses may have a severe influence on the reliability of ceramic-metal joints.[4]

In this paper the influence of residual stresses measured at the surface of X7R-MLCs on the component failure probability is discussed. Three different sizes of soldered MLCs have been fractured under four-point bending loads and are evaluated by the Finite Element Method in order to get the Weibull modulus and the characteristic strength of each series. The residual stresses near the terminations of one part of each series have also been measured. The influence of residual stresses on the characteristic strength of MLCs is investigated.

2 Experimental

Three different sizes (1206, 1210, and 1812) of $BaTiO_3$ based MLCs with X7R temperature characteristics have been investigated. The inner electrodes consist of approx. 30% Ag and 70% Pd which is related to the high sintering temperature of 1320°C. The terminations are composed of Ag, Ni, and Sn layers. Four-point bending measurements with 20 mm load and 40 mm support span have been performed on series of soldered MLCs for each type. The width of the board has been set to the width of the MLC. The Instron machine has been operating on $1\,mm\,s^{-1}$ and the load versus

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time has been recorded in order to define the fracture load. A sudden decrease in load has been interpreted as fracture ignition and the crack pattern has been investigated by microscopy. A typical crack starts at the board side of the component near the edge of the termination and runs under an angle into the termination cutting off some or all inner electrodes. The measured fracture moments are shown in Fig. 1.

The residual stresses at the surface of one unsoldered component of each type has been measured as well based on X-ray diffraction with psi-geometry. The stresses have been measured in the x direction at the x–z surface (Fig. 2). The X-ray beam is 0·1 mm wide (x direction) and reaches over the total width (z direction) of the component. The residual stresses for all three sizes are detected as near to the termination as possible. A minimum distance of 0·1 mm gives confidence for definite signal interpretation. The measuring position has been shifted in the x-direction in order to find the closest possible position to the termination. While shifting high stress gradients have been detected. The stress results are shown in Fig. 2. An error estimation is also shown. The stresses have been measured at the same side of the component near both terminations (left and right). The definition of 'left' and 'right' is by random. Different stress levels have been found for the MLCs. The stresses are compressive stresses. Due to the high stress gradients near the termination the absolute stress values of different MLC sizes are hard to compare because of the positioning resolution of the X-ray beam.

3 Numerical Evaluation

The numerical evaluation of the measured bending results is done by a two-dimensional FEM model which will be described in another paper.[5] The model is used to calculate the fracture stress distribution from the fracture load moment. The fracture stress distribution is then used to set up a Weibull diagram. Figure 1 (b)–(d) shows the Weibull diagrams for each test series together with their confidence intervals for a confidence level of 90%. The fitting functions calculated with the maximum likelihood method are also shown. The FEM simulation of the stress distribution includes the following features:

1. The total inner and outer geometry of the MLC, the solder geometry, and the board have been modelled.
2. The simulation is done for bulk material characteristics.
3. The initial condition after manufacturing is stress free (no residual stresses).

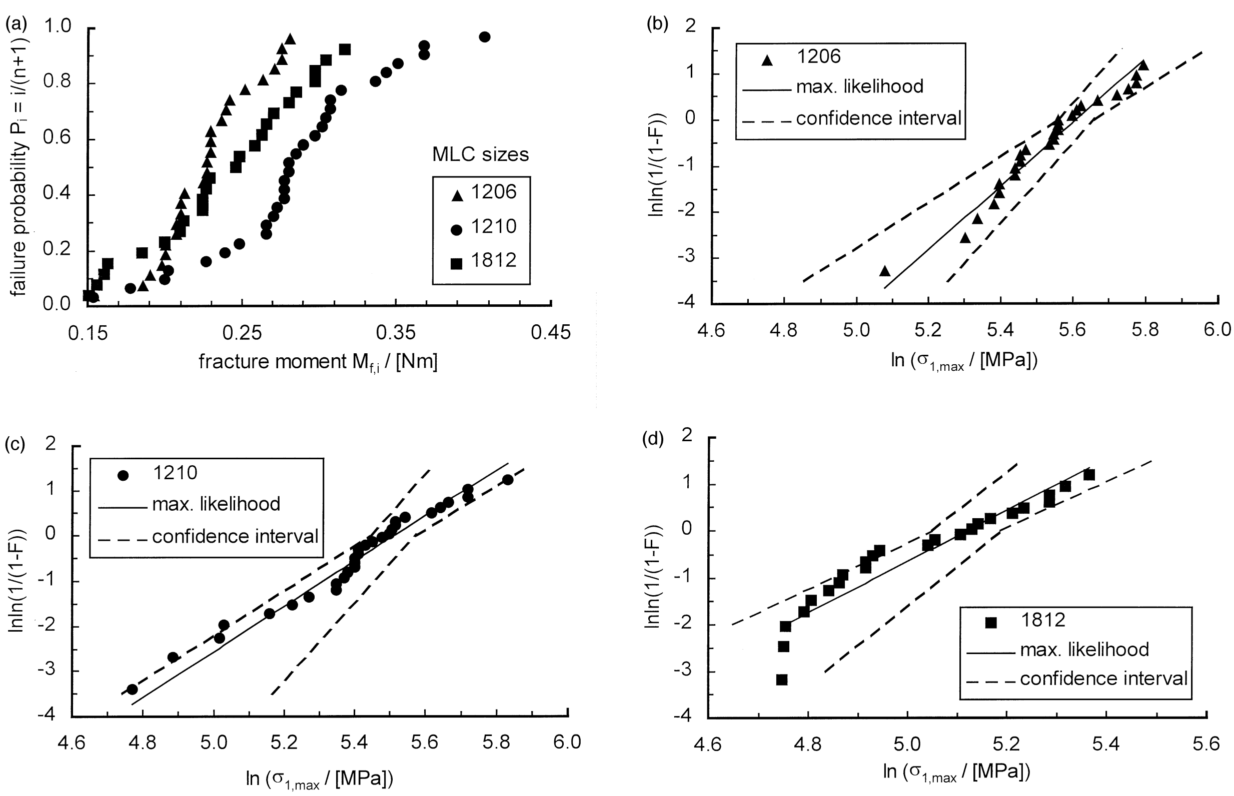

Fig. 1. Results of soldered X7R-MLCs under four-point bending loads. (a) Fracture load moments, (b) fracture stresses for size 1206, (c) for size 1210, and (d) for size 1812. Confidence intervals for 90% confidence level, fitting functions by maximum likelihood.

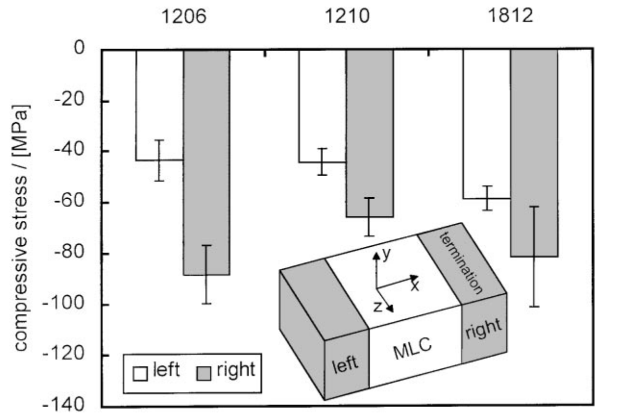

Fig. 2. Residual stresses of 1206, 1210, and 1812 MLC sizes at the *x*–*z* surface near the terminations, stresses in *x*-direction.

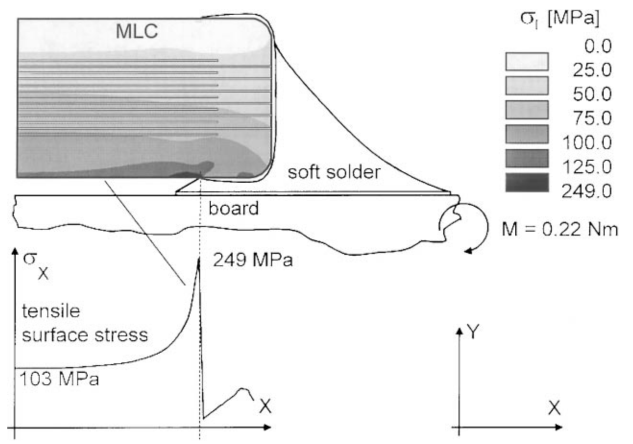

Fig. 3. Calculated distribution of 1st principal stress of a soldered and bent 1206-MLC and surface stress distribution in *x*-direction.

4. Stresses due to soft soldering are taken into account.
5. Load stresses due to bending are superimposed.

These assumptions lead to a typical stress distribution of bent components as shown in Fig. 3. The course of the stress at the surface in *x*-direction (σ_x) shows a maximum near the edge of the termination. This is the region where most of the investigated components failed. The presented stress distribution is used to calculate a normalized stress distribution which leads (Weibull theory) to the derivation of the material dependent Weibull modulus m and the characteristic strength σ_{ov} for volume flaws or σ_{os} for surface flaws. This is done for each single series (Fig. 4). The fracture stresses for 63·2% failure probability of each series show a clear tendency to lower values for larger components which may be partly explained by the size effect of ceramic components. As the derived characteristic strength σ_{ov} and σ_{os} and the Weibull modulus m are not constant, there must be other effects involved. Two possible reasons are under consideration. Changed Weibull parameters for different component sizes may be caused by a size

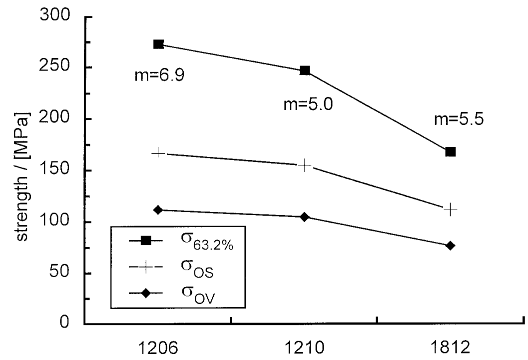

Fig. 4. Derived characteristic strength for volume (σ_{OV}) and surface (σ_{OS}) flaws, and fracture stress for 63·2% failure probability of three different MLC sizes.

dependent microstructure or by residual stresses due to the manufacturing process. As a first step the influence of residual stresses on the component reliability is investigated. If residual stresses differ with the component size they will superimpose the load stresses and can change the fracture stresses for each size. In order to derive the Weibull parameters with an improved approximation, the total distribution of residual stresses versus the coordinates *x*, *y*, and *z* should be known. As a substitute single values at the surface near the termination edge give a first indication (Fig. 2). Compressive stresses between approx. −40 and −90 MPa have been found near the terminations. These values are based on measurements of one component per size, the statistically mean values of each size may be different. The detected residual stresses at the critical position near the termination will significantly influence the derivation of the Weibull parameters. Residual compressive stresses will lower the derived characteristic strength. Different residual stresses will therefore lead to different derived Weibull parameters. The absolute amount of the maximum measured residual stress is approx. a third of the mean fracture strength at 63·2% failure probability of all three sizes. This shows the severe influence of residual stresses on the reliability of bent MLCs.

4 Conclusion

The derivation of the Weibull parameters of soldered and bent MLCs leads to a different characteristic strength and Weibull modulus for each MLC size. Two reasons are under consideration: Different microstructures or different residual stresses for each MLC size due to manufacturing. Measurements of the residual stresses in three MLC sizes near the termination show compressive stresses in the range of −40 to −90 MPa. Different residual stresses would change the derived Weibull parameters. Component size dependent residual stresses near the terminations could not be found which might depend on the low number of measured specimens and the high stress gradients near the terminations. A new estimation of the Weibull parameters could be given if the overall residual stress distribution were known. Nevertheless, the knowledge of single stress values near the terminations and the calculated bending stress distribution show the severe influence of residual stresses on the reliability of MLCs. Future simulations on MLCs will therefore include residual stresses due to manufacturing processes.

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