Shearing tests for solder joints reliability assessment

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Abstract: The goal of the current paper is to present the testing methodology for implementing the accelerated reliability testing by combining the multi-loading and multi-failure criteria, basically creep and fatigue So far, reliability testing of electronic packaging is long lasting and costly. The basic tests are due to thermal fatigue, which can last for a number of months. Therefore one of the basic procedure is accelerated thermal cycling ATC tests..

Key words: electronic packaging, solders reliability, lap-shear test, accelerated thermal cycling

1. INTRODUCTION

Reliability of solder joints is one of the most crucial issues of microelectronic packaging. Solder are the most commonly used attached materials in electronic packaging and due to ongoing miniaturization, growing number of I/O and power densities along with the market requirements, e.g. toward lead-free materials require profound study and design. The goal of the current paper is to present the testing methodology for implementing the thermo-mechanical and accelerated reliability testing methodology by combining the multi-loading and multi-failure criteria. So far, reliability testing of electronic packaging is long lasting and costly. The basic tests are based on thermo-mechanical and cycling loading, which can last for a number of months and take into account only one failure mode. Therefore current approach is based on multi-failure criteria analysis and tests, which can be directly applied in accelerated thermal cycling ATC due to shearing load conditions.

2. THERMO-MECHANICAL SHEARING ACCELERATED CYCLING TESTS

Low deformation and stress distributions between different interconnect materials and components coupled with long-term reliability becomes a hot issue. A key factor of solder joint failure is the mismatch of thermal expansion coefficient CTE between different individual component materials. The standard tests of solder joints are based on thermo-mechanical cycling due to elevated temperature and shearing loading conditions. Current paper focuses on the novel approach to cycling tests, which in addition to the standard thermal cycling propose analysis based on multi-failure criteria. The test samples are designed according to the standard lap-shear configuration setup [1-4] and loading conditions, which in fact leads to the multi-failure criteria as combination of creep and fatigue. The designed tests are meant to support the standard testing procedure of electronic packaging in order to diminish the overall testing time and cost by incorporating accelerated thermal cycling. On one hand standard tests are directed towards thermal low cycle shearing loading. On the other hand towards ATC tests, which are based partly on experiment or numerical modelling and finally Weibull analysis in order to determine the acceleration factors n, that can vary from 2 up to 4.

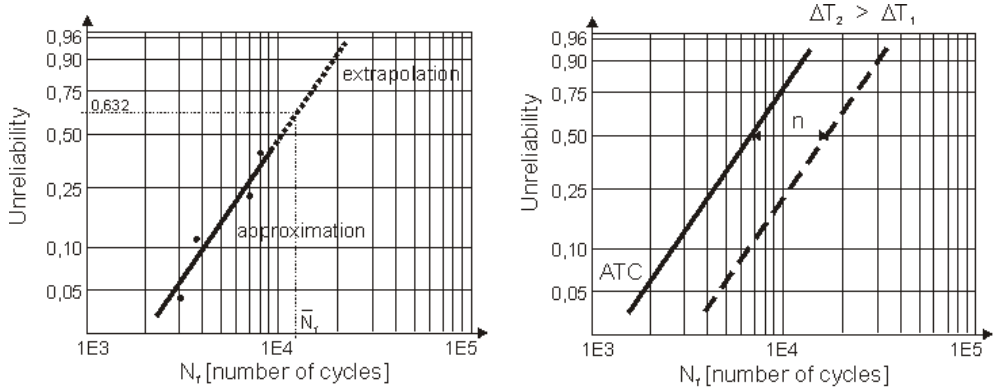

Fig.1. Typical Weibull analysis in case of the accelerated thermal cycling tests

3. MULTI-LOADING AND MULTI-FAILURE CRITERIA

In daily engineering practise most of the failure analysis is done under the simplified assumption that only one failure mode is dominating under selected loading conditions. In the current case the loading conditions are based on shearing due to cycling loading and elevated temperature. In fact there are two basic failure modes in that state, which is creep and fatigue. Creep is dominating failure mode due to elevated temperature conditions and corresponding dwell time, while fatigue is dominating failure modes due to low cycling conditions. Most often failure tests and analysis of creep and fatigue are considered separately but in fact should be considered at the same time. The above assumption can have an important meaning in the standard ATC tests.

3.1. Failure due to creep and fatigue

Failure due to creep is studied under constant loading, which means constant stress and temperature. The failure due to creep can be modelled by the power law (Fig.2a):

$$t_r = A \cdot e^{\left(\frac{B}{T}\right)} \tag{1}$$

where: A and B – material constants, T – temperature, t_r – creep limit.

On the other hand, failure due to fatigue is studied under cycling loading, which varying stress and temperature. The failure due to fatigue can be modelled by the Coffin-Manson law (Fig.2b):

$$N_f = c \cdot \left(\Delta\varepsilon_p\right)^{-n} \tag{2}$$

where: c and n – material constants, t – plastic strain range, N_f – fatigue limit.

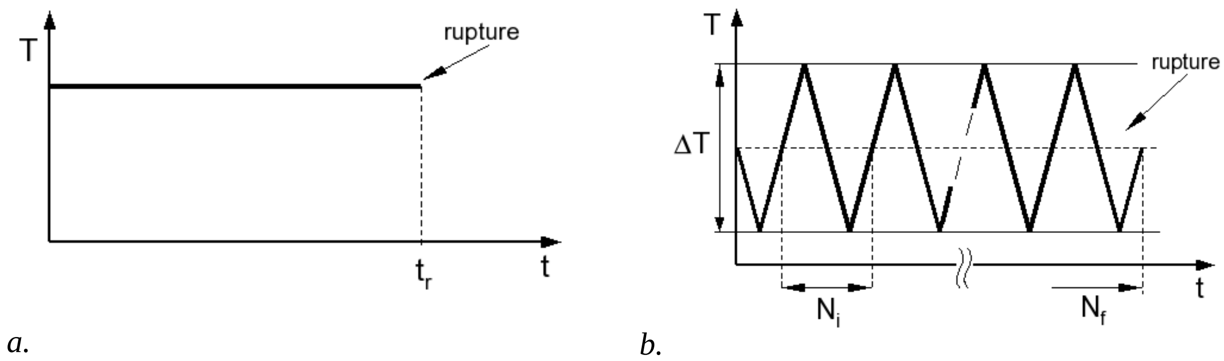

Fig.2. Creep phenomenon due to constant loading (*a*) and faigue phenomenon due to cycling loading (*b*)

3.2. Problem of multi-loading and multi-failure criteria

The main idea of ATC is based on increased temperatures comparing to the standard ones (Fig.1.) and extraction of the acceleration factors in order to shorten the total testing time, which can last for months. In case of standard cycling test the dominating failure criteria is fatigue. Unfortunately in case of ATC, due to increased temperature, the basic failure mode would be rather a combination of creep and fatigue, which is not taken into account in the standard analysis. Thus during low cycling thermal loading conditions two failure progression modes existing at the same time should be taken into account, which is shown in the figure 3.

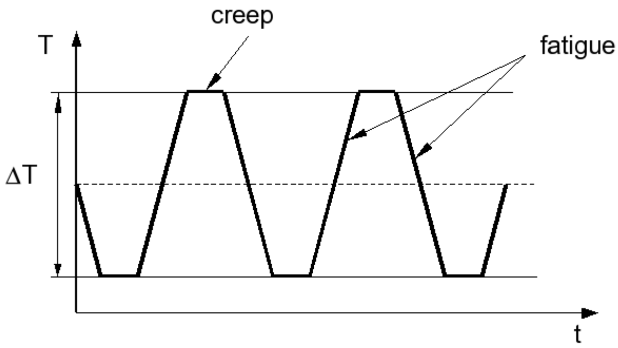

Fig.3. Failure progression modes due to creep and fatigue

The above problem can be considered analytically as the multi-loading and multi-failure state. Analytical analysis of this state could be done according to the so-called linear model of damage accumulation, based on the following formula:

$$\sum \frac{N}{N_f} + \sum \frac{t}{t_r} = D \tag{3}$$

where: N – number of cycles, t –time at given stress and temperature, N_f – fatigue limit, t_r – creep limit.

According to the above equation failure is assumed to happen when the sum of the portions of failure modes damage *D* reaches *1*, which is schematically depicted on the figure 4. Thus failure will depend on separate portions of damage accumulated by one of the failure modes, which is either creep or fatigue.

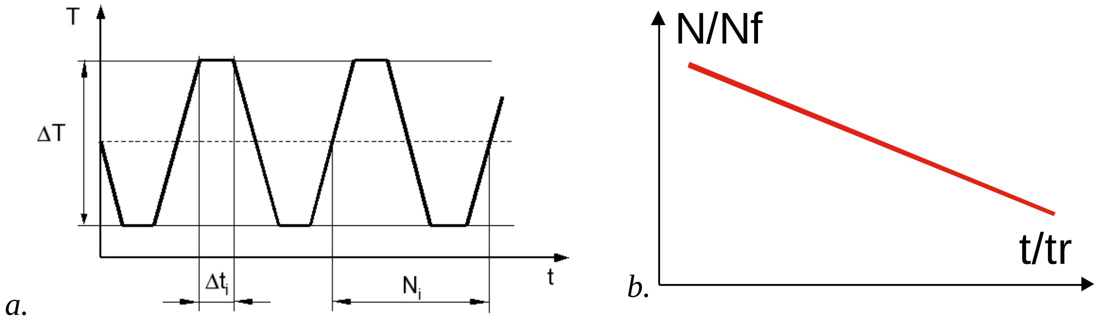

Fig.4. Typical ATC loading parameters (*a*) and corresponding linear failure superposition failure criteria (*b*)

The same the total damage accumulation and criteria can be modeled by the following formula:

$$\sum_i^N \left(\frac{N}{N_f} + \frac{\Delta t_i}{t_r} \right) = 1 \tag{4}$$

where: N – number of cycles, Δt_i – dwell time at the elevated temperature.

4. EXPERIMENTAL SETUP

In order to verify the linear accumulation damage assumption of the solder joint an experimental setup was designed. The setup is based on shearing loading conditions due to elevated temperature cycling conditions and/or mechanical loading, which is in the figure 5. One of the benefits of the designed setup is possibility of in-situ observation of the solder degradations and failure progression referring as to creep as to fatigue.

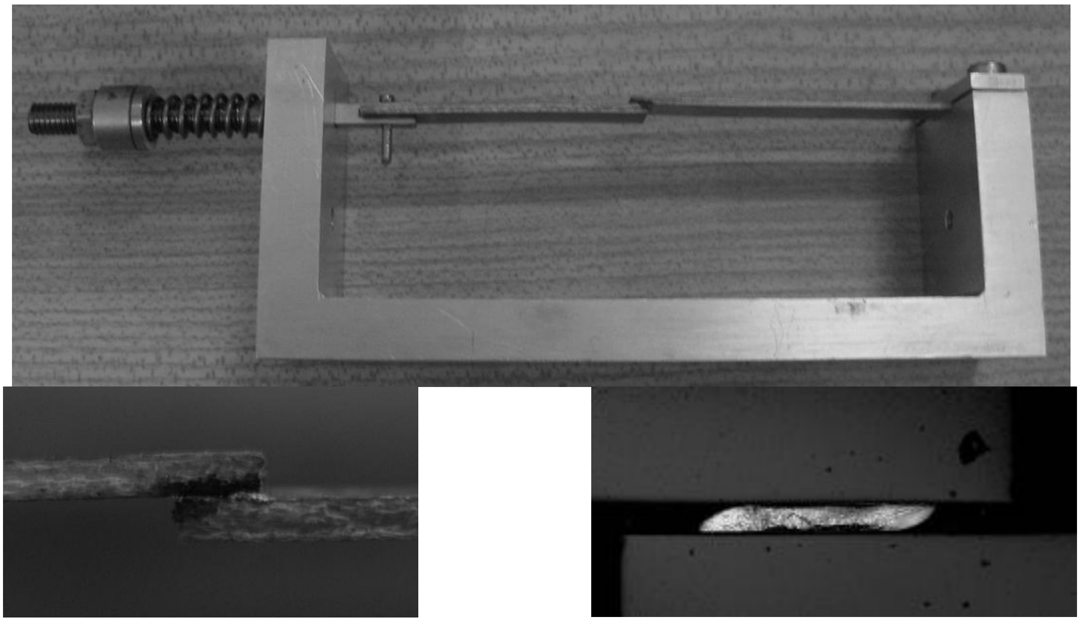

Fig.5. The designed experimental setup and solder joint layout

5. CONCLUSIONS

In the current paper a shearing loading method for multi-criteria failure analysis of solder joints in concern to the ACT reliability testing is presented. The test is based on the assumption of the linear model of damage accumulation in concern to two failure modes: creep and fatigue. Creep and fatigue are basic failure modes of solders in microelectronic packaging. The presented method is aimed towards validating the linear theory of damage accumulation and enhance the accuracy of ACT testing.

6. REFERENCES

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