Numerical and experimental approach to strength assessment of solder and adhesive joints by shearing test

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Abstract*: The goal of the current paper is to present the numerical and experimental approach to strength assessment of solder and adhesive joints by shearing tests. The benefit of the described test is ability to diminish the total time required to evaluate the strength of joints. Reliability testing based on thermal cycling is long lasting and costly and reference mainly thermal fatigue. In fact those tests can last for a number of months, therefore require so-called accelerated thermal cycling ATC. The ATC tests are based on elevated temperature due to the standard one, numerical modelling and Weibull analysis in order to determine the acceleration factor. The achieved acceleration factor values can range from 2 up to 4. Current paper focuses on the accelerated tests based on simple mechanical cycling. The test samples are placed at the selected temperature and exposed to mechanical cycling based on shear loading. The designed tests are meant to support the standard testing procedure of electronic packaging in order to diminish the overall testing time and cost.*

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 [1].

2. THERMO-MECHANICAL SHEARING 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 and adhesive joint failure is the mismatch of thermal expansion coefficient CTE between different individual component materials. The standard tests of solder and adhesive joints are based on thermo-mechanical cycling due to thermal cycling tests. Current paper focuses on the novel approach to cycling tests, which in addition to the standard thermal cycling propose analysis based on mechanical cycling at elevated and constant temperature. The test samples are designed according to the standard lap-shear configuration setup and loading conditions. The designed tests are meant to support the standard testing procedure of electronic packaging in order to diminish the overall testing time and cost [2-5].

2.1 Thermal cycling

Thermal cycling is one of the basic reliability tests in microelectronics. Failure due to thermal cycling is referenced as fatigue, which is given on Figure 1. The basic disadvantage of thermal cycling is long-lasting test procedures, which influence the competitiveness of modern microelectronic industry.

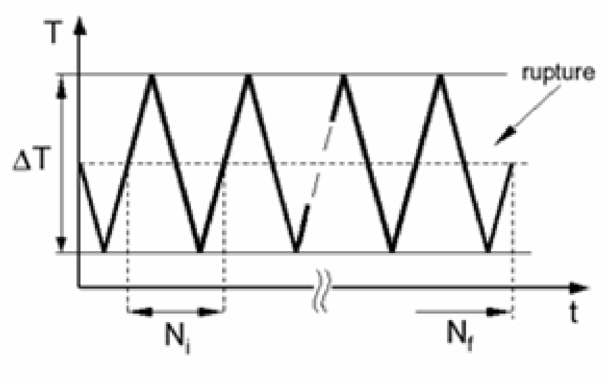

Fig.1. Thermal cycling loading conditions

On the other hand, nowadays there is a big pressure to replace the long-lasting thermal cycling by equivalent numerical validation tests. Unfortunately the numerical approach is not as precise as experiment.

In case of numerical modelling, failure due to fatigue can be studied and modeled by the Coffin-Manson formula:

$$N_f = C \cdot \left(\Delta\varepsilon_p\right)^{-n} \qquad (1)$$

where: C and n – material constants, t – plastic strain range, N_f – fatigue limit. Coffin-Manson formula is based on the assumption that failure is mainly due to inelastic energy dissipation, which can be assessed by equivalent plastic strain $\Delta\varepsilon_p$ accumulated during one thermal cycle, which is given on Figure 2.

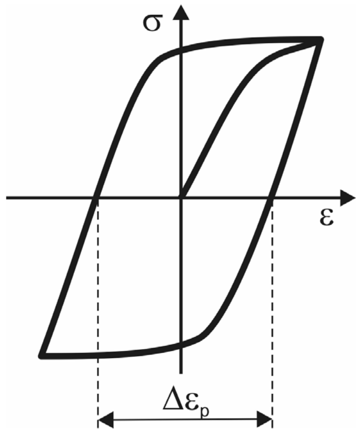

Fig.2. Equivalent plastic strain after one thermal cycle

In case of typical solder materials, the coefficient of Coffin-Manson formula are given in Table 1.

Tab.1. Coefficients of Coffin-Manson formula for selected solder materials

Solder material	*C*	*n*
SnPb	0,38-1,29	1,96
SnAgCu	4,5-12	1,0-1,3

2.2. Mechanical cycling

In fact the presented thermal cycling conditions lead to shearing stresses and loading in the solder or adhesive joints as shown in Figure 3.

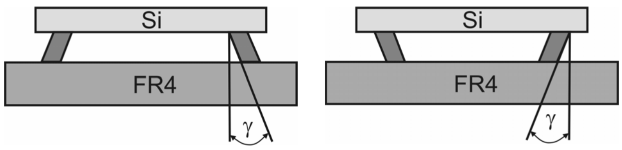

Fig.3. Flip-chip solder joints under thermal cycling

Therefore the current research focuses on possibility of replacing the thermal cycling by mechanical cycling. Unfortunately this can be applied only in cases of rough assessment of solder or adhesive strength. It worthy to underline that the above approach requires precise analysis of fatigue dependence on temperature. In that case, temperature can be treated as a parameter, which value is set for a selected test conditions, as given on Figure 4.

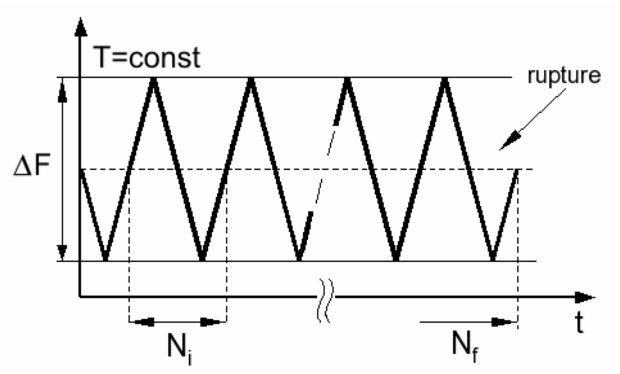

Fig.4. Mechanical cycling loading conditions with temperature T as a parameter

In order to verify the above approach an experimental setup was designed. The setup is based on shearing loading conditions, which is achieved by simple mechanical cycling at a selected constant temperature, which is shown on Figure 5.

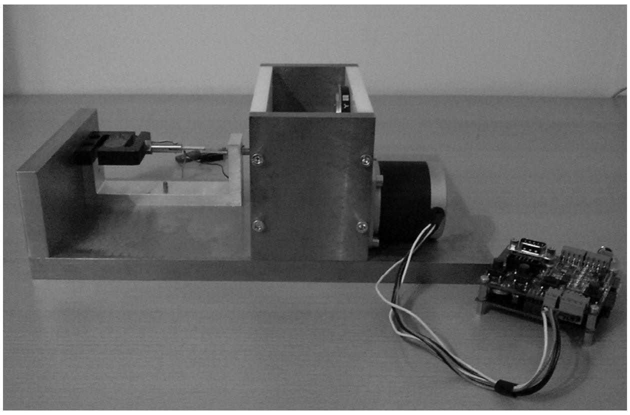

Fig.5. Experimental setup

The setup consists of two clamped plates soldered at their ends. One plate is connected to the stress gauge while the second to the step motor, which induced mechanical cycling. The whole setup can be additionally placed at a selected ambient temperature.

One of the important benefits of the designed experimental setup is possibility of in-situ observation of the solder degradations and failure progression referring as to fatigue.

3. Numerical Model and Results Of Mechanical Cycling Simulation

In daily engineering practice most of the failure analysis is done using standard experimental setups as environmental chambers. But nowadays we can observe a tendency towards performing certain reliability tests by numerical methods, which try to simulate real working conditions of electronic components. There are a number of benefits of such an approach as:

- reduction of total evaluation time,
- direct connection with the optimization procedures,
- better understanding of the key problems,
- extraction of failure criteria.

In fact the last two listed advantages were the main goal for applying numerical modelling for the designed experimental setup. The aim was to better understand the progress of the failure due to shearing conditions and finally to extract the key failure criteria or corresponding parameters. This in fact is inevitable in case of temperature influence on amount of inelastic energy dissipation due to mechanical cycling.

3.1. Numerical model

Numerical model of the experimental setup was done using ANSYS v.11 package. In fact there were three models created: simplified 2D and 3D along with the whole 3D experimental setup. Performed numerical simulations showed that simplified 3D model is sufficient for current analysis and is given on Figure 6.

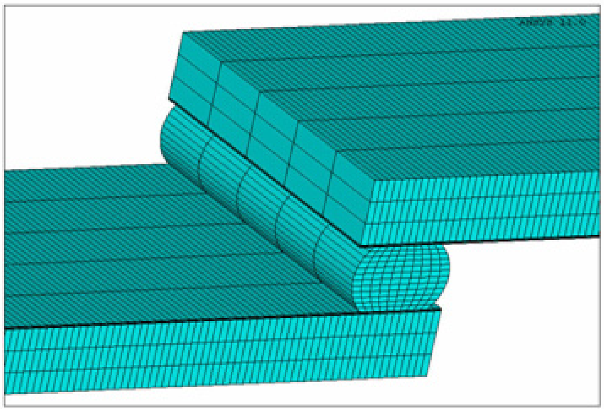

Fig.6. Numerical model of the experimental setup

The model consisted of two FR4 plates connected with an eutectic SnPb solder. Solder was modeled as elasto-plastic material with bi-linear hardening phenomena. The loading conditions were based on mechanical cycles at a selected ambient temperature and the corresponding equivalent plastic strain $\Delta\varepsilon_p$ after one mechanical cycle was recorded.

3.2. Modelling results

The main goal of the numerical analysis was to assess according to the Coffin-Manson (Eq.1) formula the number of cycle to failure N_f at different force F and ambient temperature T values. The achieved preliminary results are listed in Table 2 and presented on Figure 7.

Tab.2. Preliminary results of fatigue evolution

T[K]/F[N]	5,7	8,5	11.3
248	8,4E9	1.8E6	3.9E5
298	6.0E7	9.9E5	2.4E5
398	4.9E6	3.9E5	9.3E4

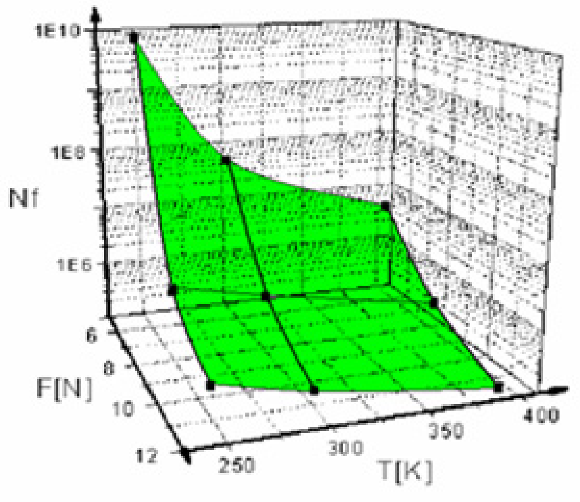

Fig.7. Evaluated dependence of fatigue N_f vs. force F and ambient temperature T value

4. Conclusions

In the current paper a shearing mechanical loading method for accelerated failure analysis of solder and adhesives joints is presented. It was suggested that because traditional thermal cycling is long-lasting it could be replaced in some cases by simple mechanical cycling at a selected temperature. The performed preliminary experiments and corresponding numerical simulations seem to be successful and promising. Basing on the current achievements, father analysis is planned, which especially will be directed towards multi-criteria loading and corresponding failure analysis, e.g. simultaneously due to creep and fatigue.

References

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