MODELLING SOLDER JOINT RELIABILITY OF BGA PACKAGES SUBJECT TO DROP IMPACT LOADING USING SUBMODELLING

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1. Abstract

With the trend towards miniaturization and multi-functionality in products such as mobile electronic devices, miniature IC packaging such as fine pitch Ball Grid Array (BGA) package and Chip Size Package (CSP) are increasingly being used. However, the inherent vulnerability of these miniature IC packagings has brought along new reliability problems. Among them, the drop/impact robustness is the most challenging in terms of testing and designing. The minute solder interconnections used to attach these packages to the printed wire board (PWB), in particular, are very vulnerable to drop impact loads, which mobile electronic equipment is reasonably expected to experience during usage.

A major challenge facing the IC package supplier is the ability to assess the reliability of the interconnection when assembled into a product that can take many forms and shape. The Joint Electron Device Engineering Council (JEDEC) is proposing a standardised methodology using a board level drop impact test. However, correlation between the board level drop impact test and the actual product drop remains unclear. This can be best understood through modelling and simulation using Finite Element Analysis techniques.

In this paper initial results are presented of work carried out using ABAQUS Finite Element Analysis software to model the board level drop impact test and hence determine the stress and strain state in the solder joint. The modelling work was divided into two stages: Dynamic modelling of the impact of the complete board assembly using beam and shell elements, followed by submodelling of the minute solder joints using solid elements. The model was subsequently validated against a fine mesh full dynamic model, the analysis time for this model was almost two days. The submodel approach allowed a full global and local simulation to be completed in less than 4 hours, all models being analysed on an Intel Pentium 4 at 1.8Ghz.

Due to the substantially reduced runtime of the validated submodel it may be of great benefit for conducting parametric studies that would aid in the design of board level tests that best simulate the drop impact tests. This modelling technique will also accelerate the development of models to simulate drop tests on production components.
2. Introduction

Fine pitch Ball Grid Array (BGA) Integrated Circuit (IC) Packaging is increasingly being used, driven by the move towards multifunctionality and miniaturisation, particularly in personal electronic devices. It is important to ensure that these products can withstand the rough handling that they can meet in day-to-day usage and so the drop impact test, shown in Figure 1 has been proposed to allow testing of a typical hard impact. A detailed view of the BGA is shown in Figure 2.

The assembly is dropped on to an impacting surface from a given height; the test allows repeatable results and a fine control on the magnitude of the impact. In particular solder joint reliability is a critical issue in the successful usage of BGA packages in mobile electronic equipment.

In an effort to replace or supplement expensive and time-consuming physical drop testing, simulation techniques have been proposed and are being developed. This paper discusses a project to use ABAQUS FEA to analyse drop testing, which has been conducted by Worley Pte. Ltd in collaboration with the Institute of Microelectronics in Singapore. The work is benchmarked against the experimental work of Sogo [1].

In order to correctly predict the impact strength of the BGA solder joints in a drop test simulation using finite element analysis, a very fine local mesh is required, which will tend to result in a very large model. This is especially true in a full assembly analysis such as the simulation of a drop test of a mobile phone.

A solution to this problem is to use the submodelling technique using global and local models. The Global model, which gives the global response of the assembly, is constructed using a relatively coarse mesh and or simple element types. The local model predicts the detailed results by modelling the area local to the region of interest using the model results at the submodel boundary of the global model to drive the boundary of the local model.

Although the submodeling techniques requires the analysis of two separate models, the total analysis time is likely to be much reduced compared to a single detailed global model due to the significant reduction in the total number of elements.

3. Modelling Objectives

There are two objectives in this study. The first is to investigate the applicability of a submodel approach in predicting the stresses in the solder connection. As part of this study a trial was conducted using dynamic submodelling, which is one of the new features in ABAQUS V6.3, due in September 2002.

The second objective of the modelling work is to demonstrate the usefulness of the approach by determining the sensitivity of stresses in the solder ball to the thickness of the fall plate, the part which impacts with the ground, in the test equipment. This will allow the experimental procedures to be optimised and provide a useful understanding of the mechanism of solder ball joint failure in the BGA.

4. Methodology

Three different models have been used in this study. The first model, “Global-Detail”, is a detailed model of the complete BGA assembly. A fine hex/tet mesh is used and this model is simulated using ABAQUS/Explicit. In the second model, “Global-Shell/Beam”, the complete BGA assembly is again modelled but the solid elements are replaced with shell and beam elements of equivalent sectional properties to produce a model with a significantly reduced number of degrees of freedom (DOF). Several versions of this model were developed to simulate changes in the thickness of the fall plate. It is these models that were used as the Global model for the Local submodel. The third model, “Local-Submodel”, is the local submodel of the region of interest, i.e. one of the solder balls. In “Local-
Submodel the solder ball and the local surrounding area is finely hex meshed and it is driven by displacements applied at the boundary nodes with results interpolated from the submodel boundary region within the Global-Shell/Beam model.

4.1 GLOBAL DETAIL MODEL

The Global-Detail model using a fine mesh was created to compare results to the local submodel. In this model the fall plate and solder ball were modelled using a three-dimensional brick element (C3D8R), while the PWB (Printed Wiring Board), the connector and BGAPWB (Ball Grid Array – Printed Wiring Board) were modelled using a three-dimensional tetrahedral element (C3D10M). Quarter Symmetry has been used and the model is shown in Figure 3. The model was analysed using ABAQUS/Explicit dynamic analysis.

4.2 SUBMODELLING

4.2.1 GLOBAL SHELL/BEAM MODEL

In the Global-Shell/Beam model the PWB, the substrate of the BGA, and the fall plate are modelled using shell elements. The connector and solder ball are modelled using beam elements. In the case of the beams used for the solder ball they have been given uniform cylindrical properties to give equivalent stiffness to that of the solder ball. The contact constraints between the beams and the PWB and the fall plates are defined using a contact equation (Multi Point Constraint). The global shell/beam model is shown in Figure 4.

A more detailed view of the BGA and the positioning of the beam elements is shown in Figure 5. Although the beam element has only an approximate stiffness this is an economical approach and gives reasonable accuracy. An alternative model approach is to use solid elements for the ball and link them to the shell elements of the PWB and BGAPWB using *TIE.

Using a beam element for the solder ball also offers a number of advantages beyond the reduced model size and simulation cost. This includes increased feasibility for conducting design sensitivity studies of the solder ball in that the location of solder ball can be change easily. The number of solder balls, their size and location can be changed easily, and without significantly affecting the total number of elements and nodes in the model.

4.2.2 DETAILED SOLDER BALL MODEL (LOCAL SUB MODEL)

A detailed solder ball model is shown in Figure 6. The C3D8R element is used throughout this model. The submodel is analysed in ABAQUS/Standard, using either as a Static analysis or a Dynamic analysis. Dynamic analysis of a sub-model is an enhancement that will be available in ABAQUS V6.3, and a pre-release has been made available for testing.

5. Analysis Results

5.1 GLOBAL DETAIL EXPLICIT DYNAMIC RESULT VS LOCAL SUBMODEL STATIC ANALYSIS RESULT.

Figure 7 shows a plot comparing the stress history for the maximum stress in the solder ball from the global detail explicit dynamic model to those of the local static submodel. It is seen that the results from these models are well matched over the entire impact period.

The distributions of stress in the solder balls from the two models are shown in Figure 8(a) for the detailed Global model and Figure 8(b) for the Local submodel. In general there is good agreement
between these results and the differences that are seen may be partially the result of the finer mesh used in the local model.

The total CPU time for the board level drop impact test using submodelling technique is only 3hrs 15mins, as compare to global detail model, the time needed is about 46 hours 39mins on a Windows PC running Windows2000 and a 1.8Ghz Pentium 4 CPU. By using the submodelling technique the total CPU time is reduced to less than 10% of the global detailed model in this drop test analysis.

5.2 SUB MODELLING ANALYSIS: LOCAL STATIC MODEL VS LOCAL DYNAMIC (IMPLICIT) MODEL

A potential deficiency of the current approach of going from a dynamic global model to a local submodel is that dynamic affects within the local model may not be calculated. In ABAQUS V6.3 a new capability will be added which allows submodelling using Dynamic Global modelling to Dynamic Local modelling in both ABAQUS/Explicit and ABAQUS/Standard. A pre-release of ABAQUS V6.3 has been made available to Worley, which has allowed the new dynamic global to dynamic local submodelling capability to be investigated for drop test modelling.

The same ABAQUS/Standard model is used for both the local static and the local dynamic analysis. The stress history plot comparing the results for both these analyses is shown in figure 9. It is found that, apart from minor deviations, the stress history of the static analysis is identical to the stress history of the dynamic analysis, however the simulation time needed for dynamic analysis is ten times that of the static analysis (see Table.2). At this early stage it may be suggested that for this particular geometry, inertia effects may not be significant, however work is ongoing to examine the sensitivities.

5.3 PARAMETRIC STUDY OF FALL PLATE

A parametric analysis was carried out to study the affect of increasing the thickness of the fall plate on the stress within one of the solder balls on the BGA. In this analysis the thickness of the fall plate was tested at 5 mm, 10mm, 15mm, and 20mm. By using the parametric capabilities within ABAQUS/CAE it was possible to carry out this study quickly and easily.

The main result of this work shows that using a thicker and stiffer fall plate will result in a greater stress within the solder ball (Figure 10). Primarily this is because the thicker plate transmits the shock load of the impact more directly into the PWB, whereas the thinnest 5mm plate in particular tend to convert the compressive shock energy into bending deformation of the plate. Plots of the displacement are given in Figure 11, which shows the lateral displacement, U1, and in Figure 12, which shows the vertical displacement, U3, from 0mm the point of impact with the test surface. From the lateral displacement plot, the vibration within the test piece can be clearly seen; the vertical displacement results are dominated by the rebound of the test piece, but the slower response with the thinner fall plates is also clear.

6. Conclusion

In this paper, the submodelling technique in ABAQUS has been used to simulate the drop test of a BGA package. The results from a detailed global model, with a very fine mesh have been used to validate the results from the submodel. These results show very close agreement and it is concluded that the use of a coarse global model followed by a detailed submodel provides an efficient means of getting to the solution due to greatly reduced model sizes and hence CPU time.

From the comparison of the dynamic versus the static local models, it is concluded that there are no noticeable differences in the model result indicating that global dynamic effects dominate the solution results. It is notable that a dynamic analysis is considerably more expensive on CPU time and in this case decreases the benefits of the sub-model approach in reducing overall analysis time.
A simple parametric study to look at the effect of the thickness of the fall plate on stress within the BGA has concluded that provided a plate of sufficient thickness is used the results should be consistent, however using a thin plate will dampen the impact of the BGA and could lead to an underestimate of the stresses within the solder balls from a drop impact event.

The work presented in this paper is the first phase of an ongoing collaboration. It is anticipated that this initial work will progress to include more detailed sensitivity analyses and customisation of ABAQUS/CAE to meet the specific requirements of IC Packaging designers.

7. Acknowledgement

The authors would like to acknowledge Takahiro Sogo of Toshiba for providing the dimensions of the fixture designed missing in ref [1]; as well as Joe Corvetti of Worley for his support and advice to this article.

8. References.


### Table 1: Material properties used for simulation [1].

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<th>Material</th>
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<th>Density (Kg/m³)</th>
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### Table 2: Comparison of simulation time for different model

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Figure 1. Outline of BGA Fall Impact Test piece [1]

Figure 2. Outline of Ball Grid Array on BGA Printed Wiring Board (BGAPWB) [1]

Figure 3. Mesh detail of Global-Detail model
Solder ball modelled using beam

Figure 4. Mesh detail of Global-Shell/Beam model.

Figure 5. Location of Solder Ball submodel on BGA

Figure 6. Mesh detail of BGA submodel
Figure 7. Stress History of Global Detailed Model compared with Local submodel

Figure 8. Comparison of distribution of S33 on solder ball
Figure 9. Stress History of Local Static vs. local Dynamic Analysis

Figure 10. Comparison of Stress History for maximum stress on solder ball with different plate thicknesses
Figure 11. Comparison of lateral displacement of point A with different fall plate thicknesses.

Figure 12. Comparison of Vertical displacement of point A with different fall plate thicknesses.