RELIABILITY ANALYSIS OF BGA PACKAGES – A TOOL FOR DESIGN ENGINEERS

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ABSTRACT

An innovative design and analysis procedure has been developed by The MacNeal-Schwendler Corporation (MSC) that enables the design engineer to perform analysis of Ball Grid Array (BGA) packages in an order of magnitude less time than was previously required by experienced analysts. This procedure captures the analytical expertise of the experienced analyst and makes it available to the design engineer with a minimum of training required.

This is accomplished using MSC's Acumen toolkit concept. MSC/Acumen is a unique programming procedure, which serves as an interface to the MSC/PATRAN pre- and post-processor. MSC/Acumen utilizes HTML programming to create the look and feel of a website devoted to a specific analytical problem. The expertise of the analyst as well as company procedures, processes and other, often proprietary, requirements, are captured by the MSC/Acumen developer.

The design engineer creates the analytical model from icon picks and a selection of pre-defined model components. Material properties are contained in the MSC/Acumen program as well as loading conditions, boundary conditions, and other analytical requirements. The design engineer needs not have an understanding of finite-element analysis to create the models or apply the loading and boundary conditions. The loading sequence is also pre-defined based upon the procedures and practices developed by the analysts or experts responsible for detailed analytical evaluations of such components. Life prediction techniques based upon large strain and creep analysis are used to calculate the location of failure and the number of allowable loading cycles. These techniques are well justified by extensive fatigue data at one of the authors' laboratories at Yokohama National University.

BACKGROUND

Electronic packages such as Ball Grid Array, Flip-Chip, Chip Scale Packages, etc. are increasingly being reduced in size to obtain higher mounting density. Surface mount technology is increasing in complexity with the introduction of new alloys and designs. Operating parameters such as power requirements and temperature excursions are more severe as products are miniaturized on the one level while the duty cycle is increased. These changes in technology require that the materials of construction be pushed closer to design limits. Simultaneously, competition for market share requires that new products must be developed quickly to insure maximum profitability over the ever decreasing life span of products. Physical testing of new designs is often impossible due to the shortened development cycle and new products are now being introduced that have been created and verified entirely through computer simulation.

GOALS OF PROJECT

The main goals of this project are to demonstrate that the analytical expertise of the electronic packaging specialist can be captured, along with the design process, in such a way that the design engineer can utilize this expertise on a daily basis without extensive training. Previous experience with similar projects in other industries indicates that the evaluation of complex nonlinear designs can be reduced from weeks to hours by using MSC/Acumen as a communication medium. This process involves carefully understanding the design and analysis procedure and creating a knowledge-based system which uses a step-by-step tutorial type interface. The technology embedded in the program is based upon the latest research in the areas of solder characterization, material property data, fatigue life estimating and finite element modeling techniques. In each area of expertise, i.e., material property characterization, finite element modeling, etc., different specialists will contribute to the procedure so that it represents the accumulated knowledge of many experts. Thus, the resulting compilation is much more comprehensive than the knowledge of any one analyst, even one devoted entirely to the particular field.

Thus, the design engineer, while limited to a specific area of design, will have the capability of creating a world-class design in an extremely short time span. Many design variations can be explored and part optimization can be accomplished in less time than a single design could be previously evaluated. Another benefit to the companies using the program is that consistent quality and confidence in the design is provided at all company locations, in all groups and by all individuals who use the software regardless of their experience or expertise. Of course, no software program will ever replace innovative designers who will invariably develop new and creative components using existing design parameters and procedures.

TECHNICAL CHALLENGES

The analytical evaluation of a BGA package involves a series of fairly complex analyses. A thermal analysis is necessary to calculate temperature distribution within the package and the attached components. Thermal stresses are induced by the difference in linear coefficients of expansion between the various components. The resulting stresses often exceed the yield point of the material, which requires an inelastic analysis. Creep, fatigue and other life prediction methods such as crack propagation and crack growth rate are necessary to determine the expected life of the various components. Simply obtaining material data, for example, can be time consuming and a source of error for the individual analyst.

One of the most important features of this tool is the capability to add new features and capabilities as new information is obtained. Currently, all changes must be made by the software developers. However, future releases will allow customization by certain users within a company so that specialized procedures or policy decisions can be included or updated.

CAPTURING EXPERTISE

Probably the most important contribution of this software is the ability to capture the expertise of numerous specialists and the design procedure of the process. This requires bringing together a team consisting of experts in electronic package design materials and analytical methodology and programmers who are capable of developing commercial software. Using existing finite element solvers, modeling software and the MSC/Acumen web-based authoring toolkit, this expertise is captured in an interactive and intuitive environment. The MSC/PATRAN pre-and post processor is accused through the MSC/Acumen interface, thus allowing the programmer to utilize a wide range of modeling features. MSC/PATRAN PCL (PATRAN Command Language) is in itself a rich programming language which may be used to crate extensive parametric models. Additionally, MSC/PATRAN has considerable interface capability with other solvers and MCAD databases, which gives added flexibility to the overall process.

SYSTEM ARCHITECTURE

Figure 1 shows the system architecture of the program. MSC/Acumen BGA uses a program named Drive Page in order to call PCL functions and utilize MSC/PATRAN. This system is based on MSC/PATRAN, and consists of a Pre-Post system, a solver (MSC/AFEA), a material database, and a fatigue life test database. The main feature of the Pre-Post system is 3D modeling. MSC/MVISION, a material data management system, will manage the two databases in the future, enabling easy maintenance for the databases. Moreover, MSC/Acumen BGA can handle various types of material data and fatigue life test data, since MSC/MVISION has an interface with MSC/PATRAN.

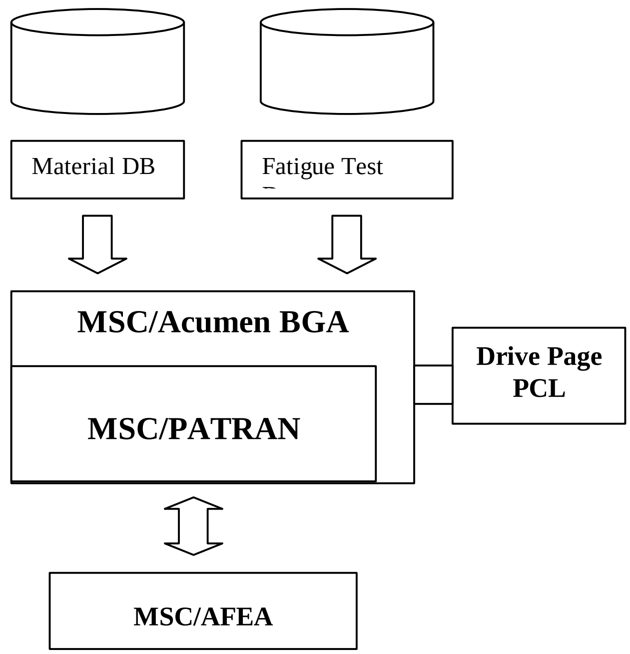

Figure 1. System Architecture

FEATURES

Model Configuration

The target IC package of this system is the Die-Up Package. Figure 2 shows a BGA assembly configuration, which consists of a chip, encapsulant, substrate, BGA, and PCB. In this case, the BGA between the chip and the substrate was ignored in order to simplify the model. However, in order to analyze the chip at a later stage, the encapsulant will be modeled by combining the underfill mold and the BGA.

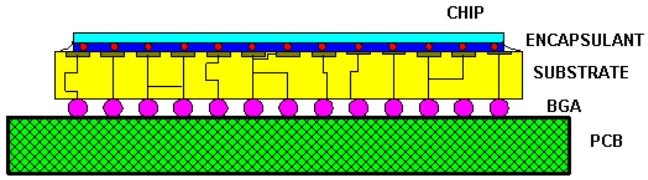

Figure 2. Ball Grid Array Package

The substrate and the PCB were modeled with one layer for simplicity, but the user can expand the system functions to handle multi-layers. There are two typical array types for solder joint balls (See Figure 3). One is the Full type, where the solder joint balls cover the base surface of the substrate, and the other is the Depopulated type, where the solder joint balls do not cover the center part of the surface.

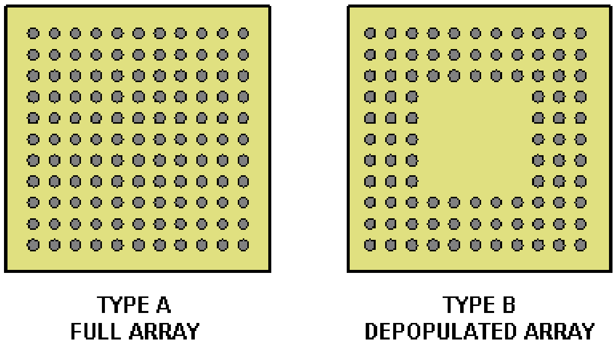

Figure 3. Configuration Types

Modeling and Analysis

In order to shorten the calculation time, all solder joint balls except for the four balls at the corner should be simplified. The four balls at the corner should be meshed using fine Hexa elements, so that the non-linear strain distribution can be evaluated. The rest will basically be modeled as cubes. The length, width and height of the hexahedral elements will be half of the cube size. A 1/2 model or a 1/4 model can be used for the analysis.

Creep property should be specified for the solder joint balls, and linear property for the other parts. Also, heat load conditions should be specified for each part. Figure 4 shows the temperature history. The temperature history is equivalent to 1.5 cycles of the heat cycle fatigue test. MSC/AFEA will be used for analysis. The length of the time step will be automatically defined while creating solver input data, based on the information programmed in to the system.

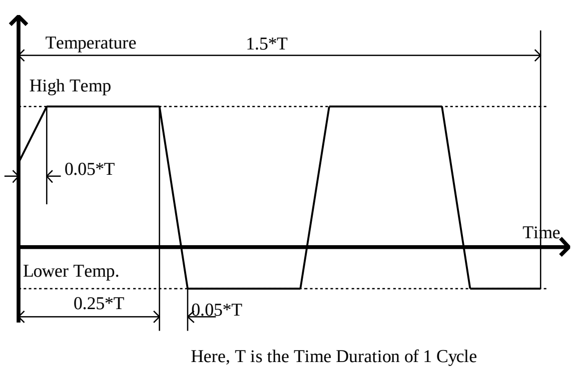

Figure 4. Temperature History

Pre-Processor

The MSC/Acumen BGA has a single User Interface Menu and a Graphics window. See Figure 5. The User Interface Menu consists of a set of icons for viewing control, the Expert Workflow Manager menu for user guidance, Dialog Area, and an Input Area.

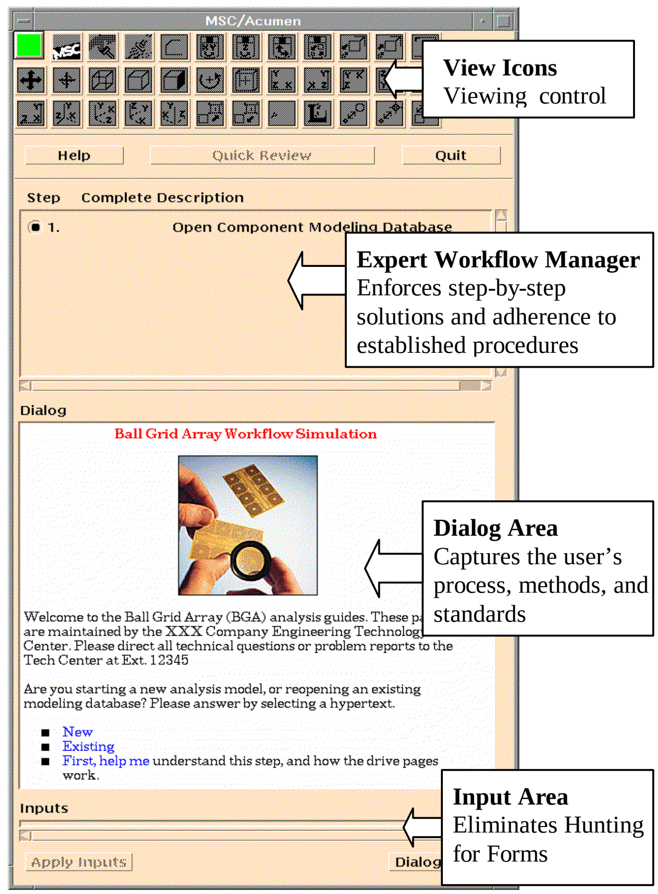

Figure 5. Initial GUI of MSC/Acumen BGA

Defining the Assembly Parts

Part dimension can be changed parametrically. The chip, encapsulant, substrate and PCB are all squares and the user inputs the length, width and thickness. Figure 6 shows a chip being defined parametrically.

As shown in Figure 7, the basic geometry of the solder joints in the BGA is represented by a barrel shape, and the user inputs the diameter, angle and height of the upper and lower parts. By specifying a smaller angle than 90 degrees for the upper and lower parts, the user can change the solder joint shape to concave geometry easily.

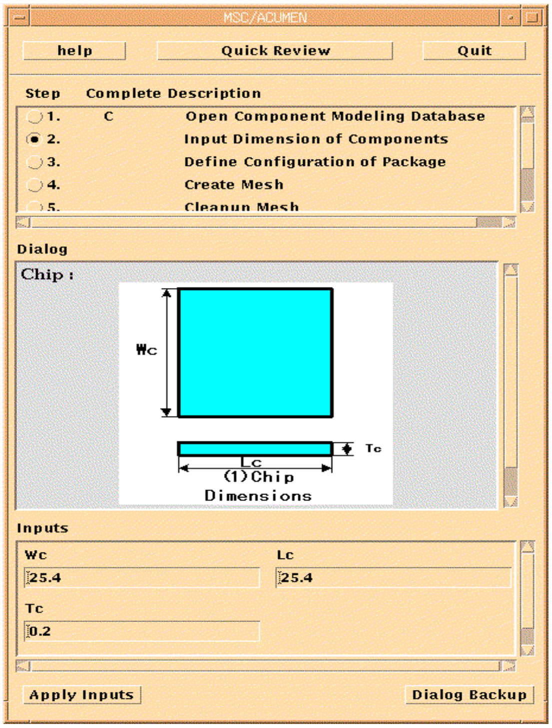

Figure 6. Chip Dimensioning Form

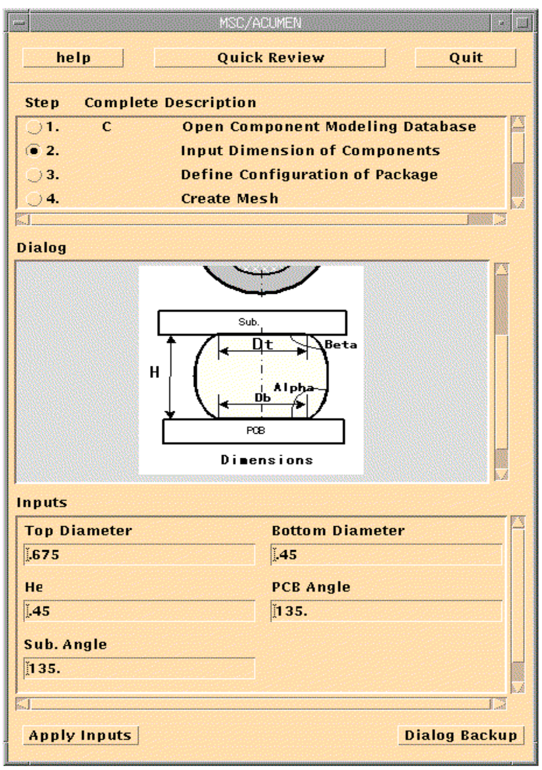

Figure 7. Solder Joint Ball Dimensioning Form

Defining the Ball Grid Array

There are two typical array types for solder joint balls. The depopulated array is defined in the menu shown in Figure 8. The array is shaped as a square, and the user inputs the pitch between the solder joint balls. The area where no balls are placed is also square shaped, and only the length need be defined.

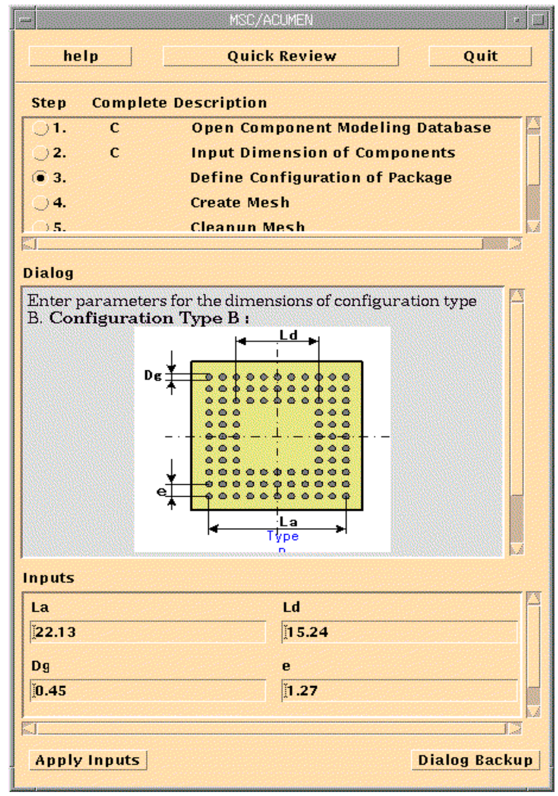

Figure 8. Depopulated Array Dimensioning Form

Automatic 3D Modeling

After defining the assembly and the ball grid array, all the user needs to do is to specify automatic modeling. MSC/Acumen BGA creates the geometry of each part and starts generating the mesh. Using the simplification technique programmed in the system, the Hexa mesh for the BGA assembly model will be generated in the optimal size. Figure 9 shows the meshed in the corner area. Figure 10 shows the detail of the mesh of the corner solder ball. This system uses the advanced meshing features of MSC/PATRAN. Because of the regularity of the ball grid array, this system utilizes an algorithm to quicken the generation speed of the meshing pattern.

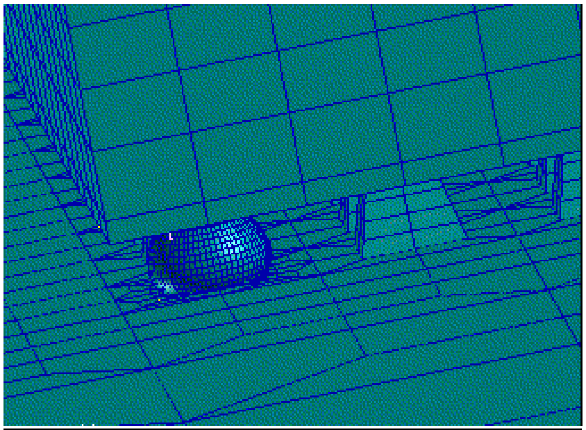

Figure 9. Meshes in the Corner

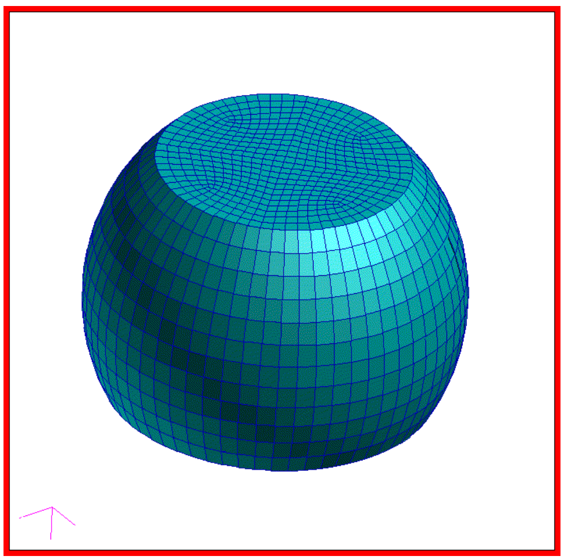

Figure 10. Detailed Mesh of Solder Balls

Post-Processor

The characteristic of a non-linear strain can be seen in the joint points of the solder joint balls. The evaluation of non-linear strains and fatigue life estimation is based on the theory by Professor Shiratori and Dr. Yu at Yokohama National University.

Analysis results (figure 11) are displayed using a deformation plot, non-linear strain contour plot, strain distribution graph, and a graph showing the comparison with the fatigue test data. These results can be displayed by selecting the item with your mouse. Users who need customized post processing can use PCL to add new functions. Users can easily create a list of the summary information in HTML format, enabling many design engineers to share the information.

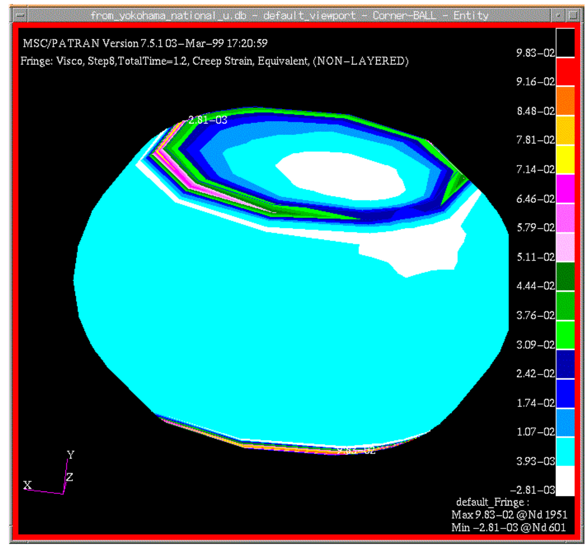

Figure 11. Results of Corner Solder Ball

CONCLUSION

An interactive computer program has been developed which captures the expertise of the dedicated analysts and combines this with the design procedure of the company as well as experimental data. This program may be utilized by the design engineer with a minimum of training. Sophisticated finite element analyses are performed and the results of these analyses are evaluated so that the useful lifetime of BGA packages can be predicted with a high degree of confidence. The theoretical and experimental work of Professor Shiratori and Dr. Yu [5,6,7,8] has been used as the basis of life prediction.

The MSC/Acumen [1] interface provides the ideal vehicle for the engineer to access this design tool. The inexperienced analyst can perform an expert analytical evaluation of a complex system of geometry and loading conditions in an order of magnitude less time than with previous methods. The user performing the simulation is not required to have any specialized FEA knowledge or knowledge of how to operate general FEA software tools. The knowledge and methodology of FEA experts is captured in the program that guides the user and performs the modeling and analysis. English and Japanese language versions of the application were written. The program communicates to the user in generic design language terms, with a methodology that is understood and easily followed by IC packaging design engineers.

The MacNeal-Schwendler Corporation is currently developing a number of applications using this basic programming procedure. These applications cover a wide range of different industries (see Ref. 4 for example). Using this tool we believe it is now possible to provide software to industry which will finally fulfill the long sought goal of enabling the casual user of FEA to produce expert level analyses in a greatly reduced timeframe. General purpose FEA programs can be focused to specialized purposes in a cost effective manner so that the full potential of the technology can finally be realized.

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