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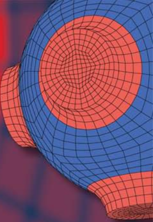

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Solder Joint Reliability Assessment

Finite Element Simulation Methodology

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Mohd N. Tamin · Norhashimah M. Shaffiar

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Finite Element Simulation Methodology

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Mohd N. Tamin
Faculty of Mechanical Engineering
Universiti Teknologi Malaysia
Skudai, Johor
Malaysia

Norhashimah M. Shaffiar
Department of Manufacturing
and Materials
Kulliyyah of Engineering
International Islamic University Malaysia
Gombak, Kuala Lumpur
Malaysia

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Preface

This book addresses various aspects of solder joints' reliability assessment for microelectronic assembly with Ball Grid Array (BGA) solder joints. Computational aspects of the reliability assessment are deliberated using Finite Element (FE) simulation methodology. The discussion begins with a systematic approach in engineering problem solving with the aid of FE simulation. The approach is elaborated based on numerical experiment framework. Essential requirements for FE simulation of engineering phenomena are described. These cover assumptions considered for a simplified physical model, FE model geometry development, constitutive models for materials used, and aspects of FE model validation and interpretation of numerical results. The explanation is further illustrated using an example of procedures for FE simulation of microelectronic assembly with BGA solder joints subjected to reliability test conditions. Fundamentals of the mechanics of solder material are adequately reviewed in relation to computational aspects of FE formulations. Constitutive models for solder alloys representing elastic-plastic response, creep deformation, and low cycle fatigue behavior are adequately described. Concept of damage is introduced along with deliberation of continuum and local approach in damage mechanics modeling. Cohesive zone model and continuum damage model is described for failure simulation of solder/intermetallic interface and bulk solder joint material, respectively. Extension of these models to account for cyclic loading cases is deliberated. Hybrid experimental–computational approach for determination of damage model parameters is presented. Applications of the deliberated methodology to selected problems in assessing reliability of solder joints in microelectronic assemblies are demonstrated. These industry-defined research-based problems related to solder joint reliability assessment include solder reflow cooling, temperature cycling, and mechanical fatigue of a test assembly with BGA solder joints, JEDEC board-level drop test, and shear fatigue of reflowed solder specimen. Emphasis is placed on accurate quantitative assessment of solder joint reliability through basic understanding of the mechanics of materials as interpreted from results of FE simulations. Validation aspects of the FE simulation including FE models and material constitutive models are equally considered. The FE simulation methodology, although demonstrated for reliability assessment of solder joints, in this book is readily applicable to numerous other problems in mechanics of materials and structures.

The book is a compilation of research experience and training in the development of validated methodology for solder joint reliability assessment based on the mechanics of reflowed solder system, typically found in Plastic Ball Grid Array (PBGA) packages and assemblies. FE models of microelectronic test assembly employed in various examples throughout this book are based on typical geometry and grid array of the solder joints. However, the simulation methodology is equally valid for different geometry and design of solder array. In addition, the FE simulation methodology deliberated in this book is software-independent although all FE results are presented using graphical output of Abaqus FEA software employed in running the FE simulation cases. The coverage and arrangement of the topics are intended to serve as a reference book or course text on Computational Methodology for Solder Joint Reliability at the undergraduate senior or graduate level. Sufficient review of essential fundamental elements of the mechanics of materials and practical coverage of damage mechanics renders the book an excellent reference for practicing engineers, technical personnel, academicians, and researchers involved in FE simulations (problem identification, modeling, and analysis) and assessment of solder joint reliability in microelectronic packages and assemblies.

Layout of the Book

The chapters in this book are arranged to address the two aspects of the contents, namely FE simulation methodology and illustration of the methodology in the assessment of solder joint reliability for microelectronic assemblies with BGA solder joints.

Chapter 1 begins with an overview of the trend in electronic packaging technology. It also describes an electronic assembly with a flip chip package and ball grid array solder joints. The terms *reliability assessment* and *reliability simulation* of the assembly are briefly described.

Chapter 2 provides an overview of the simulation methodology as applied in engineering problem solving. The various aspects of engineering simulation including the real-life problem of interest, available numerical tools, relevant physical laws, and experimental data generation are described within a numerical experiment framework. A short review on derivation of finite element equations is included. Typical process flow in FE-based solution approach to a well-identified problem is discussed.

Chapter 3 outlines and discusses the essential requirements for solving engineering problems through FE simulation. These include FE modeling processes (model geometry, element discretization, boundary conditions, and loading), accuracy of constitutive models, and aspects of FE model validation and interpretation of FE results.

Chapter 4 adequately reviews essential and relevant theories of the mechanics of materials. Uniaxial stress–strain curve covering elastic-plastic response of solder materials is described. Effects of temperature and strain rate on mechanical properties and hardening behavior of materials are discussed. Cyclic behavior and creep response of the material are discussed in terms of relevant numerical models. Of particular interest is the unified inelastic strain theory (Anand model) for lead-free solder alloys. Relevant properties and behavior of tin-based solder alloys are presented.

Chapters 5 and 6 illustrate the FE simulation methodology described above through case studies in (Case I) reflow cooling of a typical microelectronic assembly with BGA solder joints and (Case II) deformation of the BGA assembly under reliability temperature and mechanical load cycles. The latter includes case studies on BGA assembly subjected to cyclic flexural load and cyclic torsional load. The predicted evolution of internal states of displacements, strains, and stresses in critical solder joints are presented and discussed with respect to the solder joint reliability.

Chapter 7 dwells on the concept of materials damage and damage mechanics approach in predicting deformation and failure processes of solder joints in the assembly. The concept of cohesive behavior of solder/IMC interface is introduced to simulate fracture process of the interface. Continuum damage model is introduced for predicting the progressive failure process of the bulk solder joint. Extension of existing cohesive zone model formulation to accommodate cyclic loading is discussed.

Predictive capability of these damage-based models for simulation of fracture processes of solder joints is illustrated in case studies of different loading scenarios, as elaborated in Chaps. 8 and 9. Case III describes the dynamic fracture process of solder/IMC interface during board-level drop test with a BGA assembly. Case IV illustrates the characteristic incremental damage evolution and fracture process in a solder joint under fatigue loading. Competition between solder/IMC interface damage and continuum damage in the bulk solder joint is examined through a case study on an assembly with a single solder joint subjected to cyclic shear-dominated loading. Simulation of failure of solder joints in BGA assembly subjected to flexural loading is also illustrated.

A short closure on the topic is covered in the last chapter.

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