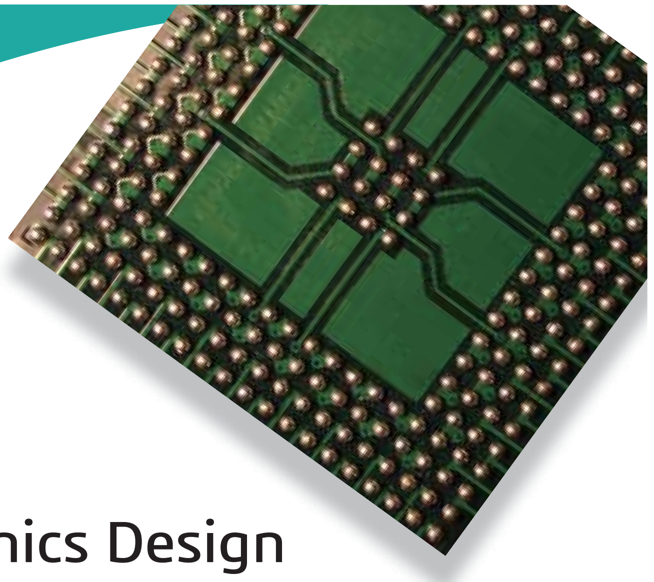

XFEM Impacts Electronics Design

Auburn University studies shock and drop in circuit board packages

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Rugged, damage-tolerant, and indestructible–this doesn't normally describe how we think of electronic products, but it does describe the way of the future for electronics. Specifically, handheld portable electronics have become more complex and smaller due to advancements in technology. Yet their size can also contribute to their vulnerability during rough use. The loss of functionality due to shock damage during everyday usage can be a source of disruption—from possible loss of time in restoring normalcy to loss of data or valuable information.

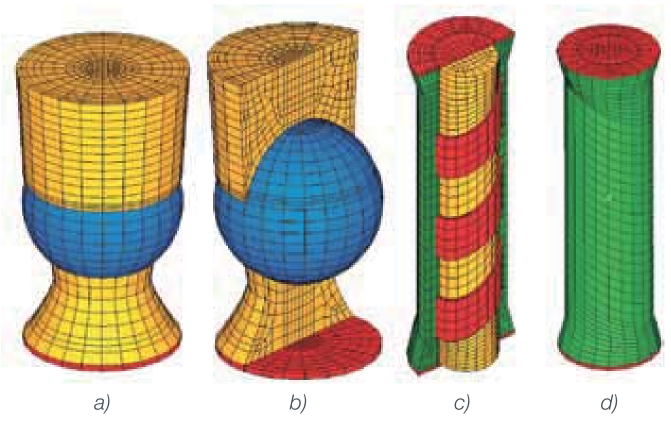
In the past, researchers have addressed the drop reliability of electronics at the product level using various experimental and analytical techniques. The transient dynamic behavior of lead-free and leaded solder-interconnects has been studied in ball-grid array (BGA) and copper-reinforced solder column package architectures using advanced finite element techniques such as cohesive element modeling for both ceramic (CBGA) and plastic (PBGA) packages.

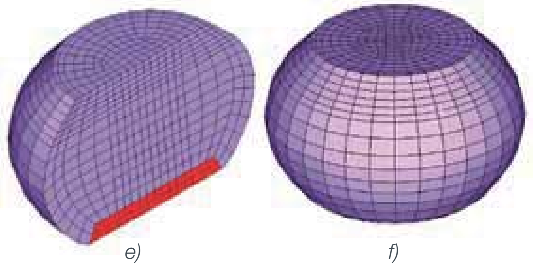
Previous modeling methods used to overcome the length-scale issues between individual interconnects and the package for shock and drop simulation include smeared property models, beam models with conventional and continuum shells, and global-local sub-models. Cohesive element models have been used to study failure at the intermetallic compound (IMC) layer of packages. But now the use of the eXtended Finite Element Method (XFEM) for the study of cracking in solder interconnects under impact loading is being explored.

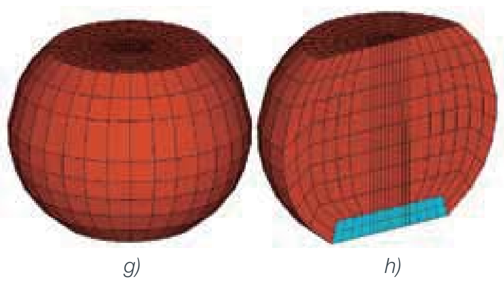
XFEM was originally introduced to solve problems involving crack growth without the need for re-meshing. The method adds a discontinuous enrichment function to regular finite elements to capture the effect of the crack. In classical finite element analysis (FEA), a crack needs to be meshed accurately, and if cohesive elements are used, then the crack can propagate along pre-defined element boundaries. If cohesive elements are not used, then crack propagation would require remeshing at each step, which affects the accuracy of the results and is inefficient.

XFEM provides more realistic crack analysis

By contrast, XFEM allows the crack to grow along an arbitrary, solution-driven path with no remeshing required. For solder interconnects in portable electronics that are subjected to shock and impact, XFEM enrichment functions are added to the elements in all the corner solder interconnects, since these joints are the most vulnerable to failure during a drop.







(a), (b) 90Pb10Sn Solder Joint on CBGA (c), (d) Cu-Reinforced Solder Column on CCGA (e), (f) Sn3Ag0.5Cu Interconnect on CBGA (g), (h) Sn3Ag0.5Cu Interconnect on PBGA324.

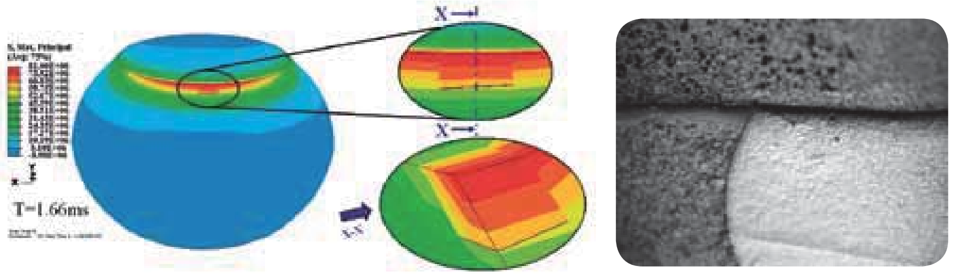
XFEM uses cohesive constitutive relationships to govern debonding, enabling nucleation and the growth of the crack. Instead of embedding a crack tip in the bulk solder, this method automatically introduces a new cohesive segment when the critical cohesive traction is reached. Cracks are introduced as jumps in the displacement fields, with their magnitude governed by the cohesive traction separation constitutive law. Similar constitutive failure laws have been used with cohesive elements to address time-dependent dynamic interface fracture from drop and shock in solder interconnects. The question was—could engineers achieve more accurate simulation by using these cohesive constitutive laws to model bulk solder failure with XFEM?

To find out, researchers at Auburn University performed simulations of drop impacts on BGA and copper-reinforced solder column package architectures using the XFEM capabilities in Abaqus FEA. Results were compared with physical drop tests to validate the analysis method.

How to model a drop

The FEA models for this project reflected the complexity of populated printed circuit boards. Because the corner solder interconnects are highly vulnerable to failure during a drop, refined meshes were required in these areas. XFEM enrichment functions were added to the regular elements to allow for crack nucleation and then propagation, as driven by the solution.

The drop analyses used three separate versions of the explicit global model, reflecting previous methods of representing solder joints in a drop analysis: a beam model, a smeared property model, and a cohesive element model. For all global models, the package was modeled with C3D8R elements, the PCB was modeled with S4R shell elements, and we used R3D4 elements to model the rigid floor.



Correlation of model predictions with failure modes from experimental data—Sn3Ag0.5Cu CBGA.

For the XFEM sub-model, the corner interconnects were modeled with fully-integrated continuum elements (C3D8), while the remaining solder interconnects were created with beam (B31) elements. The rest of the package, including the chip, mold compound, substrate, and printed board, was modeled with C3D8 elements.

Node-based sub-modeling provided displacement boundary conditions to the XFEM sub-models. The displacements at the driven nodes in the sub-model were defined by output from digital image correlation (DIC) locations on a physical speckle-coated PCB.

The XFEM enrichment functions were only added to areas where previous empirical data suggested that cracking could be expected. For the CCGA and Hi-Pb solders, enrichment was defined for only the eutectic phase at the top and bottom of the corner interconnect columns. For all the other interconnect types, enrichment was defined for the entire corner joints.

Correlation of model predictions with experimental data

Physical board assemblies were cross-sectioned after failure, to observe the failure modes. There was excellent correlation between the Abaqus model predictions and the location of failure modes in board assemblies after physical shock tests. As predicted, copper columns fail close to the package-interconnect interface and Sn3Ag0.5 Cu interconnects on the CBGA package fail close to the package-solder interface, while those on the PBGA package fail near the board interface. 90Pb10Sn interconnects fail close to the board interface in the eutectic solder. The results extracted from the models also showed good correlation, in both magnitude and phase, with experimental data taken from high-speed measurement of strains from DIC.

The potential is great for XFEM to increase the accuracy of simulating impacts and cracking in electronic components. That, in turn, will aid engineers to make their products more durable and able to withstand greater impacts.

And that is a big goal for small electronics.

Center for Advanced Vehicle and Extreme Environment Electronics

CAVE^3 Electronics Research Center is a National Science Foundation Industry-University Cooperative Research Center at Auburn University. The Center focuses on research related to electronics design, reliability, and prognostics in harsh environment applications such as automobiles, military, defense, and aerospace. Electronics in harsh environments may be subjected to high-g loads, vibration, and very high and low ambient temperatures; extreme temperature changes; moisture and high humidity; exposure to dirt, contaminants, chemicals, and radiation. Typical office electronics may not experience such extreme environments or face the reliability and life-cycle requirements needed for critical applications. These themes provide the motivation for the Center's strategic directions related to technology development and research. The Center is supported by the NSF and member companies.

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