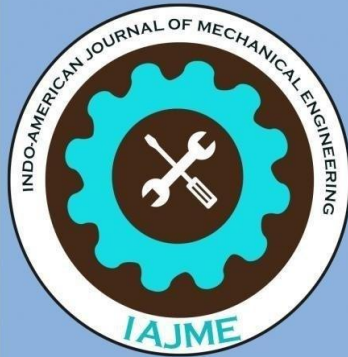


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SIMULATION OF BONDED/BREAKABLE CONTACTS IN PCB DROP TEST USING EXPLICIT DYNAMICS

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ABSTRACT

Modeling and simulation of board-level drop tests were conducted for a Flip Chip on Board (FCOB) assembly. The printed circuit board (PCB) specimen measured 185 mm × 150 mm and included large (8 mm × 8 mm) and small (3 mm × 3 mm) flip chips mounted with underfill encapsulation.

The PCB was clamped at two edges and subjected to a free-fall drop of 1 meter using a shock test machine. Experimental measurements were obtained using a high-speed camera, accelerometer, and strain gauges.

Finite Element Analysis (FEA) was performed using explicit dynamics in ANSYS 2025 R2. Two simulation approaches were implemented: a stress-based breakable model and a non-breakable bonded model. The numerical results were compared with experimental data in terms of displacement, strain, acceleration, and equivalent stress.

The study demonstrates that explicit dynamic simulation provides accurate prediction of PCB response during drop impact and allows modeling of bonded and breakable contacts effectively.

Keywords: PCB, Drop Test, Explicit Dynamics, FEA, Heat Sink, Contact Modeling

1. INTRODUCTION

A Printed Circuit Board (PCB) is a laminated structure composed of conductive copper layers and insulating substrate materials. It mechanically supports and electrically connects electronic components through soldered joints and copper traces.

Modern electronic products such as smartphones, laptops, and portable devices frequently experience accidental drops. These drop events generate high transient stresses that can lead to:

- Solder joint failure
- PCB bending
- Component cracking
- Delamination

Board-level drop reliability has therefore become a critical design requirement.

Flip Chip on Board (FCOB) assemblies are particularly sensitive to drop impact due to:

- High stiffness mismatch between silicon chip and PCB
- Local stress concentration at solder joints
- High acceleration pulses during impact

Finite Element Analysis (FEA) is widely used to simulate drop behavior and predict failure mechanisms before physical prototyping.

In this study, both **experimental drop testing** and **explicit dynamic simulation** were conducted to evaluate PCB response under a 1-meter free-fall condition.

Why Heat Sink PCBs are Important in Electronic Circuits

All electrical components in a circuit produce heat while the circuit is functioning. High-power devices such as power transistors, LEDs, and lasers produce heat. Some of these components can't dissipate heat since they have a low dissipation capability.

Heat build-up in the component can result in total failure or premature failure in the device. Therefore, heat sink boards are a perfect way to conquer these problems.

These circuit boards are used in most applications because of their cooling functions. PCB manufacturers include a heat sink in PCB due to the numerous benefits it offers.

Passive Heat Exchange

Heat sink PCBs feature a large surface area that cools off. These boards act as passive heat exchangers. The component of a device that can't control its temperature needs heat sink PCBs. To improve performance, every heat in a component of an electronic circuit must be dissipated. This will help to prevent the component from experiencing any failure.

Maintains Thermal Stability

Heat sinks in PCB help to maintain thermal stability in any electronic device. Thermal stability is very

important for electronic components of any circuit. Heat sink PCBs can survive in any temperature because of their cooling ability. This is a major reason these PCBs are employed in high-performance applications.

Heat sinks don't only dissipate heat; they also provide heat during low temperatures. They do this by generating thermal energy for the smooth functioning of the circuit.

Spreads heat

Heat sinks serve as heat spreaders in some applications. For instance, a heat sink PCB functions as covers on the memory of a computer. Heat sinks also help to cool off the graphic processors and CPU of computers.

Prevents system failure

Heat sinks prevent system failure in a circuit. The absence of a heat sink can cause the failure of components. It is advisable to implement a heat sink in a PCB to

prevent overheating. Component failure is one of the common problems of electronics or electrical devices.

Different types of mechanical and electronic devices generate heat which heat sinks absorb. Heat sink PCBs play significant roles in mechanical, electronic, nuclear, and solar processes.

Types of Heat Sink

Heat sinks are available in various types. Each of these types has its function. However, they share some common characteristics or features. Heat sinks are mostly made from metal like aluminum or copper. The commonest designs for a heat sink are the fin layout. Some versions utilize stamping and pins to increase the surface area and heat transfer rate.

Passive heat sink

A passive heat sink doesn't feature additional products while cooling a component. It isn't assisted by additional processes. These heat sinks don't have any mechanical components. They dissipate heat through the convection process. When you use this heat sink

on PCB, it gives reliable results. Experts recommend that engineers should maintain the flow of air across the fins of this heat sink.

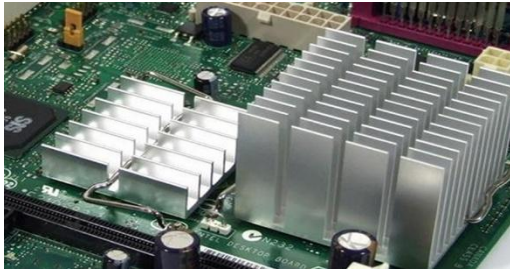


Fig. Passive heat sink

Passive heat sinks serve as a standalone solution since they don't use other cooling methods. These heat sinks are bigger than active heat sinks. Passive heat sinks disperse absorbed heat via the direct contact between them.

Active heat sink

This type of heat sink uses additional products to enhance its cooling capacity. Active heat sinks use powered processes like water pumps and fans. These processes or products help to increase the heat transfer rate.

In some electronic systems, these coolers run off the internal power supply. This type of heat sink isn't ideal for long-term applications. This is because it has moving parts.



Active heat sink

Active heat sinks make use of one or more fans. These fans are either above or on the side of the fin stack. Some advanced active heat sinks use water to transfer heat from a source.

Heat Sink Types Based on Manufacturing Techniques



Circuit board heat sink

Various manufacturing methods are used in manufacturing heat sinks. Stamped heat sink :



Stamped heat sink

This type of heat sink features stamped metals. These metals can form a certain shape. The stamp designs the heat sinks anytime metal moves via the stamping machine. Stamped heat sinks are ideal for low-power applications.

Bonded heat sink

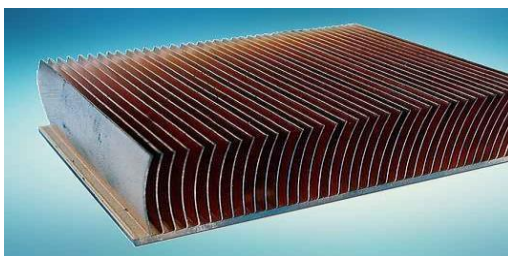
This type of heat sink is ideal for large applications that demand sensible performance.



Bonded heat sinks are designed by combining separate fins of metal to the heat sink's base. There are two different methods for doing this. They are the brazing and the thermal epoxy methods.

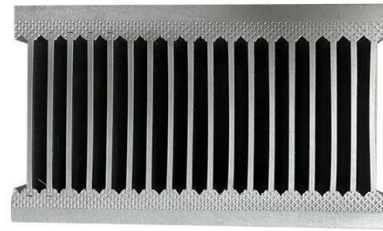
Skived heat sink

Skived heat sinks employ skiving for their manufacturing. Skiving is the use of fine blocks of metals for manufacturing heat sinks. Skived heat sinks can be high or medium-performing heat sinks.



Swaged heat sink

Swaged heat sinks are medium-performing heat sinks. Swaging is a manufacturing technique that involves a cold working forging process. However, it can undergo a hot working process.



Forged heat sink

Forging involves utilizing compressive forces. This technique is used for manufacturing aluminum and copper heat sinks.



Machining heat sink

This type of heat sink uses a machining process for its manufacturing. Gangsaw helps to eliminate a block of material. This type of manufacturing process is expensive since a lot of metal may waste.



Applications of Heat Sink PCB

Heat sink PCBs are used in several applications due to the functions they

perform. These circuit boards are ideal for high-performance applications. They are also suitable for use in devices that produce a high amount of heat.

LEDs

Heat sink PCBs are commonly used in Light-emitting diodes (LED). These PCBs provide effective cooling for LED pcb. Heat sink circuit boards prevent excess heat from damaging LEDs. Most high-power LEDs feature heat sink PCBs.

Computers

Heat sink PCBs are a common component of computers. The CPU of computers needs a heat sink. Electrical activity in the CPU produces a good amount of heat. This may cause damage to the chipset. A heat sink helps to offer a good path for heat to pass through. The CPU comes with a heat sink. Some manufacturers use a particular type of heat sink for their CPUs.

Industrial facilities

Most industrial devices generate heat while in use. Therefore, a heat sink PCB is ideal for use in industrial equipment. Heat sinks are connected on a circuit board because of their cooling properties. They reduce the amount of absorbed heat in a mechanical device while running.

Soldering

During the soldering process, heat sinks help to protect electronic components.

Some components need the protection of a heat sink during soldering.

Consumer products

Heat sink PCBs are used in most consumer products. Some electronic devices in the home come with heat sinks. This is because some components of these devices generate a lot of heat. Therefore, heat sink PCBs help to dissipate heat in these devices.

The Limitations of Heat Sink PCB

The cooling of electronic devices is important for their long-lasting function. The need for circuit board cooling has continued to increase. Heat Sink PCBs help to dissipate heat in electronic devices. The importance of the use of heat sinks in PCBs can't be overemphasized.

2. LITERATURE REVIEW

Previous research has focused on drop impact reliability of electronic packages and solder joints.

- Seah et al. (2002) investigated PCB mechanical response during portable device drop impact.
- Arra et al. (2002) studied lead-free solder joint performance under dynamic loading.
- Tee et al. (2003) conducted board-level drop test simulations of BGA packages.
- Suhir (2002) discussed whether shock testing adequately mimics drop conditions.

Most studies highlight:

- Fundamental vibration mode dominates PCB response.
- Maximum strain occurs near package center.
- Drop base stiffness significantly affects impact duration.

- Softer bases reduce peak acceleration but increase pulse duration.

Explicit dynamic methods have become preferred for high-speed transient simulations due to their ability to handle:

- Large deformation
- Nonlinear contact
- Breakable connections
- Highly transient events

3. EXPERIMENTAL SETUP

3.1 Drop Test Machine

The drop test was conducted using a Lansmont Model 65/81 shock test machine.

- Drop height: 1 meter
- Pulse type: Half sine pulse
- Drop table mass: 190.5 kg
- Mounting surface: 650 mm × 810 mm

Four felt pads were used to avoid metal-to-metal contact.

3.2 Specimen Description

- PCB dimensions: 185 mm × 150 mm
- Large flip chip: 8 mm × 8 mm
- Small flip chip: 3 mm × 3 mm
- Clamped at two longer edges

3.3 Instrumentation

- High-speed camera for displacement measurement
- Accelerometer at PCB center
- Strain gauges near chip center

3.4 Experimental Observations

- Fundamental frequency ≈ 195 Hz
- Measured vibration period ≈ 5.2 ms

- Maximum strain ≈ 1500 microstrain
- Vibration amplitude at center ≈ 4.9 mm

The PCB motion resembled simple harmonic motion dominated by first bending mode.

4. NUMERICAL MODELING

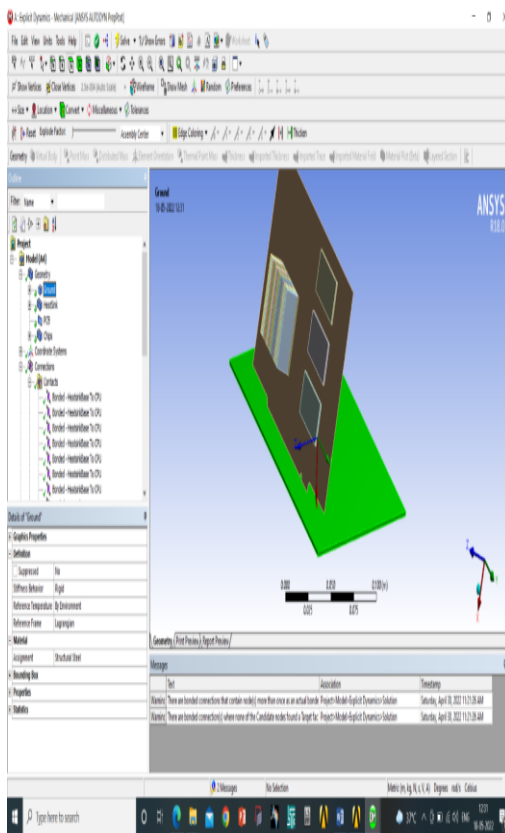
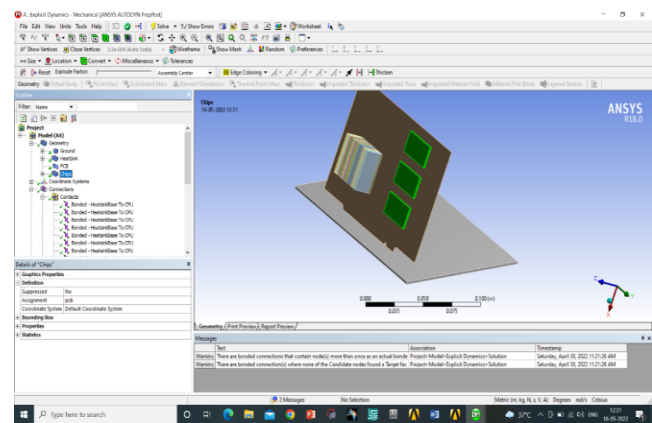
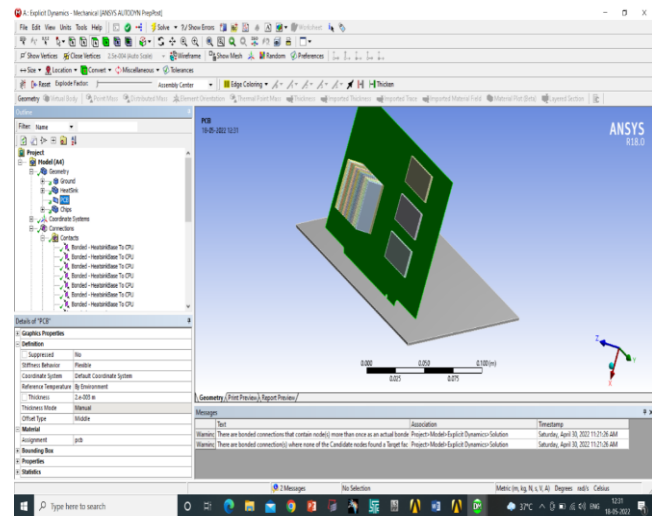
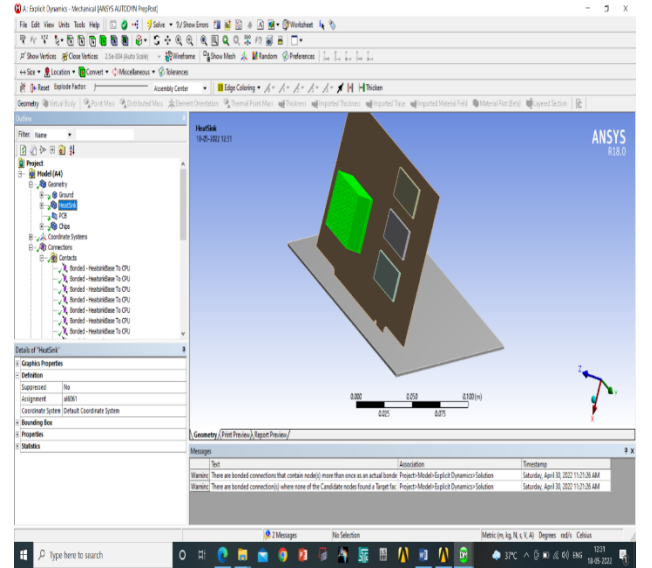
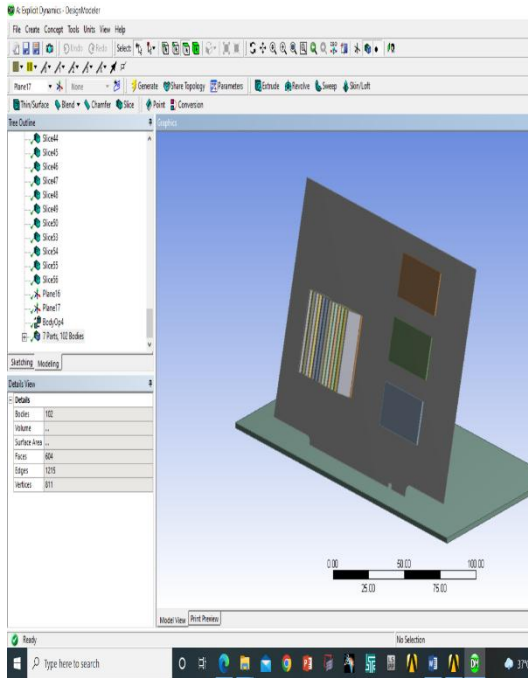
4.1 Finite Element Model

The FEA model included:

- PCB (modeled using shell elements)
- Flip chips (solid elements)
- Fixture
- Drop table
- Bottom buffer

Space claim:

- SpaceClaim is a solid modeling CAD (computer-aided design) software that runs on Microsoft Windows and developed by SpaceClaim Corporation. The company is headquartered in Concord, Massachusetts.
- SpaceClaim Corporation was founded in 2005 to develop 3D solid modeling software for mechanical engineering. Its first CAD application was launched in 2007 and used an approach to solid modeling where design concepts are created by pulling, moving, filling, combining, and reusing 3D shapes.



Circuit board

- Parts – cpu

Boundary Conditions

- Two longer edges clamped (spot-weld constraint)
- Motion allowed only in drop direction (Y-axis)
- Other DOFs constrained

Solder joints were simplified as rigid connections (3x3 node groups).

5. FINITE ELEMENT METHOD (FEM)

The Finite Element Method is a numerical technique used to solve structural problems governed by partial differential equations.

The governing dynamic equation is:

$$M \ddot{u} + C \dot{u} + K u = F$$

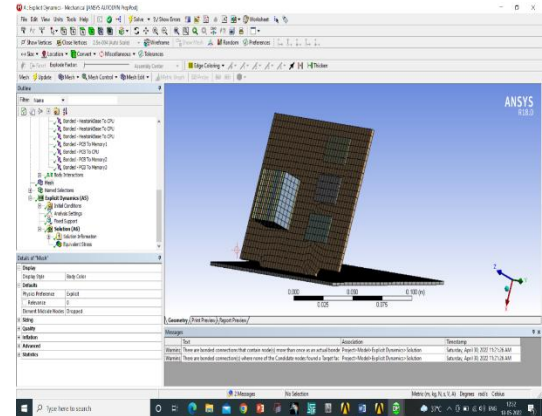
Where:

- M = Mass matrix
- C = Damping matrix
- K = Stiffness matrix
- u = Displacement
- v = Velocity
- a = Acceleration
- F = External force

The structure is discretized into finite elements, forming a system of algebraic equations.

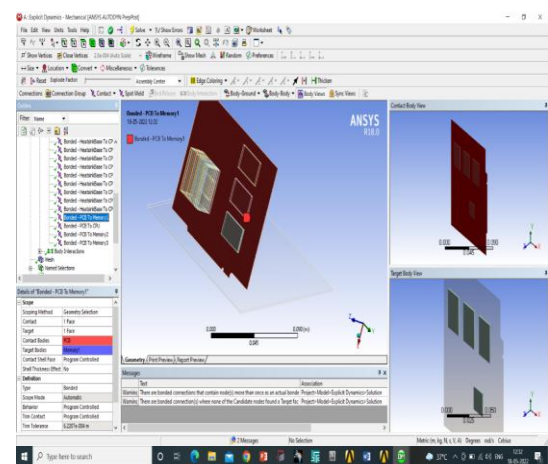
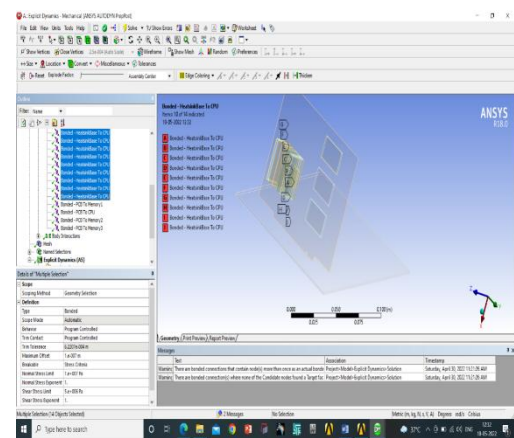
Advantages:

- Handles complex geometry
- Suitable for nonlinear materials
- Capable of contact and impact simulation

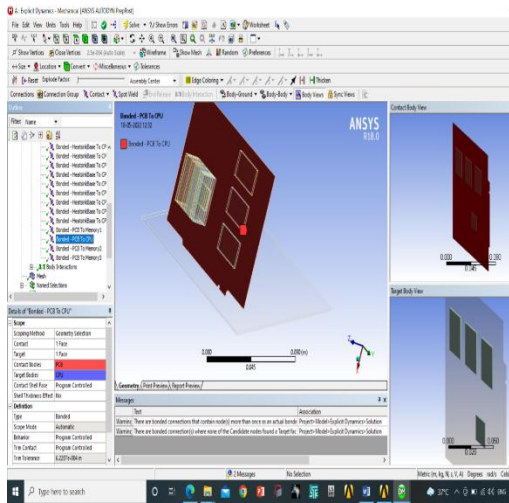


Mesh

1. Connections:



Bonded connections



Bonded pcb to cpu

6. EXPLICIT DYNAMIC ANALYSIS

Traditional implicit methods require:

- Matrix assembly
- Iterative convergence (Newton-Raphson)
- Large computational effort

Explicit dynamics differs by:

- Direct time integration
- No need for convergence iteration
- No matrix decomposition
- Suitable for high-speed transient problems

However, explicit analysis requires very small time steps determined by:

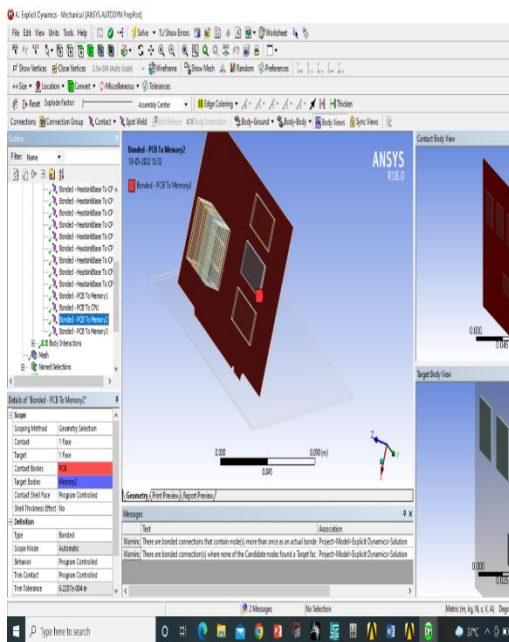
$$\Delta t \leq T_{\min} / \pi$$

Where T_{\min} is the smallest natural period in the system.

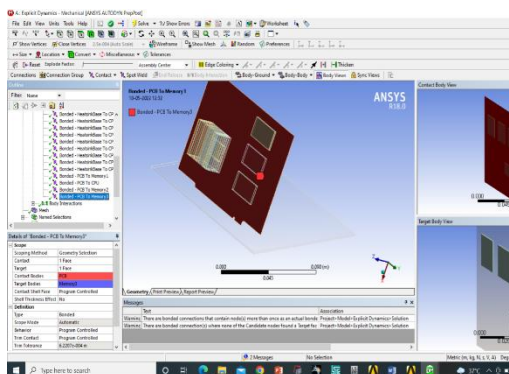
Advantages in drop test simulation:

- Handles large deformation
- Models contact and separation
- Simulates element breakage
- Efficient for short-duration events

7. CONTACT MODELING



Bonded connections



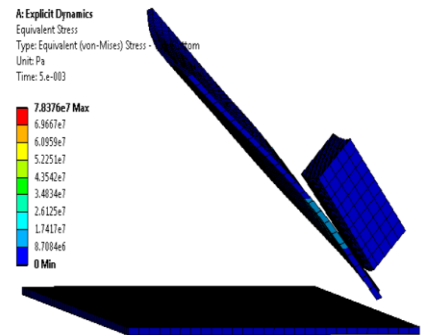
Two contact approaches were implemented:

1. Bonded (Non-breakable) Contact

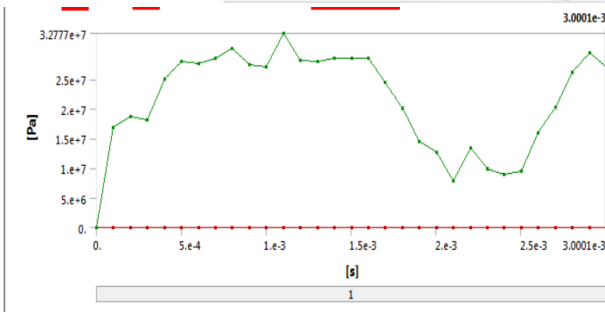
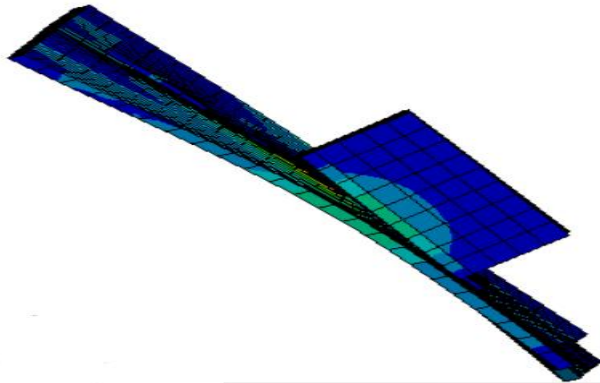
- No separation allowed
- Nodes share same displacement
- Suitable for rigid connection

2. Stress-Based Breakable Contact

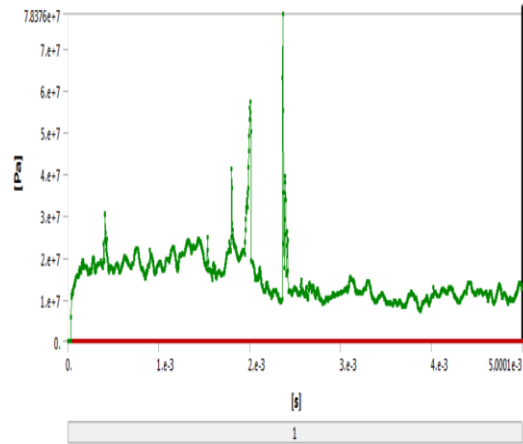
- Contact fails when stress exceeds limit
- Allows element deletion
- Models realistic failure



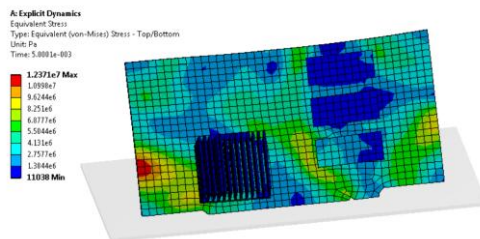
8. RESULTS



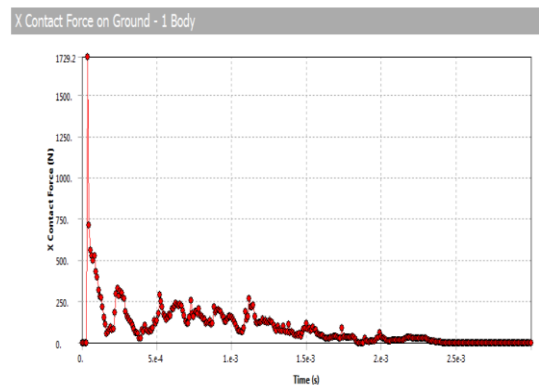
Contact



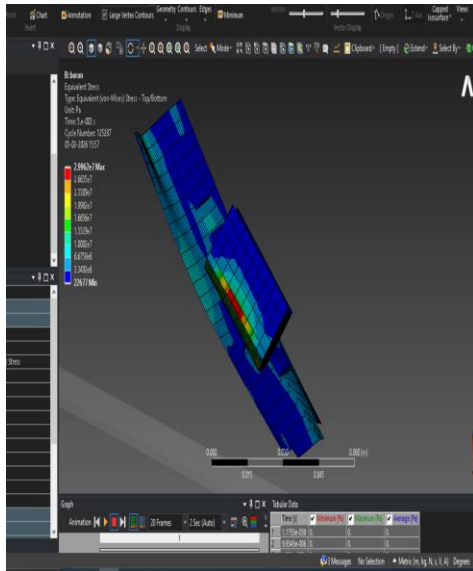
Graph energy of aluminum



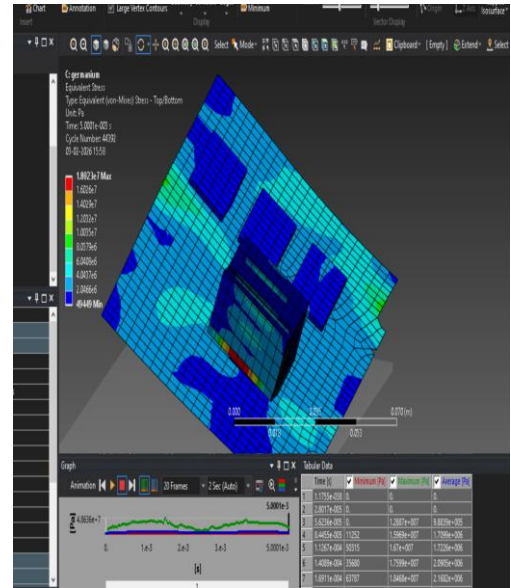
Stress



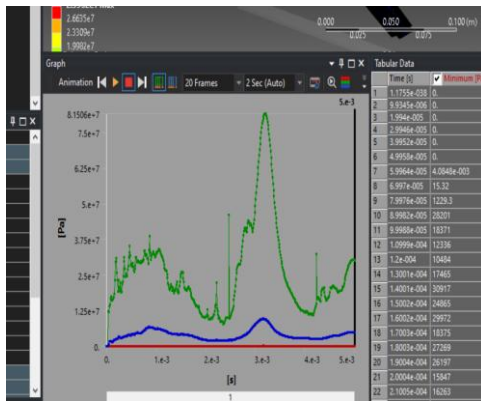
Contact force



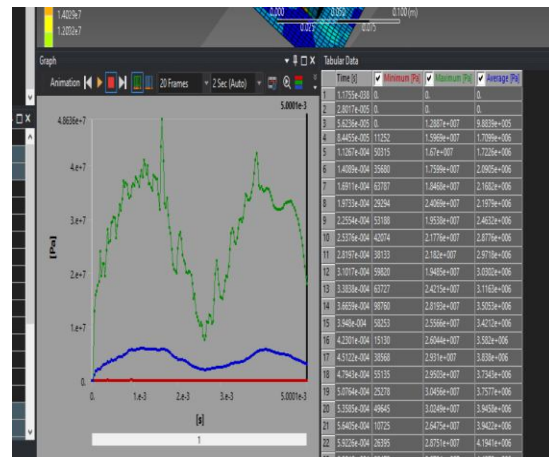
Equivalent stress of boron



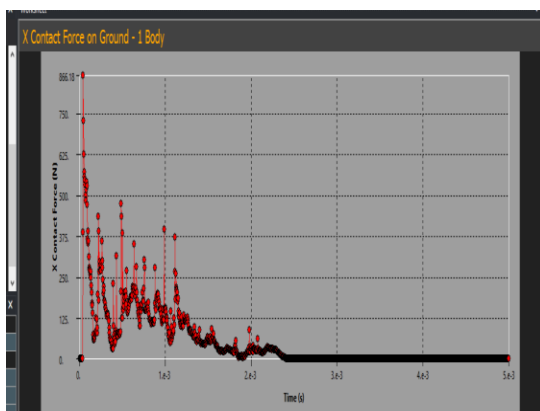
Equivalent stress of Germanium



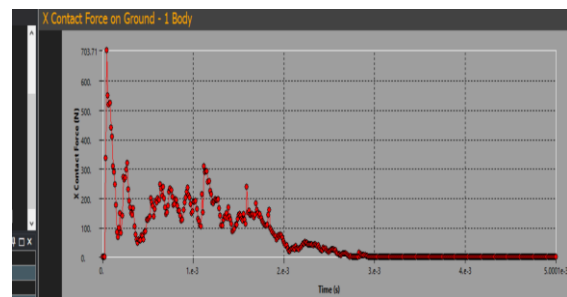
Contact Energy of boron



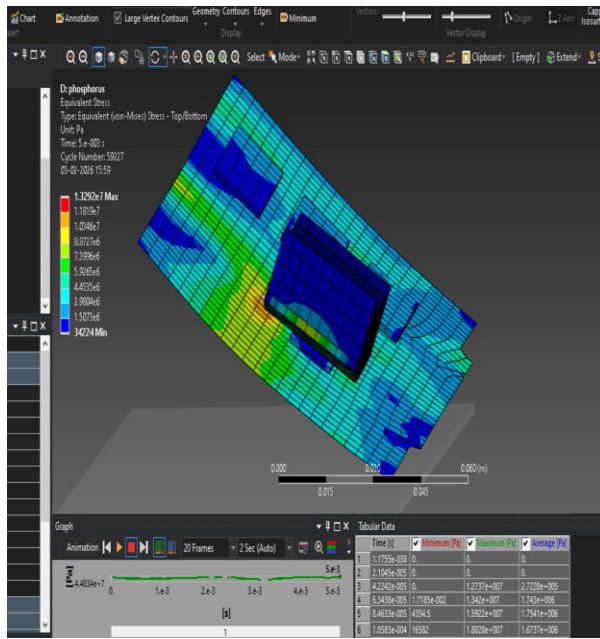
contact Energy of germanium



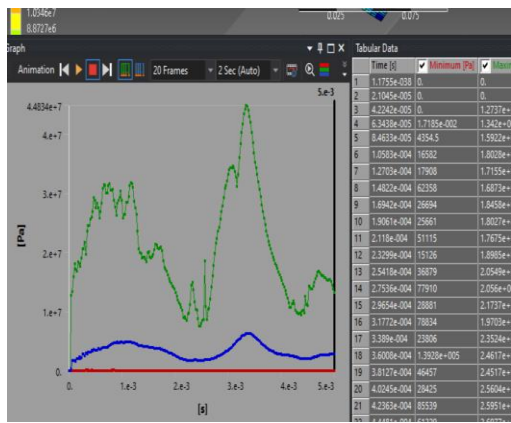
Contact force of boron



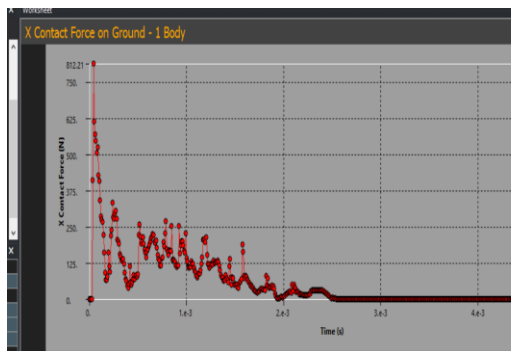
Contact force of Germanium



Equivalent stress of phosphorus



Contact Energy of phosphorus



Contact force of phosphorus

8.1 Displacement

- Maximum central deflection ≈ 4.9 mm
- Simulation period ≈ 5.4 ms
- Close to experimental frequency

8.2 Strain

- Maximum strain ≈ 1500 microstrain
- Good repeatability across tests
- Accelerometer increased strain by $\sim 25\%$

8.3 Stress Comparison

Material	Equivalent Stress (MPa)
Structural Steel	78
Boron	29
Germanium	18
Black Phosphorus	13

Softer drop base reduced peak acceleration and stress.

9. DISCUSSION

- Explicit dynamics accurately captured PCB bending behavior.
- Fundamental mode dominated system response.
- Breakable contact modeling improved realism.
- Drop base stiffness significantly influenced impact severity.
- Accelerometer mass affected measured strain.

The stress-based breakable model showed better agreement with experimental data compared to non-breakable model.

10. CONCLUSION

Board level free fall drop test of 1 meter drop height was conducted for FCOB assembly considering two different drop bases. High speed camera,

accelerometer and strain gauge measurements were implemented on the PCB specimen during the drop test and they gave similar results. Softer drop base would reduce the maximum deflection and acceleration during impact and extend the duration of impact.

A board-level free-fall drop test from 1 meter height was conducted on an FCOB assembly.

Key findings:

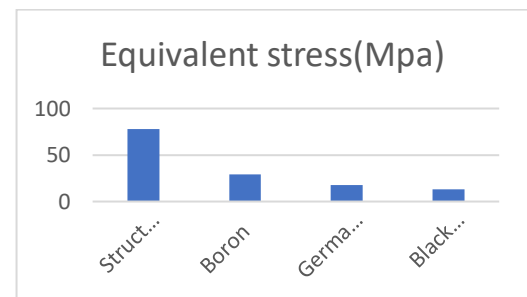
- Maximum strain \approx 1500 microstrain
- Fundamental frequency \approx 195 Hz
- Softer drop base reduces peak acceleration
- Explicit dynamic simulation closely matches experiment
- Stress-based breakable model gives more realistic results

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Explicit dynamics is highly suitable for PCB drop impact analysis due to its ability to handle nonlinear contact and high-speed events.

S.No	Material	Equivalent stress(Mpa)
1	Structural steel	78
2	Boron	29
3	Germanium	18
4	Black phosphorus	13



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