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Experimental and Numerical Verification of Impact Durability of Electric Vehicle Battery Pack Cases †

Mingoo Cho [1], Eulyong Ha [2], Younghyun Kim [2], Sungwook Kang [3] and Jaewoong Kim [2,*]

1 Extreme Process Control Group, Korea Institute of Industrial Technology, Jinju-si 52845, Republic of Korea; cmg0142@kitech.re.kr

2 Purpose Built Mobility Group, Korea Institute of Industrial Technology, Gwangju 61012, Republic of Korea; 23hey0302@kitech.re.kr (E.H.); kyh1927@kitech.re.kr (Y.K.)

3 Department of Smart Ocean Mobility Engineering, Changwon National University, Changwon-si 51140, Republic of Korea; swkang@changwon.ac.kr

* Correspondence: kjw0607@kitech.re.kr

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Abstract

The structural safety of lithium-ion battery systems in electric vehicles (EVs) has become increasingly important with growing concerns over battery-related accidents. In particular, external impacts on the battery pack case (BPC) can cause cell deformation or short-circuiting, potentially leading to thermal runaway. In this study, the mechanical integrity of a commercial BPC was evaluated using both drop-weight impact tests and finite element method (FEM) simulations. A 10 kg hemispherical or cylindrical weight was dropped from a height of 7 m to generate high-energy vertical impacts. The deformation and potential failure of the BPC were examined experimentally, and equivalent FEM simulations were conducted to analyze stress and deformation responses. In both cases, the BPC maintained structural integrity without cracking or intrusion into the battery cell region. The hemispherical impact resulted in relatively shallow, distributed deformation, whereas the cylindrical impact produced more localized indentations due to stress concentrations. The close agreement between experiment and simulation confirms the suitability of FEM for pre-assessment of BPC impact on safety. These findings provide a useful basis for establishing mechanical design criteria and improving battery protection strategies for EV applications.

Keywords: battery pack case (BPC); finite element method (FEM); drop test; drop weight; structure analysis

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1. Introduction

The safety of lithium-ion batteries in electric vehicles (EVs) has become essential as incidents related to battery fire and structural failure have been reported in recent years. Among various battery-system components, the battery pack case (BPC) plays a critical role in preventing mechanical intrusion into the battery cells during external impact events such as road debris strikes, curb collisions, and underbody impacts [1].

If a BPC is excessively deformed, compressive interaction with internal cells may occur, increasing the likelihood of electrical short circuits and subsequent thermal runaway [2,3]. As a result, vehicle manufacturers have strengthened mechanical requirements for BPC design in parallel with the expansion of lightweight materials [4,5]. While several studies have assessed module-level and crash-level battery integrity, experimental investigations on localized impact resistance of full-scale BPC structures remain limited.

To address this problem, we evaluated the drop-impact response of a commercial BPC subjected to severe vertical loading. Both experimental tests and finite element method (FEM) simulations were carried out under consistent conditions. The primary objective was to confirm whether the BPC can maintain sufficient mechanical integrity to protect cells during a drop-like impact scenario and to verify whether FEM analysis can be reliably used in the structural design stage.

2. Finite Element Analysis of Drop-Weight Impact

To analyze the impact response of BPC under drop-weight loading, a finite element analysis was performed using the Explicit Dynamics module in ANSYS Workbench 2024 R2 (ANSYS Inc., Canonsburg, PA, USA) Workbench. The analysis model constructed for the drop simulation is shown in Figure 1.

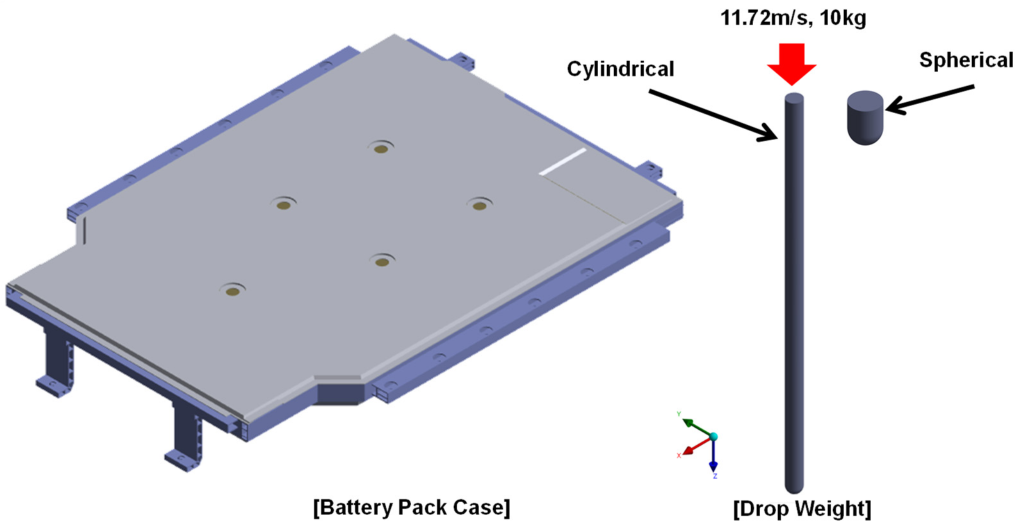

Figure 1. The analysis model used in this study.

A commercially manufactured BPC model was used, and both a spherical and a cylindrical impactor were assumed to strike the BPC. The material properties applied to the analysis are summarized in Table 1, and these material data were provided by the BPC manufacturer. Although the drop height was intended to be 7 m, directly modeling a free fall from this height significantly increases computation time. Therefore, the free-fall velocity calculated using Equation (1) was applied as the initial velocity condition, where v is the free-fall velocity, g is the gravitational acceleration, and h is the drop height.

$$v = \sqrt{2gh}, \tag{1}$$

Each impactor had a mass of 10 kg, and the six impact points used in the simulation are shown in Figure 2.

The analysis results indicate that stresses exceeding the yield strength occurred at all impact points, suggesting that permanent deformation would be expected during actual testing (Figure 3). However, the predicted stresses did not exceed the material's tensile strength, implying that fracture or catastrophic failure of the BPC is unlikely.

Table 1. Material properties.

Material	Elastic Modulus (GPa)	Yield Strength (MPa)	Poisson's Ratio
SGACUD 60/60 (Galvannealed Steel Sheet/Coil)	210	142.66	0.3
PA6_GF30	9.7	30	0.3
A3003-O	68	61	0.3
A6082S-T6	68	260	0.3
A6N01S-T6	68	240	0.3
A6061P	68	245	0.3
Structure steel	200	250	0.3

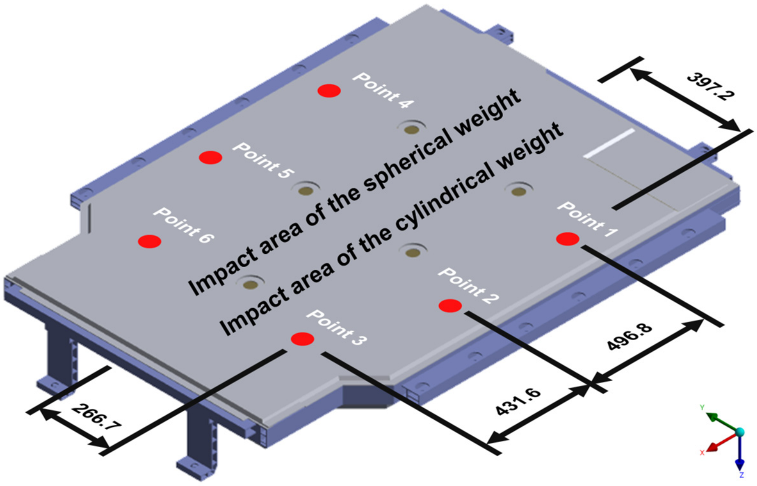

Figure 2. The drop position of the weight.

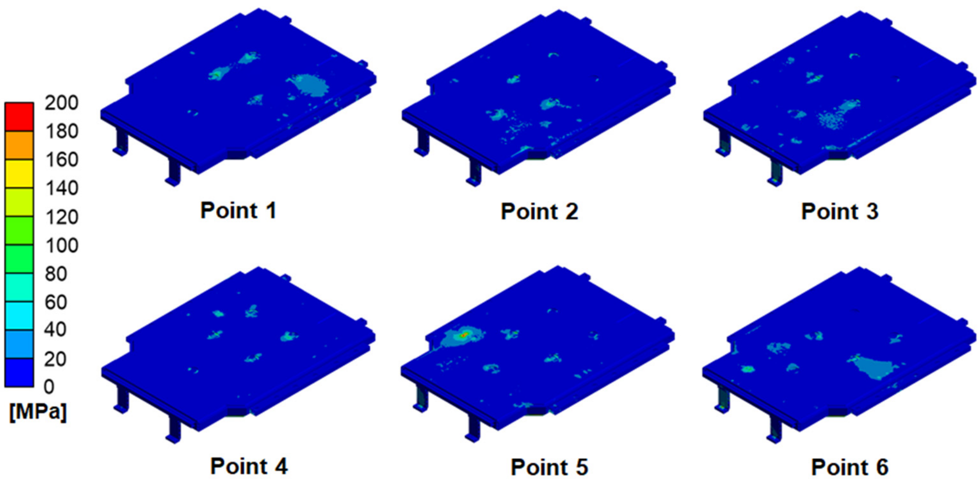

Figure 3. Drop impact analysis results.

3. Drop-Weight Impact Test

To evaluate the response of BPC under drop-induced impact, a series of drop-weight impact tests was conducted. Two types of impactors, a hemispherical weight and a cylindrical weight, were used, each with a mass of 10 kg and a drop height of 7 m. Although the commonly adopted drop height in industry is approximately 5 m, a more severe condition was selected in this study to assess the structural robustness of the BPC.

A total of six impact points were designated on the BPC, and each weight type was dropped on three points. As a result, deformation was observed at all impact locations, with the largest deformation occurring at position No. 4, where the spherical weight was dropped. Approximately 10 mm of deformation was observed in the lower cover of the BPC, which may potentially damage the cooling channels located beneath the cover (Figure 4). In Figure 4, the non-English annotation refers to impact position No. 4, where the spherical weight was dropped. However, no adverse effects were observed on the battery cells inside the pack.

Figure 4. Drop result.

4. Results and Discussion

In this study, the drop-impact behavior of the BPC was investigated through both finite element analysis and drop-weight impact testing. In the numerical analysis, the impact of 10 kg spherical and cylindrical impactors dropped from a height of 7 m was simulated using ANSYS Explicit Dynamics. The free-fall velocity calculated from the drop height was applied as the initial condition. The results showed that the equivalent stress exceeded the yield strength at all impact locations, indicating that permanent deformation could occur under actual impact conditions. However, the maximum stress remained below the tensile strength, suggesting that fracture of the BPC is unlikely under the investigated conditions.

The drop-weight impact tests showed approximately 10 mm of deformation in the lower cover of the BPC. This trend was generally consistent with the analysis results, which also predicted local permanent deformation rather than catastrophic failure. These results indicate that the lower cover can absorb impact energy through local deformation under severe impact loading.

From a structural safety perspective, the results suggest that although the lower cover may deform and potentially affect the cooling channels beneath it, the deformation did not reach the battery cells and no cell damage was observed in the present tests. This implies that the investigated BPC has a certain level of structural robustness against severe drop impact.

However, several limitations should be noted. The material properties used in the numerical analysis were provided by the BPC manufacturer, and the simulation applied an initial impact velocity instead of directly modeling the full free-fall motion. In addition, only limited impact locations and two impactor shapes were considered. Therefore, further studies are needed to evaluate a wider range of impact conditions and to assess possible effects on cooling performance and long-term structural reliability.

5. Conclusions

This study evaluated the drop-impact resistance of a commercially manufactured BPC through finite element analysis and drop-weight impact testing. The results showed that severe impact can cause permanent deformation of the lower cover, but a fracture of the BPC and direct damage to the internal battery cells were not observed under the investigated conditions. These findings indicate that the BPC has a certain level of structural robustness against drop impact. However, the results should be interpreted with consideration of the simplified numerical conditions and limited impact scenarios used in this study.

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Conflicts of Interest: The authors declare no conflict of interest.

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