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# Structural Simulation Analysis of Liquid Cooling and Load-Bearing Integrated Component for Liquid Cold Plates Based on ANSYS

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**Abstract:** Energy storage liquid cold plates serve dual functions in battery packs: heat dissipation and structural load bearing. Their structural stiffness directly affects the reliability and safety of battery modules. This paper takes a liquid cold plate assembly of an energy storage system as the research object, and establishes a complete assembly finite element model including the liquid cold plate, module beams, and bottom profile frame based on ANSYS software. A load-bearing performance simulation analysis is conducted under a static load condition. The study demonstrates that ANSYS-based finite element simulation can effectively identify structural weak links in liquid cold plate assemblies, providing a reference basis for the structural-functional integrated design of liquid cold plates in energy storage systems.

**Keywords**:liquid cold plate; finite element analysis; structural stiffness; load-bearing performance; ANSYS

## 1.INTRODUCTION

Lithium-ion battery energy storage systems have become a key technology supporting the grid integration of new energy generation and the safe and stable operation of power grids. With the continuous evolution of energy storage systems toward larger capacity and higher energy density, the capacity of single cells has gradually increased from 120 Ah to 314 Ah and even above 580 Ah, while the system capacity of a single energy storage unit has jumped from 2.5 MWh to 5 MWh or even 6.25 MWh [1]. This development trend poses greater challenges to the thermal management of energy storage systems. Cold-plate liquid cooling, with its advantages of high heat exchange efficiency and compact structure, has become the mainstream cooling solution for large and medium-sized energy storage systems [1]. As the core component of cold-plate liquid cooling systems, the liquid cold plate plays a dual role in the battery pack: on one hand, it removes heat generated by cells through internal coolant circulation; on the other hand, it serves as the structural base plate bearing the entire weight of the battery modules above. Under the trend toward larger capacity in energy storage systems, the module mass borne by the liquid cold plate has increased from several hundred kilograms in early designs to over one ton, imposing higher requirements on the stiffness and strength of the liquid cold plate and its supporting structure. Excessive deformation of the liquid cold plate can lead to poor contact between the cell bottom and the cold plate, increased thermal contact resistance, and deteriorated heat dissipation performance; in severe cases, it may cause failure of cell tab connections, posing safety risks [2]. Therefore, the load-bearing performance of the liquid cold plate is one of the key indicators that must be prioritized in system design.

In terms of structural strength simulation of liquid cold plates, Bi Ran et al. [2] conducted a static load-bearing simulation of a stamped liquid-cooled battery box for energy storage based on ANSYS Workbench, applying a module mass of approximately 350 kg uniformly onto the top surface of cross beams. They found that the stress in the region between adjacent flow channels at the bottom of the liquid cold plate reached 52.29 MPa, exceeding the yield strength of AL3003 (50 MPa), and optimized the structure by adding convex features. Xian Dazhong [3] studied the deformation control of aluminum liquid cold plates and found that after adding welded supports inside the flow channels, the deformation under 1 MPa pressure decreased from 2.1 mm to 0.275 mm, a reduction of approximately 87%. Le Ningjian et al. [4] designed a brazed liquid cold plate with internal fin supports, controlling deformation within 0.5 mm under 150 kPa hydraulic pressure. The above studies focused on hundred-kilogram-level loads or single liquid cold plate components, lacking quantitative analysis of the structural response of complete assemblies under loads exceeding one ton.

This study employs the ANSYS finite element method to perform numerical simulation of the load-bearing performance of an energy storage liquid cold plate assembly, investigating the influence patterns of static load magnitude, bottom support conditions, and profile frame cross-sectional parameters on the deformation and stress distribution of the liquid cold plate assembly. The study systematically reveals the mechanical effects of the liquid cold plate assembly under a 1638 kg heavy load from the perspective of structural mechanics, quantitatively identifies the contribution of each component to the overall deformation, and elucidates the mechanical mechanism by which insufficient stiffness of the profile frame leads to excessive overall deformation, providing data support and theoretical basis for the optimal design of load-bearing structures of liquid cold plates.

## 2.MODEL AND METHODS

### 2.1 Geometric Model

In the load-bearing analysis of the battery pack in this paper, the load-bearing structure studied consists, from bottom to top, of the bottom profile, the liquid cold plate, and the module beams. The liquid cold plate body, module beams, and bottom profile frame are connected through welding or bolting to form a complete cooling-load-bearing integrated assembly. To balance computational efficiency and simulation accuracy, the following simplifications and equivalent treatments were applied to the original model:

(1) Geometric simplification: Non-critical local features such as fillets and chamfers were removed to reduce mesh generation difficulty and element count. Meanwhile, the flat plate and flow channel plate of the liquid cold plate were separately mid-surfaced and converted into shell element models, significantly reducing computational scale while ensuring in-plane stress accuracy.

(2) Load equivalence: The battery pack geometry was removed, and the pressure exerted by the battery pack on the liquid cold plate was equivalently represented as a distributed mass load applied to the corresponding load-bearing areas.

The above simplifications do not significantly affect the overall structural load-bearing response, and the processed model is used for subsequent finite element static analysis.

### 2.2 Material Properties

The liquid cold plate body is made of AL3003 aluminum alloy, which possesses good thermal conductivity and formability, making it suitable for stamping and brazing processes. The bottom profile frame and module beams are made of high-strength structural steel with high yield strength and bending stiffness. The combination of these two materials achieves a collaborative design of "heat dissipation function" and "load-bearing function."

### 2.3 Load, Boundary Conditions, and Mesh Generation

This study simulates the load-bearing state of the energy storage battery pack under static conditions. The load condition is as follows: the total weight of the battery module (1638 kg) is applied as a uniformly distributed pressure on the mounting surface of the module beams, with the direction vertically downward, and standard Earth gravity is also applied. The boundary condition is set by applying fixed constraints to the bottom surface of the bottom profile frame, constraining translational degrees of freedom in the X, Y, and Z directions. A mesh size of 3 mm is set with adaptive refinement enabled.

## 3 RESULTS AND DISCUSSION

### 3.1 Deformation Analysis

Under the conditions of 1638 kg vertical uniformly distributed load combined with gravity and full fixed constraints at the bottom frame, the overall deformation distribution shows a maximum total deformation of 6.3611 mm. The deformation near the fixed boundaries of the structure is close to 0 mm, representing optimal stiffness. Two independent red deformation peak regions are formed along the length direction, with deformation gradually increasing from the edges toward the middle. The mid-span position exhibits the most prominent downward deflection. The overall deformation distribution of the panel completely follows the bending pattern of the internal support beams.

The simulation results of the extracted support frame skeleton show values nearly identical to those of the panel model. The two deformation peak positions and deformation gradient distributions correspond exactly to the panel contour maps, demonstrating that the overall structural bending stiffness is determined by the internal main beams, while the panel only serves to transmit loads with negligible stiffness contribution. The peak deformation zones correspond to large-span intervals of the main beams without lateral secondary beam supports, where concentrated mid-span bending moments are the core cause of large deflections. The maximum deformation of 6.36 mm poses risks such as assembly misalignment and connector fatigue during service.

### 3.2 Stress Analysis

The overall equivalent stress distribution is shown in Figure 1. Under full fixed constraints at the bottom frame, the vast majority of the structure maintains stresses at very low levels, with the overall background appearing dark blue. Stress concentration only occurs at the root corner positions where the main beams connect to the frame. The global maximum equivalent stress reaches 1358 MPa. The stress concentration zone is located at the sharp transition corner of the profile bend, where cross-sectional abrupt changes cause sharp amplification of local stress during load transmission. As the conventional yield strength of aluminum alloy is far below this value, this location has already exceeded the material's load-bearing limit, posing significant risks of plastic yielding and structural fracture failure

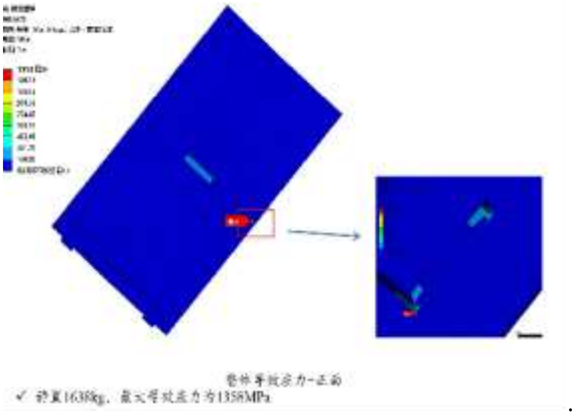

Figure 1 Overall equivalent stress

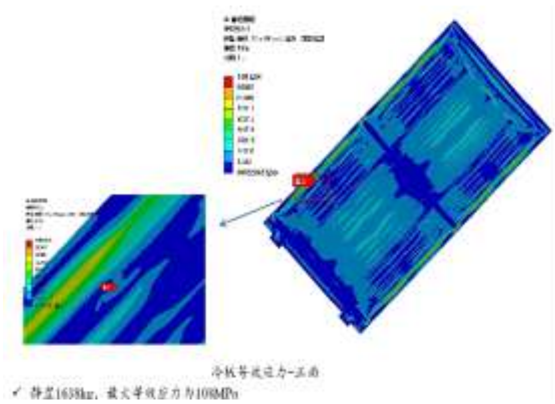

Figure 2 Equivalent stress of the cold plate

The overall stress level of the cold plate component is relatively low, with large areas showing low-stress blue zones. Only along the plate edges and overlapping areas with support beams do strip-shaped medium-to-high stress zones form. The cold plate surface shows no obvious local stress concentration, and the stress distribution is uniform and smooth, demonstrating that the cold plate primarily functions to transmit loads with sufficient structural strength reserve and overall safety.

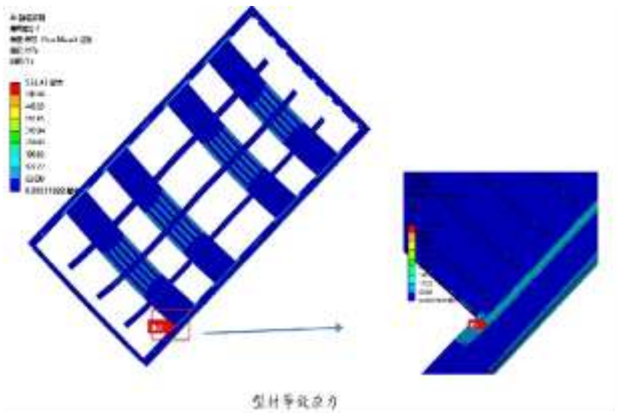

Figure 3 Equivalent stress of the profile

As shown in Figure 3, the vast majority of the profile area remains in a low-stress state, with stress concentration only forming at the corner cross-sectional transition where the main beams connect to the outer frame. This location is prone to plastic deformation or even cracking. The middle sections of the main beams exhibit uniformly distributed moderate bending stresses without local stress peaks. The structural failure risk is concentrated at the frame corners, which can be mitigated through geometric transition optimization to reduce peak stresses.

## 4. Conclusion

(1) Deformation analysis: Under the given static load, the overall deformation of the liquid cold plate assembly and the bottom profile frame exceeds the allowable design range, indicating insufficient structural stiffness. This demonstrates that the focus of structural improvement should be on enhancing the stiffness of the bottom profile frame.

(2) Stress analysis: Local stress concentration points exist in the cold plate component, the profile component, and the module beams. Except for the stress concentration zones, the overall stress levels of each component are not high. The stress value of the cold plate component exceeds the material's yield strength, and it is recommended to improve this through additional bottom supports or localized thickening in subsequent optimization.

(3) Weak links: Insufficient stiffness of the profile frame is the root cause of excessive overall deformation, specifically manifested as excessively small sectional moment of inertia, overly large support spans, and limited connection stiffness. The optimization priority should be placed on the bottom profile frame rather than the liquid cold plate itself.

(4) Optimization directions: It is recommended to increase the sectional moment of inertia of the bottom profile, add auxiliary supports at the mid-span to reduce support span, add fillet transitions at geometric abrupt change zones to alleviate stress concentration, and verify the optimization effectiveness through secondary ANSYS simulation.

## 6. ACKNOWLEDGMENTS

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