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Bead Pattern Optimization for Sheet Metal Panel using 3D Experience Platform

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Abstract

The significance of this research lies in its relevance to the automobile industry, particularly in the context of Electric Vehicles (EVs), where the demand for lightweight yet robust components is paramount to enhance efficiency and ensure safety standards. By employing sophisticated bead pattern optimization techniques, this study aims to markedly enhance the structural performance of battery cover panels, thus contributing to the production of more dependable and enduring vehicles. This research presents a pioneering approach to strengthen the structural integrity of battery cover panels in four-wheeler EVs through meticulous bead pattern optimization. Leveraging the advanced capabilities of the 3DExperience platform, this study facilitates the creation of intricate model geometries and facilitates comprehensive simulation studies. The primary objective of this optimization process is to maximize the minimum frequency of the component, consequently bolstering its structural resilience and longevity. The methodology entails an exhaustive exploration of various bead patterns and the execution of parametric design studies to ascertain the most optimal configuration. Through iterative simulations and meticulous analyses, the study strives to achieve a pragmatic solution that maintains structural robustness while ensuring minimal impact on weight and manufacturing feasibility. Furthermore, this research offers practical design guidelines and proposes an optimal bead design method to address the inherent deficiencies in plane sheet panels, which typically exhibit poor stiffness and vibration performance due to their flexibility. In the automotive industry, the addition of beads to sheet panels is a common and cost-effective approach to improve stiffness and vibration performance.

Major Findings: *The research successfully optimized the bead pattern of sheet metal panels for automotive components, enhancing structural stiffness and natural frequencies, particularly achieving a first mode frequency of 38.87 Hz without increasing weight.*

Keywords: *3DExperience Platform, Automobile Industry, Bead Pattern Optimization, Lightweight Design, Structural Performance*

1.0 Introduction

In the realm of sheet metal fabrication, "beads" refer to raised, elongated features or patterns that are strategically incorporated into the surface of a metal panel. These beads serve multiple functions, primarily aimed at enhancing the structural integrity, stiffness, and vibration performance of the panel[1,2]. In automotive applications, beads are often employed in various components to address challenges associated with flexural deflection, resonance, and overall durability. The importance of beads in sheet metal panels cannot be overstated, especially in the context of automotive engineering. By introducing beads, manufacturers can effectively mitigate issues related to panel flexibility and vibration, thereby significantly improving the overall performance and longevity of vehicle components[3–5]. Beads serve as reinforcement elements, distributing stress more evenly across the panel and reducing the risk of deformation or failure under load conditions. Without proper

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reinforcement, the sheet metal panel is susceptible to excessive vibration and flexural deformation, especially as the vehicle traverses uneven terrain or encounters dynamic loads during operation. The absence of beads or optimized bead patterns can exacerbate these issues, leading to diminished ride comfort, increased noise levels, and potential structural fatigue over time. Ultimately, the optimization of beads emphasizes both the enhancement of structural integrity and the improvement of durability and acoustic performance in automotive panels. The effective design of bead patterns contributes to enhanced vehicle design, resulting in greater resistance to mechanical stress, improved passenger comfort, and lower levels of Noise, Vibration, and Harshness (NVH). Through the utilization of sophisticated computational tools, manufacturers are able to model different bead pattern configurations and enhance their designs to attain maximum panel performance, all while minimizing material weight and ensuring cost effectiveness.

The primary objective of the optimization process outlined in this research is to maximize the minimum frequency of the Sheet metal flat panel component. By elevating the minimum frequency, the panel's natural vibrational modes are shifted to higher frequencies, reducing the likelihood of resonance and enhancing its overall structural resilience. This optimization strategy aims to bolster the panel's ability to withstand dynamic loads, minimize vibration-induced fatigue, and extend its service life within the vehicle chassis.

2.0 Literature Survey

The quest for enhanced stiffness and NVH (Noise, Vibration, and Harshness) performance in automotive body structures remains a pivotal concern within the automotive industry[6–8]. Traditionally, bead pattern design has relied on empirical or trial-and-error approaches, lacking a systematic methodology. However, recent research endeavors have introduced a topology optimization concept to streamline bead pattern design[9]. The paper describes an interactive approach for analyzing the impact of enhanced design freedom in Additive Manufacturing (AM) combined with topology optimization. The main goal is to identify weight-saving potentials on a holistic vehicle level and evaluate the influence on vehicle performance utilizing lap time savings[10]. The dynamic behaviour of a Body-In-White (BIW) structure has a significant influence on the Noise, Vibration, Harshness (NVH) and crashworthiness of a car[11]. Therefore, by improving the dynamic characteristics of BIW, problems and failures associated with resonance and fatigue can be prevented. Recent applications of sheet metal panels have concentrated on enhancing manufacturing processes, including the improvement of material formability, the optimization of forming operations, and the assurance of superior part quality. For example, contemporary methods such as high-speed cutting, hybrid additive manufacturing, and incremental forming have attracted considerable interest due to their effectiveness in fabricating sheet metal components. Furthermore, advancements in digital manufacturing, such as the application of AI for process optimization and real-time simulation, have transformed the design of sheet metal components, minimizing trial-and-error approaches and facilitating quicker production[12–17]respectively.

3.0 Methodology

The flowchart of the methodology used for the present work is shown in Figure 1. The flowchart outlines the process for bead pattern optimization in sheet metal panels, incorporating both simulation and experimental validation steps. The initial step involves establishing the parameters for the bead layout, which is subsequently followed by simulation through Finite Element Analysis (FEA) to forecast stress distribution and deformation across different loading scenarios. The refined bead arrangement is subsequently confirmed through practical experiments, wherein the real-world performance of the sheet metal panel is assessed in relation to the simulation outcomes. This comprehensive method guarantees that the ultimate design attains both durability and economic viability, while also permitting modifications informed by experimental insights to further improve functionality.

3.1 Model Details

In practical applications, the width of the battery floor panel is assumed not to exceed 1500 standards and vehicle design specifications. The CAD model of the sheet metal

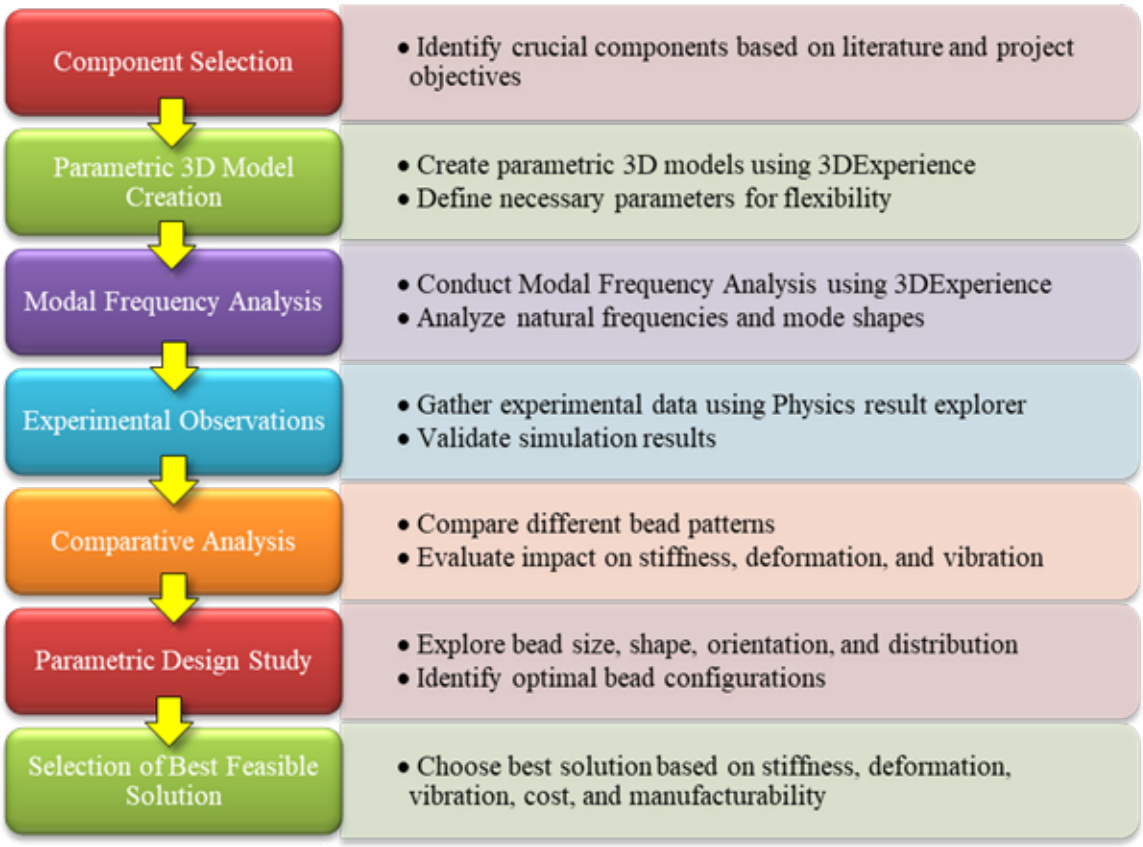


Figure 1. The flowchart of the methodology used for the present work.

panel is shown in Figure 2. The detail of the CAD model is given in Table 1.

Table 1. CAD model details

Parameter	Details
Length	2404 mm
Width	1536 mm
Thickness	2 mm
Material	Aluminium
Density	2700 kg/m^3
Weight	18.9 kg
Young's Modulus	7×10^{10} N/m^2
Poisson's ratio	0.3

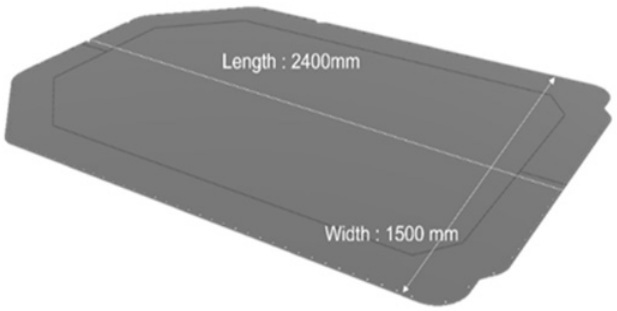


Figure 2. Sheet metal panel.

3.2 Analysis Steps

3.2.1 Mesh Generation

Generated a 7 mm mesh for battery floor panel geometry using the meshing tools provided on 3DExperience software. The mesh model is represented in Figure 3. Ensure the mesh is sufficiently refined to capture the structural details and geometry complexities of the

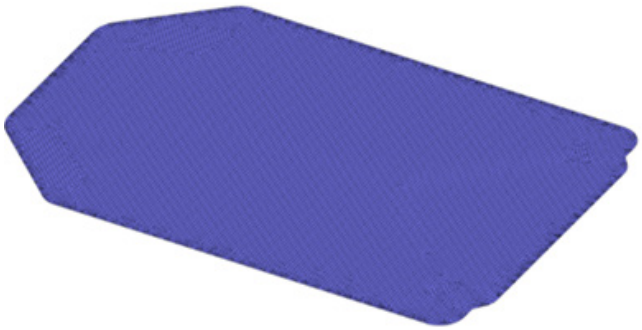


Figure 3. Mesh model.

component, especially in regions of interest such as areas expected to affect the frequency of the model.

3.2.2 Boundary Conditions

Functional Region Preservation: The analysis preserves the functional region of the battery floor panel, ensuring that the structural behaviour within this region accurately represents real-world conditions. This ensures that the analysis focuses on the areas critical for supporting the battery pack and other components.

3.2.3 Clamped Side Mounting Flange

The side mounting flange of the battery floor panel is clamped to simulate its attachment to the vehicle chassis. This constraint condition ensures that the panel remains securely fixed at one end, mimicking the boundary conditions it would experience in actual use.

3.3 Simulation Step

The Frequency modal analysis is selected to investigate the natural frequencies and mode shapes of the component, providing insights into its dynamic behaviour. A total of 30 modes are considered in the analysis. However first minimum mode is sufficient, as our focus is on maximizing minimum frequency. These modes represent the different vibration patterns or oscillation modes exhibited by the component under study. The Lanczos algorithm is chosen as the solver type for the frequency modal analysis. Lanczos method is particularly effective for calculating a small number of eigenvalues and eigenvectors, making it suitable for modal analysis with a limited number of modes.

3.4 Post Processing

Following the completion of the simulation, post-processing tools within the CAE software, specifically the Physics Result Explorer, were employed to visualize and analyse the results. The natural frequencies of the Sheet metal panel are analysed to identify the frequencies at which the panel tends to vibrate. These frequencies provide insights into the structural dynamics of the panel and its susceptibility to vibration-induced issues.

The result for all three bead pattern designs is obtained and reviewed below:

Design 1: Flat Sheetmetal panel design (First Mode Frequency: 8.927 Hz)

The first mode result of flat sheet metal panel is shown in Figure 4. The result indicates that the flat panel design exhibits a low natural frequency, suggesting poor structural integrity. The initial frequency falls significantly below the desirable threshold of 30 Hz, indicating weakness in design.

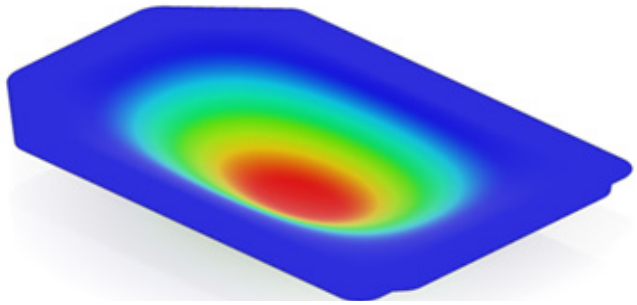


Figure 4. First mode flat sheet metal panel.

Design 2: Bead Along Length of Sheet Metal Panel Design (First Mode Frequency: 13.07 Hz)

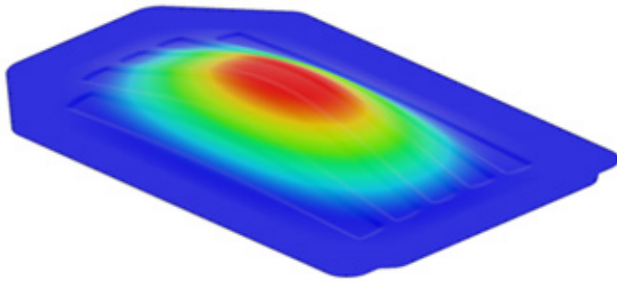


Figure 5. First mode for bead along design length.

The first mode result of bead along design length is shown in Figure 5. Similar to Design 1, the bead along the length of the floor panel design also shows a low natural frequency. While slightly higher than Design 1, the frequency is still below the desired threshold of 30 Hz, indicating inadequate structural integrity.

Design 3: Bead Across Length of Sheet Metal Panel Design (First Mode Frequency: 24.43 Hz)

The first mode result of bead across design is represented in Figure 6. The bead across the length of the floor panel design demonstrates a higher natural frequency compared to the previous designs. Although closer to the desired threshold of 30 Hz, the result indicates average structural integrity, with room for improvement.

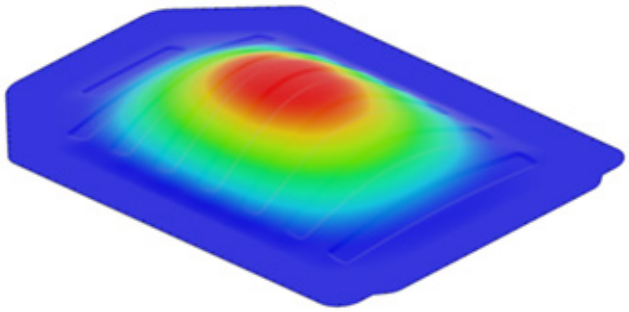


Figure 6. First mode for bead across design.

Based on the review of results, Design 3 with beads across the length of the floor panel shows the most promising performance in terms of natural frequency. While not optimal, it provides a foundation for further improvement through parametric design study. Moving forward, the focus will be on refining Design 3 through a parametric design study to enhance its structural integrity. By systematically exploring various parameters and configurations, the aim is to improve the natural frequency and overall performance of the floor panel design, ensuring robust structural integrity and reliability.

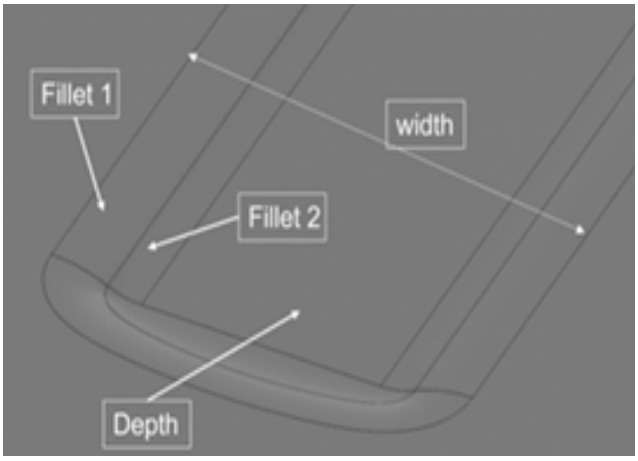


Figure 7. Bead design parameters.

4.0 Parametric Design Study

For the parametric design study aimed at improving the structural integrity of the floor panel design, the width, department, filet 1, and fillet 2 parameters of the bead design were considered. The bead design parameters are depicted in Figure 7 and the corresponding range is listed in Table 2. The obtained results for the considered parameters are shown in Figure 8.

Bead Width Parameter: The parameter study for width is shown in Figure 8(a). From the parametric design study, it is determined that a bead width of 90 mm emerges as the best solution. This conclusion is based on the observation that the bead width of 90 mm yields the

Table 2. Bead design parameters range

Sr. No.	Design Variable	Min (mm)	Max (mm)
1	Width	70	90
2	Depth	5	10
3	Fillet 1	30	50
4	Fillet 2	30	50

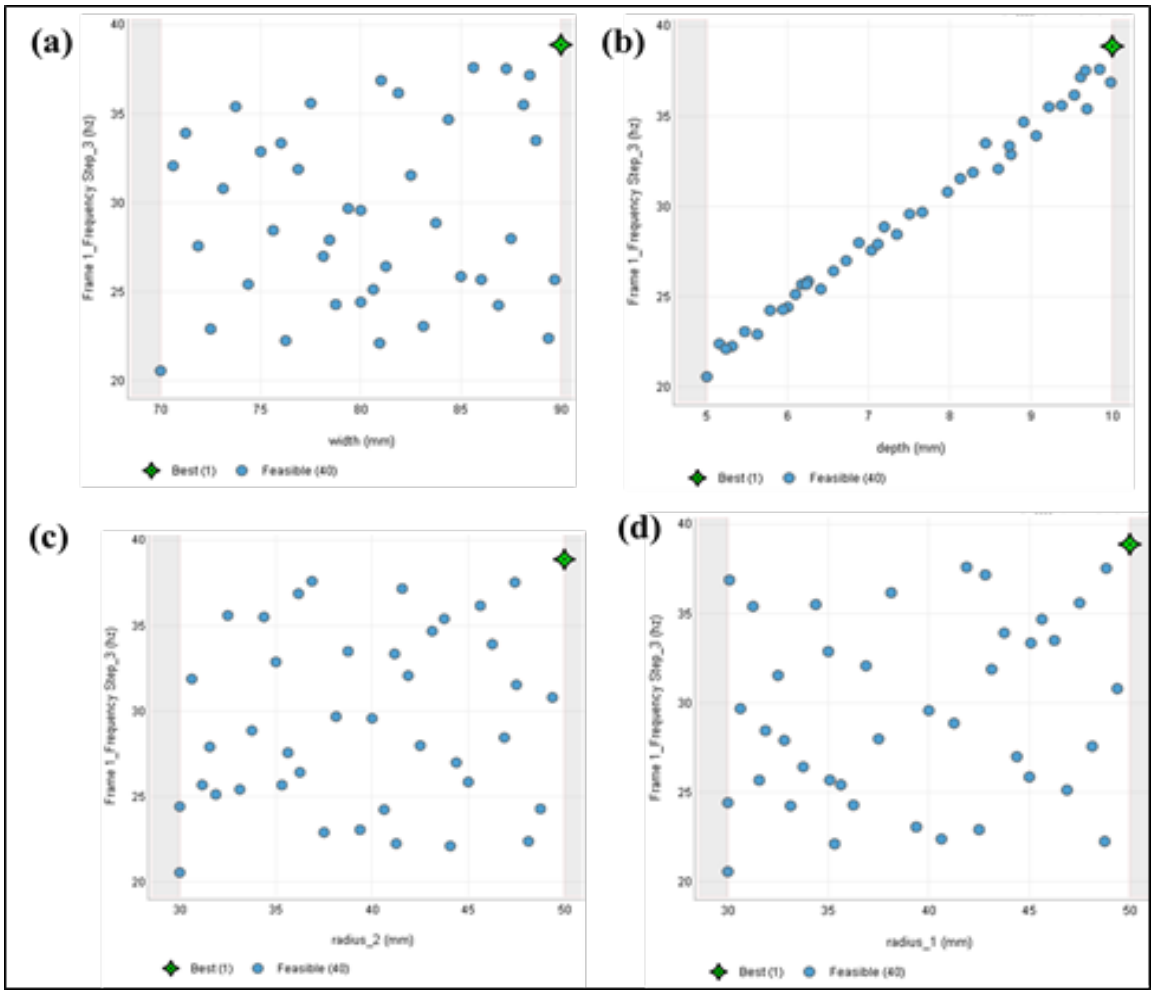


Figure 8. **(a)** Parameter study for width, **(b)** Parameter study for depth, **(c)** Parameter study for fillet 1, and **(d)** Parameter study for fillet 2.

highest natural frequency when compared to other values tested in the study.

Bead Depth Parameter: The parameter study for depth is shown in Figure 8(b). The optimal bead depth parameter is determined to be 10mm. This conclusion is drawn based on the observation that a bead depth of 10 mm yields the highest natural frequency when compared to other values tested in the study.

Fillet 1: The parameter study for fillet 1width is shown in Figure 8(c). The optimal bead fillet 1 parameter is identified as 50mm. This determination is made based on the observation that a fillet width of 50mm yields the highest natural frequency compared to other values tested in the study. The selection of a fillet width of 50mm is driven by its ability to improve stress concentration and distribution within the panel. This, in turn, enhances the overall durability and fatigue resistance of the panel, contributing to its longevity and reliability.

Fillet 2: The parameter study for fillet 2 is shown in Figure 8(d). Through comparative analysis of natural frequencies obtained for different fillet widths, it is evident that a fillet width of 50mm results in the highest frequency among all tested values.

With the optimized parameters for bead design determined through the parametric study, the next step is to run the simulation for the Sheet Metal Panel using these best feasible parameters. The simulation will involve conducting a frequency modal analysis to evaluate the

natural frequency of the panel with the optimized bead design. Upon completion of the simulation, the results will be analysed to determine the natural frequency of the Sheet metal panel with the optimized bead design. The focus will be on evaluating whether the natural frequency meets the desired threshold, ensuring adequate stiffness and structural integrity of the panel for automotive applications.

5.0 Virtual Validation

Figure 9 shows the first mode natural frequency has been substantially improved to 38.87 Hz through the parametric Design of Experiments (DOE) study. This demonstrates a significant increase from the initial frequency and surpasses the desired threshold of 30 Hz, indicating enhanced stiffness and vibration resistance. The virtual validation of the improved Sheet Metal Panel design reveals significant enhancements in structural integrity and performance.

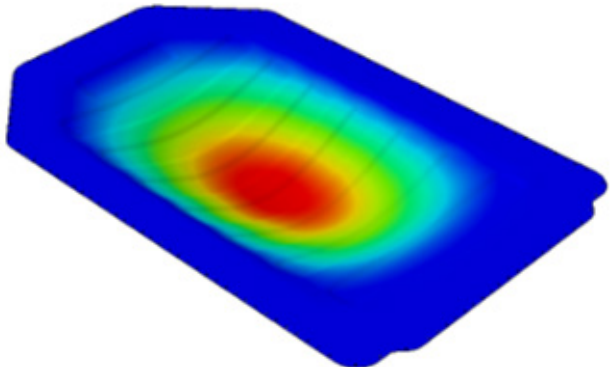


Figure 9. Improved 1st mode frequency is 38.87 Hz.

6.0 Conclusion

In conclusion, the research has successfully addressed the bead optimization of the Sheet metal panel for automotive components, resulting in significant improvements in structural stiffness and natural frequencies. Through the utilization of parametric design studies, the panel's first mode natural frequency has been substantially enhanced to 38.87 Hz, indicating enhanced resilience against vibrations and dynamic loads. Importantly, these improvements in structural stiffness have been achieved without adding any extra weight to the battery cover panel. This underscores the efficiency of the optimization process in enhancing performance while maintaining weight constraints, thereby contributing to the overall efficiency of electric vehicles. The research introduces a novel approach to optimal bead design for sheet panels by incorporating topology optimization techniques. In general, this advanced methodology allows for the exploration of optimal bead configurations to enhance the structural integrity and performance of the vehicle. The results from optimizing beads on sheet metal panels can be applied in manufacturing through the integration of simulation and topology optimization tools, enhancing performance while ensuring lightweight designs that are essential for industries such as electric vehicles.

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