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Comparative FEM Study of Thermal Behavior in Sheet Metal and SMC Battery Pack Cases for Electric Vehicles: Insights into Thermal Management Strategies

David Setiadhi*, Murat Beypars**, Yunus Emre Kınacı** and Kadir Çavdar***

Keywords：electric vehicles, battery pack cases, sheet molding compound (SMC), thermal management strategies runaway.

ABSTRACT

The electric vehicle (EV) market is rapidly expanding, necessitating the development of efficient and safe battery technologies. The material of the battery pack case is crucial, as thermal management is a primary concern due to thermal runaway risks. This paper compares sheet metal and boron nitride doped sheet molding compound (SMC) for electric vehicle battery pack cases. A verified finite element method (FEM) is used to investigate thermal behavior and potential mitigation strategies. During thermal tests, sheet metal cases conduct heat better for efficient distribution, while SMC cases limit heat spreading due to lower conductivity. In the thermal cyclic test, sheet metal cases react rapidly to temperature changes, unlike SMC cases, which have slower responses. To reduce the risk of thermal runaway, SMC materials with boron nitride doping and hybrid systems featuring microchannels are effective options. This indicates that SMC could serve as a practical substitute for EV battery packs.

INTRODUCTION

The increasing popularity of electric vehicles has led to significant interest and investment in the development of high-performance, safe, and cost-effective lithium-ion battery packs (Bandhauer et al., 2011). Lithium-ion batteries are the most promising type of traction battery for electric vehicles due to their high energy density, long cycle life and lack of a memory effect (Y. Chen et al., 2023). However, thermal runaway-related safety incidents are common, seriously compromising the safety of passengers and their property (Zhu et al., 2022). Thermal runaway is a phenomenon where the battery temperature increases exponentially under operating conditions. This temperature rise leads to heat generation, which adversely affects heat dissipation, shortens battery life, and sometimes leads to explosions and fires (K. Zhang et al., 2023). The battery pack or case plays a critical role in preventing thermal runaway in electric vehicle batteries. Previous research has incorporated the thermal behavior of the battery pack and its packaging into modeling techniques to predict the likelihood of thermal runaway (Abada et al., 2018). Another study reports that extreme overheating of Li-ion batteries in electric vehicles can lead to thermal runaway and damage to the battery case (Koch et al., 2018a). In addition, a study on battery sizing for mild hybrid electric vehicles suggests that battery thermal limitations could be implemented in a supervisory control to avoid the risk of thermal runaway (Wang et al., 2016). In addition, a film with a positive temperature resistance coefficient was developed for thermal protection of batteries (X. Zhang et al., 2023). To improve the operating performance of the large-capacity battery pack of electric vehicles during continuous charging and discharging and to avoid its thermal runaway, a new hybrid thermal management system that couples the phase change material (PCM) with the liquid cooling plate with microchannels has been proposed (Y. Zhang et al., 2022). In battery development, researchers have conducted comparative studies of different materials and manufacturing

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* *Ph.D.(C), Department of Mechanical Engineering, Bursa Uludag University, 16059, Nilüfer, Bursa, Türkiye.*

** *RnD Engineer, STA Kalıp Makına Industry and Trade Inc., Mınarelı Cavus Osb Mah. 201. Sk.No:3 16140 Nilüfer, Bursa, Türkiye*

*** *Professor, Department of Mechanical Engineering, Bursa Uludag University, 16059, Nilüfer, Bursa, Türkiye.*

processes to identify the most suitable options (Luk et al., 2017). One of the search results mentions that three materials including fiberglass composite, carbon fiber composite and metal steel are used to develop the same battery case and their strengths are simulated. The study proves that carbon fiber composite materials offer the advantages of high strength and light weight when applied in the battery case (Y. Zhang et al., 2020). Another search result indicates that the trend in electric vehicles is towards the complete replacement of steel by aluminum alloys in the form of sheets, extrusions and die-cast parts, with the partial use of magnesium-based die-cast parts (Luk et al., 2017). In addition, a study on the numerical thermal analysis of a battery pack in an electric motorcycle application proposes a battery pack housing made of highly conductive materials such as copper and aluminum with an appropriate liquid cooling system (Kittleson & Muhkerjee, 2022). In the composites category, there are SMC (Sheet Molding Compound) materials, which are composed of fiberglass, resin, and fillers. SMC is widely used to manufacture automotive parts, including the inside of battery cases in electric vehicles. SMC offers a variety of material configurations that can be customized to the battery case design, offering different levels of performance, mass and cost. Additionally, using a lightweight material can help improve fuel efficiency and reduce emissions (Luk et al., 2017). The development of battery pack boxes with a focus on thermal management has been an important area of research in recent years. To address this issue, researchers have focused on various aspects of battery pack design, including materials, thermal management systems, and structural integration. One approach to preventing thermal runaway is the use of composite phase change materials (PCMs) for thermal management in lithium-ion batteries (K. Zhang et al., 2023). PCMs can help regulate the temperature inside the battery pack, thereby reducing the risk of thermal runaway. Another aspect of battery pack design is the selection of suitable materials for the battery box. Lightweight materials such as aluminum alloy sheets have been evaluated for their potential to reduce the overall weight of the battery pack while maintaining structural integrity (Q.-S. Chen et al., 2017). Chen et al. studied the material replacement of mild steel sheets with aluminum alloy steel sheets for battery box parts with the aim of achieving lightweight design (Q.-S. Chen et al., 2017). In addition to material selection, researchers have been exploring the integration of battery packs into the vehicle structure to optimize safety and performance. Arora et al. developed a study on battery packaging design to maximize reliability and mitigate safety risks in case of impact, with a focus on side impact scenarios (Arora et al., 2016). Kukrejia et al. examined the battery pack's structure to enhance its damage-tolerant features, particularly in frontal impact situations (Kukreja et al., 2016). According to our literature review, no study has addressed the development of battery pack housings that are designed to prevent thermal runaway using SMC material. To prevent thermal runaway while considering lightweight battery packs, it is important to analyze the thermal behavior of battery pack cases with SMC. The aim of this study is to investigate the thermal behavior through thermal and cyclic thermal tests, as stipulated by UN/ECE Regulation No. 100: Uniform provisions for the approval of vehicles concerning specific requirements for the electric powertrain (*UN/ECE Regulation No. 100: Uniform Provisions Concerning the Approval of Vehicles with Regard to Specific Requirements for the Electric Power Train.*, 2022). The test uses a finite element method with a base model verified by calculations. The results section presents the data obtained through finite element method analysis. The results of this study are expected to improve the understanding of the thermal behavior of sheet metal cases and SMC cases in thermal and cyclic thermal tests.

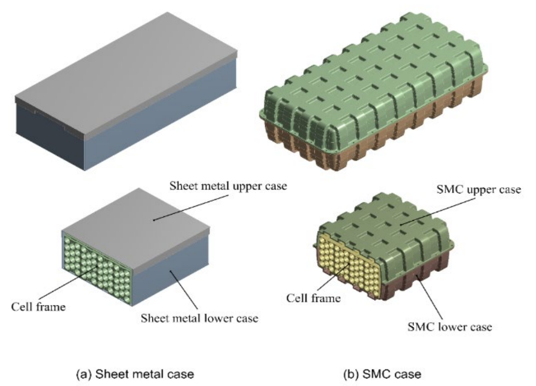

Fig. 1. Components of the (a) Sheet metal case and (b) SMC case

METHODOLOGY

Finite Element Model and Material Properties

To evaluate the thermal behavior of two types of battery cases, one made of sheet metal and the other from Sheet Molding Compound (SMC), a finite element method model was developed specifically for thermal analysis. The complete model along with its half-section representation for both the sheet metal case and the SMC case is depicted in Fig. 1. the thickness of the sheet metal case measures 1.7 mm, whereas the SMC case has a thickness of 4 mm. To reduce computational time, it is possible to simplify the simulation by reducing the model by half. Fig. 2. shows the dimensions of the sheet metal case and SMC case. The present study prioritizes the assessment of the case's performance through testing, and thus does not necessitate the inclusion of a battery cell model or other minor components. Table 1 provides the physical, mechanical, and thermal properties of the materials used, namely stainless steel for the sheet metal case, and SMC.

Table 1. Material properties of stainless steel and SMC (An et al., 2022; Im et al., 2021)

Property	Symbol	Material		Unit
		Structural Steel	SMC	
Mass Density	E	7850	1770	kg/m^3
Elastic Modulus	ρ	200000	6000	MPa
Poisson's Ratio	v	0.3	0.3	-
Yield Strength	σ_y	250	175	MPa
Tensile Strength	σ	460	223	MPa
Thermal Conductivity	α	60.5	1.453	W/m.K
Specific Heat	c	434	1200	J/kg.C

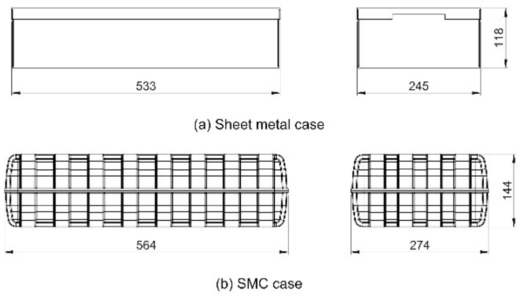

Fig. 2. Dimension of the (a) Sheet metal case and (b) SMC case

Fig. 3. illustrates the thermal conductivity of the SMC case. Thermal conductivity of SMC was obtained by conductivity testing with various Boron Nitride ratios at STA Kalıp Makina laboratory. In thermal tests and cyclic thermal tests model using steady state thermal and transient thermal tests respectively. In contrast to the steady-state model, the transient thermal model takes temperature changes into account over time. Both steady-state and transient thermal simulations were performed with a meshing model of a 3D tetrahedron shape, which adapts to the shape of the model, with an average mesh size of 3.15 mm.

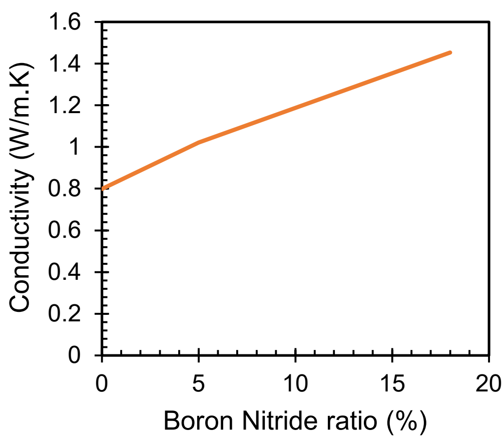

Fig. 3. Thermal conductivity of SMC

THERMAL SIMULATION METHODS

Thermal test

The thermal test was used to analyze heat distribution in the battery case, a crucial factor for ensuring safety and optimal functioning of electric vehicle batteries. The process of charging and using electric vehicle batteries generates heat, necessitating effective thermal management strategies. Excessive temperatures could lead to battery malfunction or even explosion and shorten battery life. In our steady-state thermal analysis, we assumed that the battery case is not subject to any thermal load apart from the high temperatures generated internally in the battery pack, and that air convection inside the battery case remains stable. The convective heat transfer coefficient on the outer surface of the battery container is assumed to be 15 W/(m2.K) due to natural convection of air (Yang et al., 2020). Based on data obtained from the STA Kalip Makina laboratory, the battery experienced a temperature of 80 °C as a result of the heat load. We omitted the effects of radiation from this thermal test model due to its insignificance, as validated by previous research (Szulborski et al., 2021).

Cyclic thermal test

The cyclic thermal test was designed to assess the ability of the battery case to endure abrupt temperature changes. As stipulated by UN/ECE Regulation No. 100: Uniform provisions for the approval of vehicles concerning specific requirements for the electric powertrain (*UN/ECE Regulation No. 100: Uniform Provisions Concerning the Approval of Vehicles with Regard to Specific Requirements for the Electric Power Train.*, 2022), the battery pack case was subjected to a predetermined number of temperature cycles, starting at ambient temperature (T_∞), followed by high and low temperature cycles. This test simulates rapid ambient temperature (T_∞) changes that the battery case might experience during its operational life. As per the testing protocol, the case was exposed to 60°C for six hours, then -40°C for six hours, with a transition time of 30 minutes. This temperature test cycle was repeated five times.

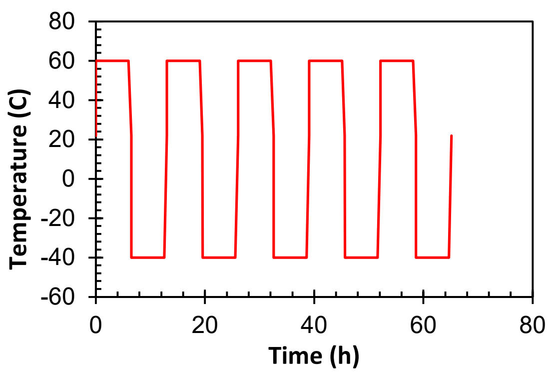

Fig. 4 Thermal cycle profile.

This combination of tests provides a comprehensive assessment of case durability under different conditions, answering our research question regarding the comparative performance of sheet metal and SMC cases. The data from these tests will be analyzed using statistical methods to determine whether there is a significant difference in performance between the sheet metal and SMC cases.

RESULTS AND DISCUSSION

Model verification and validation

In the process of validating our finite element models, we refer to Fig. 5. for an illustration of heat conduction and convection. The validation is necessary to ensure that the numerical analysis results obtained from the finite element method (FEM) match the physical or calculated reality encountered by the structure or system being analyzed. Validation helps reduce uncertainties and errors that may arise from assumptions and simplifications used in the FE model. To test the validation of the thermal analysis model, comparisons are made with calculations with the Fourier's law of heat conduction and Newton's law of heat convection equations. From the calculation of the output value sought is the outer right-side temperature (T2). Fig. 5. presents an illustration of the thermal load being applied on the left side of the objects, leading to a temperature of T1. Following this, heat conduction occurs, propagating the heat from the left to the right side, which then results in convection.

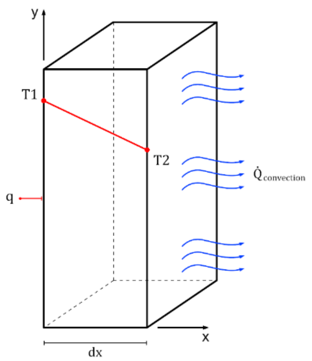

Fig. 5. Heat conduction and convection illustration.

At steady state, the amount of heat entering the wall is equal to the amount of heat leaving the wall. Therefore, it can be assumed that the heat flow rate through the wall (q) is equal to the heat flow rate lost due to convection $\dot{Q}$:

$$q = \dot{Q} \tag{1}$$

The length and width of the wall affect the surface area in contact with the air, but do not affect the heat flow rate through the wall. The heat flow rate through the wall can be expressed using Fourier's law of heat conduction, which is given by the equation:

$$q = -k.A\frac{dT}{dx} \tag{2}$$

Newton's law of heat convection equation:

$$\dot{Q} = h.A(T_1 - T_\infty) \tag{3}$$

Since $q = \dot{Q}$, it can be equalized these two equations into:

$$k.\frac{(T_1-T_2)}{dx} = h.(T_1 - T_\infty) \tag{4}$$

It can be equated the two equations since the heat flow rate through the wall is the same in both cases. After rearranging the equation, it can be expressed the temperature on the right side (T_2) as follows:

$$T_2 = \frac{h.T_\infty + k.\frac{T_1}{dx}}{h + \frac{k}{dx}} \tag{5}$$

Table 2. Comparison of the calculated and simulated results

No	Material	Thickness (mm)	Temperature (C)		Error (%)	Avg. Error (%)
			Calculation	Simulation		
1	Structural steel	20	79.73	79.73	4.53E-06	1.88E-06
2		30	79.59	79.59	-4.59E-06	
3		40	79.46	79.46	2.39E-06	
4		50	79.33	79.33	1.96E-07	
5		60	79.19	79.19	1.98E-06	
6	SMC	20	70.59	70.59	2.29E-06	
7		30	66.99	66.99	4.08E-06	
8		40	63.93	63.93	2.29E-06	
9		50	61.28	61.28	2.60E-06	
10		60	58.96	58.96	3.03E-06	

Table 2 shows a comparison of the calculated and simulated results. To validate the accuracy of our results, we varied the thickness between 20 and 60 mm. The specified thermal load is 80 °C at an ambient temperature (T_∞) of 22 °C. The difference between the calculated and simulated results is extremely small, specifically 1.88×10^{-6} suggests that our model's deviation is negligible, thus confirming its validation. This validation confirms that our finite element model is reliable and can be utilized for further thermal simulations.

Thermal test

The objective of the thermal test in this study is to compare the thermal behavior of the sheet metal case and the SMC case when subjected to the thermal load from the cell frame located within each case, which is considered to have the highest operational temperature of an electric battery at 80 °C. Fig. 6 (a) illustrates the thermal distribution of the sheet metal case. The simulation is conducted utilizing steady-state thermal, thereby excluding the consideration of time. The thermal distribution circulates until the model attains a state of equilibrium, characterized by the balance between the inflow and outflow of heat. At approximately 40°C, the thermal spreads to the upper section of the module case. Fig. 6 (b) displays the thermal distribution of the SMC case. Unlike the sheet metal case, the thermal does not extend to the upper part of the SMC case. This is attributed to its different material composition and structure, with a lower thermal conductivity due to its composition of fiberglass reinforced with a thermoset resin matrix (Trauth et al., 2017). Furthermore, the SMC case features a more complex design and a thicker structure (4mm) compared to the sheet metal case (1.7mm).

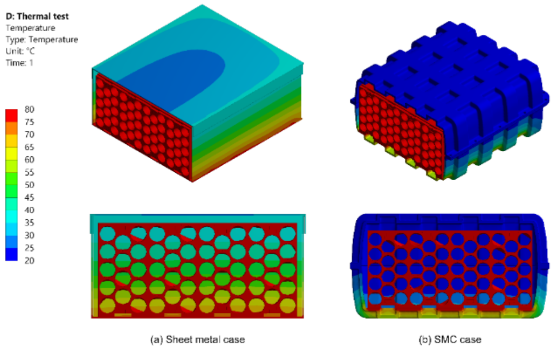

Fig. 6. Thermal distribution on (a) Sheet metal case and (b) SMC case

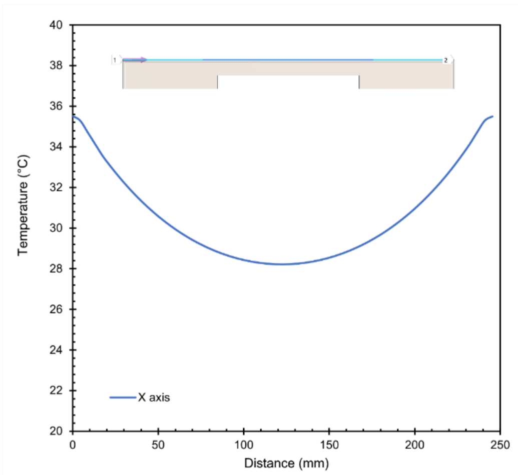

Fig. 7. Profile of temperature distribution along X axis line on top cover of Sheet metal case

Fig. 7. shows the temperature distribution profile along the X-axis on a sheet metal case. For this simulation, radiation was ignored due to its negligible effect. The results indicate that the temperature at the left and right ends of the top cover is approximately 35°C, dropping to the lowest temperature of 29°C at the center of the sheet metal housing.

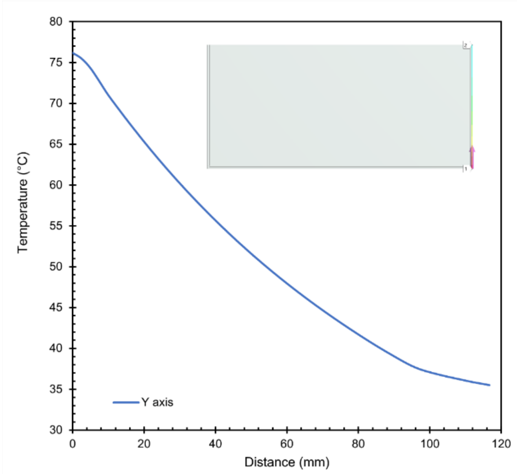

Fig. 8. Profile of temperature distribution along Y axis line on bottom Sheet metal case

Fig. 8. presents the temperature distribution along the Y-axis line on the bottom sheet metal case, showing that the highest temperature reaches up to 76°C while the lowest is at 35°C. The temperature decreases as the distance from the direct contact with the frame of the conduction cell increases. The overall temperature on the bottom of the case on the X-axis is 80°C.

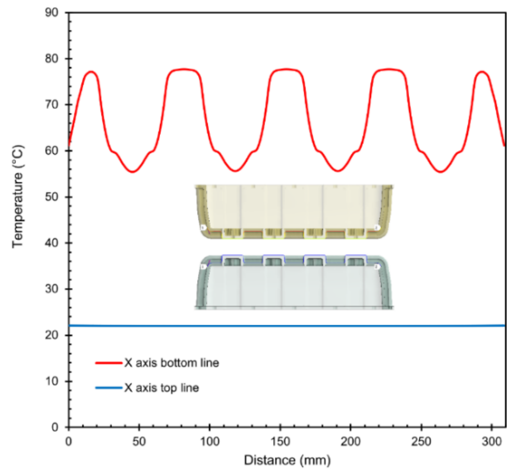

Fig. 9. Profile of temperature distribution along X axis top and bottom line on SMC case

Fig. 9. displays the temperature distribution profile along the top and bottom lines of the X-axis of the SMC case. Unlike the sheet metal case, no temperature change was detected in the top line of the SMC case. On the bottom line, the lowest temperature is 55°C while the highest is 80°C. Fig. 10. presents the temperature distribution along the Y-axis line on the SMC case, showing that the highest temperature reaches 77.146 °C while the lowest is 22 °C. It was found that the top cover did not experience heat propagation, indicating that under steady-state conditions, the heat from the cell frame will not reach the top cover.

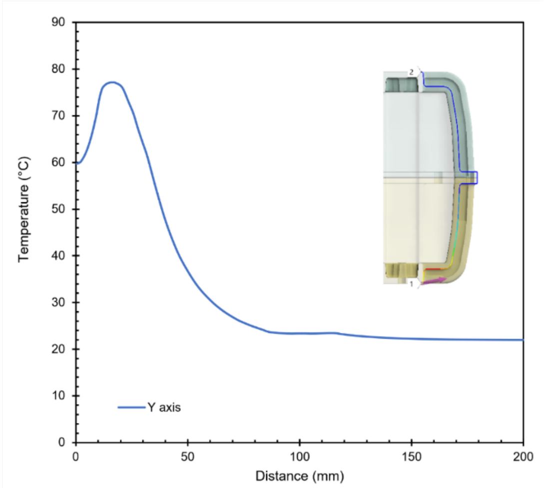

Fig. 10. Profile of temperature distribution along Y axis line on SMC case

The steady-state thermal analysis provides us with a clear depiction of how the thermal conductivity of the case materials influences the heat dissipation in the battery case. The sheet metal case, with its higher thermal conductivity, was able to spread heat more efficiently, reaching the upper parts of the case at approximately 40°C. On the other hand, the SMC case, composed of fiberglass reinforced with a thermoset resin matrix and having lower thermal conductivity, was unable to spread the heat to its upper parts. This observation aligns with the fundamental principle of thermodynamics that heat transfer is more efficient in materials with higher thermal conductivity. These results provide insight into the impact of material composition and case design on thermal behavior under steady-state conditions. While these results are based on simulations that exclude radiation effects, they serve as a useful comparison between sheet metal and SMC cases.

Thermal cyclic test

This thermal cyclic test is designed to ascertain the resilience of the battery case against abrupt temperature changes. The test temperature ranges from -40 to 60 °C and lasts for 65.15 hours. The battery pack case undergoes testing at 60°C for 6 hours, with a transitional period of 30 minutes in between. The subsequent test at -40 °C also lasts 6 hours. This test yields a temperature distribution profile throughout the thermal cyclic process, providing insight into the thermal behavior of sheet metal and SMC cases at distinct temperatures. Fig. 11. provides a comparison of the input and measured temperatures for the sheet metal case across five cycles. The case takes about 0.55 hours to reach 60°C with an input temperature of 60°C, whereas it takes 3.46 hours for all parts of the cell frame to reach the same temperature. Similar patterns are observed when the input temperature is -40°C: the case takes 0.52 hours to reach this temperature, while the cell frame takes 3.42 hours.

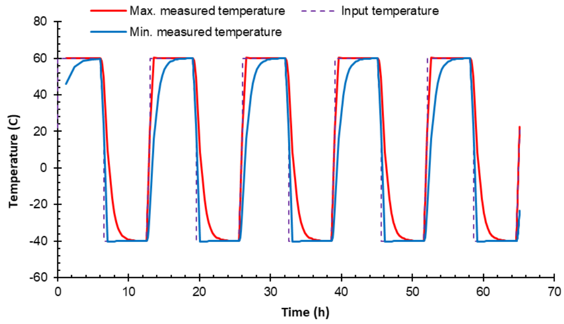

Fig. 11. Comparison Between Input and Measured Temperature on Sheet Metal Case

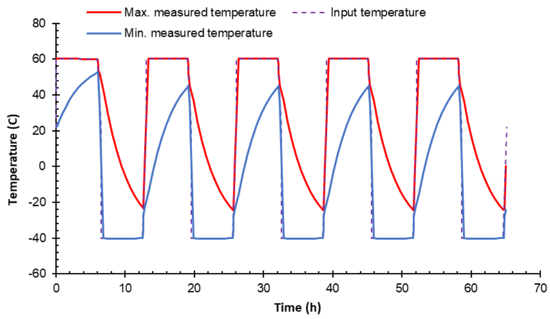

Fig. 12. Comparison Between Input and Measured Temperature on SMC Case

Fig. 12. compares the input and measured temperatures for the SMC case. In all five cycles, the temperature change patterns are identical, barring the first cycle due to its initial temperature of 22°C. In the first cycle with an input temperature of 60 °C, the cell frame reached a temperature of 52.8 °C. In contrast to the sheet metal case, the SMC case's cell frame only reaches 45.16 °C after 6 hours with an input temperature of 60°C. In the six-hour -40°C test, the cell frame reaches a maximum temperature of -24.44°C. Fig. 13. provides a schematic representation of the measured temperature profile to facilitate understanding of the visualizations presented in Fig. 14 and 15.

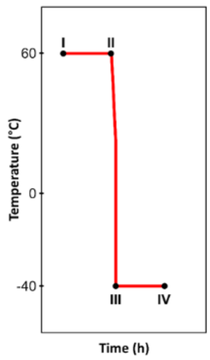

Fig. 13. Schematic of the measured temperature profile

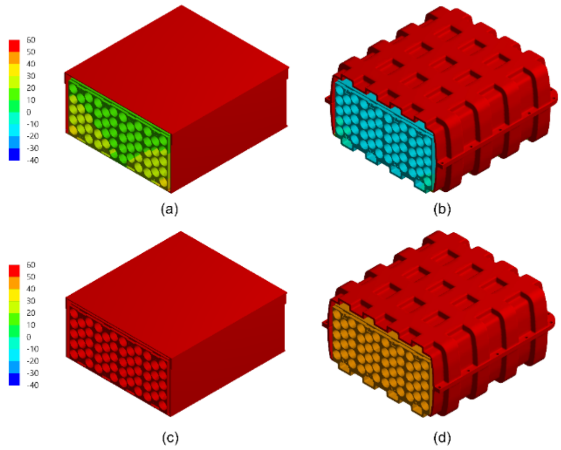

Fig. 14. Temperature distribution in I (a-b) and II (c-d) steps of thermal cyclic test on Sheet metal case and SMC case

To ascertain the impact of sudden temperature changes, data is collected using the I-IV configuration illustrated in Fig. 13. By examining the visualization at points I-IV, the thermal behavior over a specific duration can be determined. Points I-IV were recorded in the third of the five cycles. Fig. 14 (a-b) presents the temperature contour of the sheet metal case and the SMC case at point I, which marks the start of the 6-hour test at 60°C. Both battery cases reach 60 °C. The cell frame in the sheet metal case undergoes a rapid temperature shift from -40 °C to 20-40 °C. However, slower temperature changes occur in the SMC case's cell frame, reaching a measured temperature of -10°C. Fig. 14 (c-d) presents data collected at point II, where the temperature remains at 60°C for 6 hours. The cell frame and sheet metal case reach a temperature of 60 °C in Fig. 14 (c), whereas the cell frame in Fig. 14 (d) reaches 50 °C.

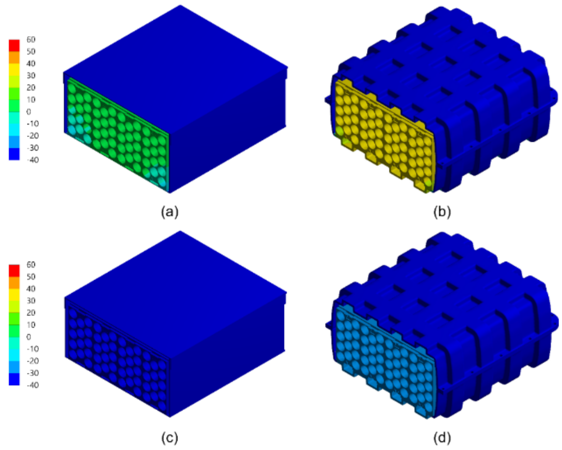

Fig. 15. Temperature distribution in III (a-b) and IV (c-d) steps of thermal cyclic test on Sheet metal case and SMC case

Fig. 15 (a-b) depicts the temperature contour of the sheet metal case and SMC case at point III. Following a 30-minute cooling period at room temperature (22°C) after point II, point III commences with a 6-hour test at -40°C. Both battery cases are exposed to -40 °C. The sheet metal case's cell frame experiences a temperature of 20°C, while the lower end of the cell frame starts cooling to a temperature of -10°C. Fig. 16 (b) shows the temperature contour of the cell frame at around 30°C. Continuing to Fig. 16 (c-d), data collection is performed at point IV, with a 6-hour test at -40°C. In Fig. 16 (c), the cell frame and sheet metal case reach a temperature of -40°C, while in Fig. 16 (d), the cell frame reaches a temperature of -20°C. The thermal cyclic stress test showed how the case materials responded to drastic temperature changes. The battery case composed of sheet metal reacted more quickly to the changes in temperature compared to the SMC case, both when heated to 60°C and cooled to -40°C. This rapid response can be attributed to the higher thermal conductivity of the metal (Wei et al., 2020). However, such rapid changes can induce thermal stress in the material, possibly leading to structural damage over time (Y. Zhang et al., 2023). In contrast, the SMC case showed a slower response to temperature changes, suggesting that it might be less prone to thermal shock. Yet, its inability to reach the input temperatures during the heat and cold tests implies that it might not protect the battery cells effectively under extreme temperature conditions. Overall, these findings provide valuable insights into the effects of temperature changes on the thermal behavior of sheet metal and SMC cases.

Thermal runaway

Thermal runaway represents a crucial concern within the scope of battery safety. This phenomenon entails a process where an uptick in temperature modifies conditions, subsequently causing a further escalation in temperature, thereby triggering a potentially devastating chain reaction (H. Hu et al., 2020). Concerning battery systems, an uncontrolled temperature surge can lead to battery cells igniting or even exploding. It is essential to clarify that this section mainly entails a discussion rather than experimental testing. Despite acknowledging the significance of thermal runaway tests within this context, such tests were not performed in the current study. Consequently, the focus lies on a literature-based discussion concerning the potential impact and the control of thermal runaway in lithium-ion batteries, anticipated to offer invaluable insights for upcoming research and development. The conducted steady-state and cyclic thermal stress tests, while not directly simulating a thermal runaway scenario, deliver significant insights into the behavior of the battery case materials under high-temperature conditions. The sheet metal case, demonstrating superior heat distribution owing to its increased thermal conductivity, could potentially alleviate the risks of thermal runaway by swiftly dissipating the heat away from the battery cells (Koch et al., 2018b). In contrast, the slower heat transfer observed with SMC packages may indicate a higher risk of heat being trapped near the battery cells, potentially increasing the possibility of a thermal runaway. Despite the high risk of thermal runaway in SMCs, SMCs are lightweight and mechanically sound, making them suitable for use in EV structural parts. SMC materials, such as glass fiber composites, have been shown to withstand extrusion tests up to 100 kN, making them a viable option for battery pack boxes (An et al., 2022b). Additionally, the use of lightweight materials in EVs, such as SMC, can improve energy efficiency while counteracting the weight increase due to the battery pack (Martawirya et al., 2014). SMCs have also been shown to have potential as anode materials for lithium-ion batteries, with their electrochemical performance being improved by their micron cage structure (Li et al., 2022). To overcome the problem of low SMC conductivity which can risk raising the battery temperature to thermal runaway, measures such as a thermal runaway mitigation mechanism are required (Shahid & Agelin-Chaab, 2022). Thermal runaway mitigation mechanism utilize cooling media such as water, liquid, phase change material (PCM) and a hybrid thereof (Shahid & Agelin-Chaab, 2022). One approach is to reduce the heat conduction resistance of the casing material to increase the portion of heat conduction in heat dissipation (Amiribavandpour et al., 2013). Furthermore, selecting the right components of SMC makes them attractive as the sum of the material, manufacturing process, and design of the electrical machine (Jakubas & Najgebauer, 2018).

Nevertheless, it is imperative to acknowledge that real-life scenarios concerning thermal runaway are considerably more complex and hinge on numerous factors, including the battery cell design, the battery management system (BMS), and the cooling system's efficacy (L. Hu & Xu, 2014; Xu et al., 2017; Yuan et al., 2014). Thus, while the current findings offer valuable starting points, dedicated tests and simulations focusing on thermal runaway scenarios would be indispensable to draw definitive conclusions regarding the safety performance of different battery case materials. In subsequent studies, probing material combinations and designs that both effectively dissipate heat and act as a barrier to inhibit thermal runaway propagation in the event of a single cell failure could represent a promising direction. It may also be beneficial to examine the inclusion of advanced safety mechanisms in the battery case design, such as vents to release pressure and gases should a cell failure occur.

CONCLUSIONS

This paper conducted a comprehensive evaluation of two potential materials for electric vehicle (EV) battery housings: sheet metal, specifically mild steel, and sheet molding compound (SMC). Using a comparative approach and finite element method simulations, this study has advanced the understanding of the advantages and limitations of both materials and shed light on aspects such as thermal conductivity, mechanical strength, weight, and potential risk of thermal runaway. Thermal management is of paramount importance in the design of electric vehicle batteries, as the conductivity of the case material plays a crucial role in maintaining the battery temperature and thus affecting the risk of thermal runaway. While previous studies in this area have produced mixed results, there is a need for a more in-depth comparison of these materials, which this study aims to provide. Based on the finite element method analysis, in the thermal test, the sheet metal case exhibits efficient heat distribution, attributed to its higher thermal conductivity, enabling heat to reach the top of the casing. In contrast, the SMC case exhibits lower thermal conductivity, restricting heat propagation to the top of the case, likely a result of its thicker composition and structure. During the thermal cyclic test, the sheet metal case exhibits rapid responses to temperature variations due to its higher thermal conductivity, whereas the SMC case demonstrates a slower response, indicating reduced vulnerability to thermal shock due to its composition. The potential risk of SMC thermal runaway can be mitigated by utilizing boron nitride doped SMC materials to improve thermal management and implementing hybrid systems that combine phase change materials (PCM) with liquid cooling plates featuring microchannels, which have shown effective thermal control in previous studies. This paper suggests that with effective risk mitigation strategies, SMC could serve as a feasible alternative for housing EV battery packs, offering improved thermal management and enhanced safety features.

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