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Heat Dissipation Analysis of Thermal Conductive Adhesive Based on Liquid Cooled Battery Pack

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Abstract: In view of the serious heating problem of the automotive power battery, different thermal conductive adhesive cooling structures of the liquid cooled battery pack were designed. Based on a battery cell for an electric vehicle, five battery pack models in series are used to measure the discharge internal resistance data under constant normal temperature and high temperature conditions respectively. The influence of thermal conductive adhesive structure on temperature field is analyzed through Fluent. The results showed that the thermal conductive adhesive structure between the monomers had a significant effect on reducing the maximum temperature of the battery pack and improving the temperature field balance.

Keywords: Electric vehicle, Battery pack, Liquid cooling, Thermal conductive adhesive.

1. Introduction

The power battery pack has become the most suitable energy storage device for electric vehicles due to its high energy density, stable voltage and long life. The battery pack is sensitive to temperature, and the heat released during the working process will increase the working temperature, which may even lead to thermal runaway [1].

At present, the battery thermal management system (BTMS) is mainly designed with air, liquid or phase change materials [2]. Liquid cooling is widely used because of its fast heat conduction, compact structure and flexible pipeline layout. Duh et al. [3] pointed out that the extreme high and low temperature environment will affect the operating efficiency and cycle life of lithium batteries; S. Panchal et al; Wang et al. [5] applied the thermal conductive adhesive to a monomer in BTMS. The temperature distribution of the monomer is affected by the number of microchannels and liquid flow rate, but has no obvious effect on the flow direction of the coolant; Xu Xiaoming et al; Liu Yifan et al. [2] analyzed the influence of four types of thermal conductive adhesive shapes on the thermal performance of the battery pack. With the reduction of the contact area between the thermal conductive adhesive and the battery pack, the maximum temperature of the battery pack increases and the temperature difference decreases, but the influence of changes in the internal resistance of the battery cell on the heat dissipation cannot be ignored. The experimental measurement of the change of cell resistance with SOC is conducive to improving the accuracy of simulation analysis, and there is a certain air gap between the cells, which causes uneven heat transfer. The thermal conductive adhesive has a good effect on the battery temperature field.

In this paper, by designing different heat dissipation structures of thermal conductive adhesive for liquid cooled battery packs, the relationship between the internal resistance of battery cells and SOC is experimentally measured and the fitting formula is used. The influence of thermal conductive adhesive structure on the temperature field distribution of battery packs is analyzed by using Fluent simulation, and the temperature field distribution under normal and high temperature conditions is further analyzed to verify its effectiveness.

2. Calculation Model

2.1. Theoretical model

(1) Continuity equation:

$$\frac{\partial (u\rho)}{\partial x}+\frac{\partial (v\rho)}{\partial y}+\frac{\partial (w\rho)}{\partial z}=0 \tag{1}$$

Where ρ Is the density; u. V, w and x, y, z are the direction of the velocity vector.

(2) Energy conservation equation:

$$\rho C_p=\frac{\partial T}{\partial t}=\lambda_x\frac{\partial^2 T}{\partial x^2}+\lambda_y\frac{\partial^2 T}{\partial y^2}+\lambda_z\frac{\partial^2 T}{\partial z^2}+q \tag{2}$$

Where ρ — Battery density; Cp - specific heat capacity of battery; λ x、 λ y， λ Z-thermal conductivity in three orthogonal directions; Q - Battery heat generation rate.

(3) Calculation model of heat generation rate

$$q=\frac{1}{V_b}\left[(U-U_0)+T\frac{dU_0}{dT}\right]=(I^2R_0+IT\frac{dU_0}{dT}) \tag{3}$$

Where, I - current, Vb - volume of single battery, U - open circuit voltage, U0 - working voltage, T - battery temperature, dU0/dT - temperature coefficient.

2.2. Geometric model

The battery pack is composed of five strings, and four micro channels are evenly distributed on the bottom liquid cooling plate; Three thermal conductive adhesive structural schemes are adopted. The microchannel liquid cooled plates are distributed at the bottom of the battery pack, and a layer of thermal conductive adhesive with a thickness of 1 mm is coated between the bottom of the monomer and the liquid cooled plate, wherein (a) the structure is not filled between the monomers, (b) and (c) the thermal conductive adhesive filled between the monomers is 5 mm and 1 mm thick, and the thermal conductive adhesive structure is shown in Figure 1 (d). Based on different thermal conductive adhesive structures, the geometric model of the liquid cooled battery pack is established, Relevant thermophysical parameters are shown in Table 1.

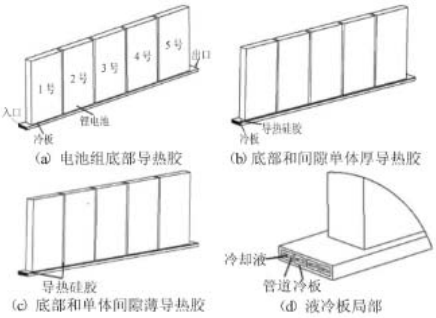

Figure 1. Partial enlarged view of different heat transfer adhesive structures and liquid cooling plate

Table 1. Thermophysical Parameters of Battery Pack and Thermal Conductive Adhesive

名称	材料	密度 (kg/m³)	比热容 (J·kg⁻¹/K⁻¹)	导热率 (W·m⁻¹/K⁻¹)
正极极柱	铝	2 713	903	238
负极极柱	铜	8 900	385	398
电芯等效材料	铜、铝、石墨、磷酸铁锂等	2 214	1 419.16	k_r=0.84; K_x=k_y=24.39
导热胶	有机硅树脂等	1 500	1 500	1.96

2 Test

Through the charging and discharging test system platform, the mixed pulse power characteristic method (HPPC) is used to measure the change relationship between the internal resistance of the battery cell and SOC. The test is carried out at different ambient temperatures. The battery is placed in a constant temperature box at the corresponding ambient temperature, and the bottom is insulated from the box plate. The charging and discharging test is carried out on the battery cell. The relevant battery parameters are shown in Table 2.

The relationship between the cell internal resistance and SOC is transformed into the relationship between SOC and time t, and the expression is:

$$SOC=SOC_0\frac{It}{C} \tag{4}$$

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Where, SOC0 - SOC value at the initial time; I - charging and discharging current; T - charging and discharging time; C - Battery capacity.

Fitting the experimental data, UDF was compiled by Fluent to simulate the heat generation rate of the battery pack at the corresponding ambient temperature. The fitting relationship is:

$$R_{25℃}=-46.2963SOC^6+117.735SOC^5-103.1339SOC^4+33.105SOC^3-0.53056SOC^2-1.5328SOC+2.8444 \quad (5) \tag{5}$$

$$R_{30℃}=111.8056SOC^6-369.9840SOC^5+480.0988SOC^4-309.114SOC^3+102.6716SOC^2-17.1920SOC+3.3857 \quad (6) \tag{6}$$

$$R_{35℃}=-599.3056SOC^6+1988.8622SOC^5-2542.7431SOC^4+1574.8794SOC^3-487.5807SOC^2-68.5570SOC-1.6183 \tag{7}$$

$$R_{40℃}=100.01SOC^6-313.9744SOC^5+380.32051SOC^4-224.9668SOC^3+68.3225SOC^2-11.08234SOC-1.5328 \tag{8}$$

Table 2. Battery Parameters

参数名称	数值
尺寸(mm)	20× 100× 140
重量(g)	620± 5
标称电压(V)	3.2
额定容量(Ah)	24
工作电压(V)	2.0~3.65

3. Result Analysis

3.1. Temperature distribution of battery pack under normal temperature

The initial temperature is normal temperature 25 ℃, and the coolant inlet temperature is 20 ℃. The convection coefficient is 5 W/(m2/K) - 1, and the temperature rise and temperature balance of the battery pack are compared and analyzed.

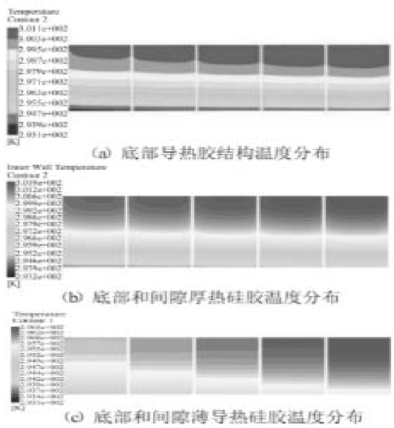

Figure 2. Comparison of Temperature Fields of Different Thermal Conductive Adhesives

The temperature field distribution of different heat transfer adhesive structures is shown in Figure 2. A. The heat dissipation performance of the structure is poor, which shows that the top temperature of the battery is the highest, and the closer to the bottom, the lower the temperature is, as shown in Table 3. The lowest temperature is 20.1 ℃, which is close to the coolant inlet temperature of 20 ℃, indicating that reducing the coolant temperature can effectively promote heat dissipation, but the lower coolant temperature will increase the maximum temperature difference. Compared with structure a, structure b is filled with 5mm thick thermal conductive adhesive between monomers, and the maximum temperature is 28.9 ℃, and the maximum temperature is increased by 0.8 ℃, indicating that the thickness of thermal conductive adhesive has an impact on the heat dissipation of the battery pack; Compared with b structure, the highest temperature of c structure monomer filled with 1mm thick thermal conductive adhesive was 23.2 ℃, the highest temperature was reduced by 5.7 ℃, and the cooling effect was better; The maximum temperature curve is shown in Figure 3.

Table 3. Battery Parameters

环境温度(℃)	最低温度(℃)	最高温度(℃)	最大温差(℃)
30	25.1	32.6	7.5
35	25.1	33.2	8.1
40	25.1	33.4	8.3

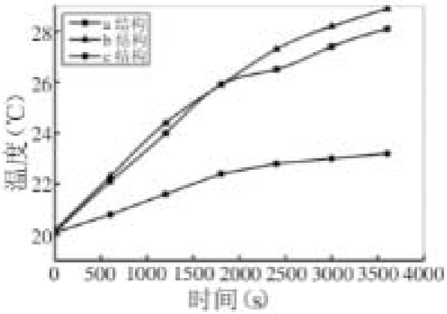

Figure 3. Maximum Temperature Curve of Different Thermal Conductive Adhesives

3.2. Temperature distribution of battery pack under high temperature condition

The coolant inlet temperature is 25 ℃, and the c structure with a thickness of 1 mm is filled between monomers. Fig. 4 (a)~(c) shows the temperature field distribution of the battery pack under high temperature conditions.

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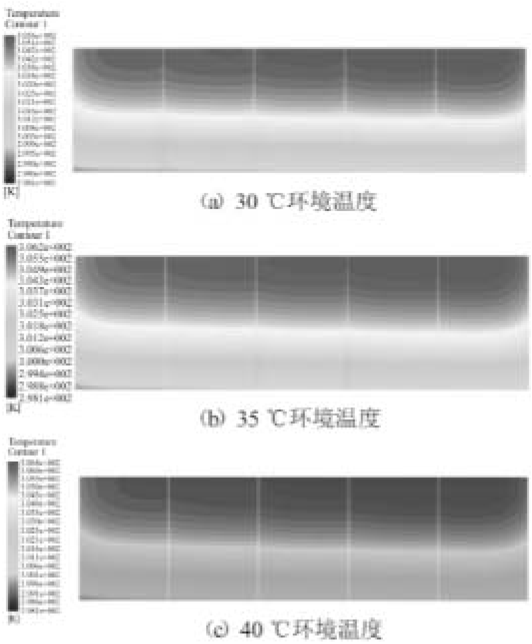

Figure 4. Comparison of Temperature Field under High Temperature Conditions

As shown in Figure 4, under the working condition of 30 ℃, the maximum temperature is 32.6 ℃, and the maximum temperature difference is 7.5 ℃; At 35 ℃, the maximum temperature is 33.2 ℃, and the maximum temperature difference is 8.1 ℃, which is 0.6 ℃ higher than that at 30 ℃; Under the working condition of 40 ℃, the maximum temperature is 33.4 ℃ and the maximum temperature difference is 8.3 ℃, which is 0.8 ℃ higher than that under the working condition of 30 ℃, as shown in Table 4 and Figure 5. It can be seen that with the increase of temperature under high temperature conditions, the maximum temperature and the maximum temperature difference of the battery pack tend to be stable, and the thermal conductive adhesive in the structure equalizes the temperature field.

Table 4. Battery Pack Temperature under High Temperature Condition

环境温度(℃)	最低温度(℃)	最高温度(℃)	最大温差(℃)
30	25.1	32.6	7.5
35	25.1	33.2	8.1
40	25.1	33.4	8.3

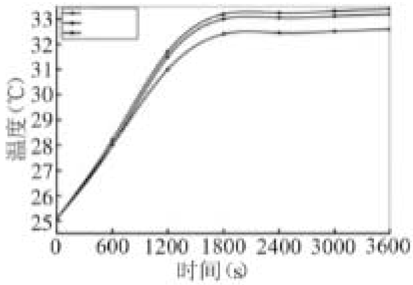

Figure 5. Comparison Curve of Maximum Temperature

4. Conclusion

The fitting formula between the internal resistance of the battery cell and SOC was obtained through the test. According to the fitting formula, UDF was compiled to more accurately simulate the heat generation rate of the battery cell. The simulation analysis was carried out on the liquid cooled battery packs with different thermal conductive adhesive structures, and it was concluded that (c) structure was an optimal thermal conductive adhesive structure. The influence of the optimal thermal conductive adhesive structure on the heat dissipation of the thermal conductive adhesive battery pack at high temperature is simulated and analyzed. The results show that the thermal conductive adhesive is helpful for the heat dissipation of the battery pack at normal temperature, but its thickness will lead to heat accumulation; Under high temperature conditions, the (c) thermal conductive adhesive structure used is conducive to reducing the maximum temperature of the battery pack and improving the temperature field balance of the battery pack.

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