

Thermal Behavior Analysis of Polymer Composites in Lithium-Ion Battery Cell

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ABSTRACT

Polyamide 6(PA6)/hexagonal boron nitride(h-BN) and polyphenylene sulfide(PPS)/graphite composites have been prepared to investigate the possible usage as battery housing materials. The addition of the highly conductive filler improved thermal conductivity of polymer matrix more than 2 times. On the basis of the experimental results and intrinsic material parameters, thermal behavior in a battery pack has been monitored by computational simulation. The heat generated within a cell was readily dissipated as a highly thermal conductive aluminum(Al) was used and thus the temperature was evenly distributed over a whole package. In the case of a battery pack made of polymer or polymer composites, on the other hand, the temperature inside cell is much higher due to the accumulation of heat. The predicted heat flow behavior may be useful in selecting proper housing materials.

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INTRODUCTION

As global warming becomes a serious issue, the emission of greenhouse gas from vehicle has been restricted. In order to reduce the consumption of fossil fuel the transport system is directed towards the development of zero-emission electric vehicles (EV). Lithium (Li) battery is an attractive energy source for EV because of high energy density, high voltage, light weight, and low self-discharge performance [1,2]. Since its introduction in 1990s, the usage of lithium-ion battery has increased noticeably due to high demand in electric vehicles as well as electronic devices. In spite of various advantages, Li battery can be operated efficiently within a certain temperature range. Suppose that it is operated at high or low temperature, the life span and efficiency drop quickly. Thermal issues of battery pack are more concerned in electric vehicles because of higher power and more aggressive charge/discharge characteristics. Thousands of cells are placed together in a pack in order to maintain high power and capacity. However, heat generated from each cell hampers the reliability. Therefore, effective manipulation of residual heat is of particular importance to keep the pack within the desired operating temperature range.

In general, cool air or liquid circulates through the pack in order to dissipate the waste heat. For air cooling system, the design and operation are relatively simple and thus applicable to any type of cells by direct contact. Thermal conductivity of

housing materials plays a pivotal role in determining pack temperature. Highly conductive aluminum ($k=201$ W/mK) is a representative housing material. Even though metals are idealistic in terms of thermal conductivity, for electric vehicles where light weight is critical they are problematic. Therefore, replacement of metal housing material is one of the approaches to manufacture lighter vehicle. Polymer composite is considered as replacement since it is light, cheap, and easy to process [3,4]. Thermal conductivity of intrinsically insulating polymer may be endowed by adding thermal conductive fillers such as carbon black, graphite, and boron nitride(BN) [5, 6, 7].

In present work, thermally conductive composites have been prepared by adding hexagonal boron nitride(h-BN) and graphite fillers into polyamide 6(PA6) and polyphenylene sulfide(PPS), respectively. Temperature and velocity profile has been predicted over the whole battery pack by conducting numerical calculation. The feasibility of polymer composites as housing materials has been examined by monitoring temperature profile in a pack.

COMPUTATIONAL SIMULATION

Heat generated in a battery pack is primarily transferred by convection and conduction. Convection can take place both by external forces such as fan and pump, defined as 'forced convection', and internal temperature gradient (natural convection). In our system, the forced convection is

assumed to dominate the heat transfer. The thermal behavior under a constant air flow may be described using a combined Navier-Stokes (N-S) and heat transfer equation.

$$\rho(u \cdot \nabla)u = \nabla \cdot \left[-pI + \mu(\nabla u + (\nabla u)^T) - \frac{2}{3}\mu(\nabla \cdot u)I \right] + F \quad (1)$$

$$\rho C_p u_{trans} \cdot \nabla T = \nabla \cdot (k \nabla T) + Q \quad (2)$$

$$\nabla \cdot (\rho u) = 0 \quad (3)$$

where u and μ represents velocity and dynamic viscosity of fluid, respectively. F indicates the volume force. Pressure (P) decreases constantly and finally reaches to zero at the outlet. Heat generation from each cell is constant, i.e., $Q=129964.4$ W/m³. Other material parameters are summarized in Table 1. Thermal conductivity of pure polymer and polymer composites has been measured experimentally by means of heat flow method (Unitherm™ Model 2022, Anter Corp) (Figure 1). At steady state, the mass is conserved as expressed by continuity equation in eq(3). No-slip boundary condition is imposed at cell (or pack)-air interface, i.e.,

$$V_{wall} = V_{fluid} = 0 \quad (4)$$

Table 1. Properties of pure aluminum, PA6, PPS, PA6/h-BN, PPS/EG/KS150 composites.

Materials	Heat capacity, C_p (J/kg·K)	Density, ρ (kg/m ³)	Thermal conductivity, k (W/mK)
Air	1	1.16	0.025
Aluminum	900	2700	201
PA6	1700	1150	0.26
PA6/h-BN	2500	1506	0.468
PPS/EG/KS150	2700	1651	1.518

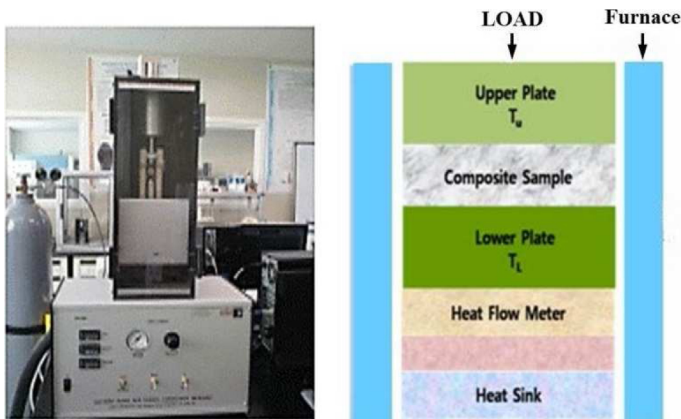


Figure 1. Picture and scheme of thermal conductivity testing machine by heat flow method.

Numerical calculation of a combined N-S and heat transfer equation has been conducted using Comsol Multiphysics. For modeling, ten cylindrical cells (5 rows $\times$ 2 columns) with 18mm in diameter and 65mm in height are placed in a rectangular pack (95.5mm in length $\times$ 38.5 mm in width $\times$ 72mm in height). The gap between 1st and 2nd columns is 0.5mm. The geometry and free tetrahedral mesh composed of 1,863,977 elements are shown in Figure 2. Air at 35°C constantly flows from the left to the right side at 0.007 m³/s, i.e., uni-directional air flow. Air path is delineated on the front and side surface of a pack (Figure 2b).

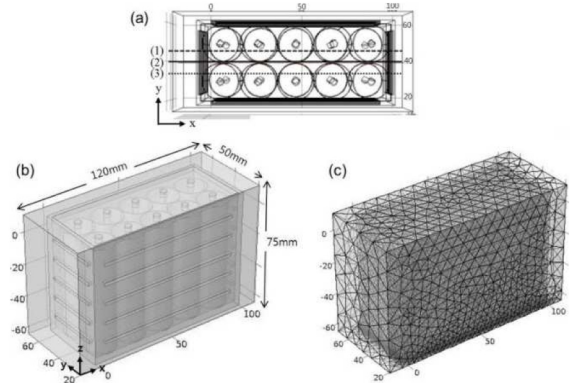


Figure 2. (a) Top view, (b) geometry, and (c) computational mesh of analyzed battery pack containing ten cylindrical cells.

RESULTS AND DISCUSSION

The effect of air flow on temperature profile has been depicted in Figure 2. Aluminum is selected as housing material to clarify the difference. The pack on the right side is isolated from air, i.e., no flow from the top, bottom, and sides. It is apparent that the heat generated from each cell is accumulated along the flow direction, i.e., y-axis, regardless of employing air cooling. With the aid of air flow, however, the pack reveals lower temperature over the whole pack, decreasing from 36.9 °C to 35.9 °C after traveling the pack. It is expected that the convective heat transfer is more active as flow rate increases.

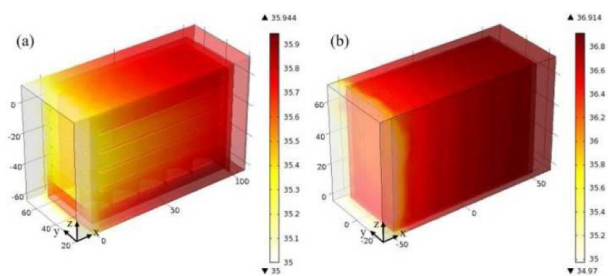


Figure 3. Comparison of steady state 3D temperature distribution in a battery pack (a) with air path and (b) without air path.