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Feasibility study of Boron Nitride coating on Lithium-ion battery casing

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HIGHLIGHTS

- We studied the Boron Nitride coating on battery casing using Taguchi method.
- We investigated the effect of surface roughness and coating thickness on adhesion strength.
- We compared the effect of coating and polymer insulator in heat transfer.
- The Boron Nitride coating could enhance the thermal management of the battery.

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ABSTRACT

Increasing in public awareness about global warming and exhaustion of energy resources has led to a flourishing electric vehicle industry that would help realize a zero-emission society. The thermal management of battery packs, which is an essential issue closely linked to a number of challenges for electric vehicles including cost, safety, reliability and lifetime, has been extensively studied. However, relatively little is known about the thermal effect of polymer insulation on the Lithium-ion battery casing. This study investigates the feasibility of replacing the polymer insulation with a Boron Nitride coating on the battery casing using the Taguchi experimental method. The effect of casing surface roughness, coating thickness and their interaction were examined using orthogonal array L_9 (3^4). Nominal the best is chosen for the optimization process to achieve optimum adhesion strength. In addition, the thermal improvements of the coating as compared to conventional polymer insulator on the battery are further investigated.

1. Introduction

Lithium-ion battery with its high energy and power per unit mass, no memory effect and relatively long cycle life as compared to Nickel Metal Hydride and lead acid battery has received vast attention recently especially in portable electronic devices and automotive applications. The battery cells are connected in series and in parallel and close packed to provide the necessary power for the devices [1]. Although Lithium-ion battery possesses an immense potential in automotive and aerospace application, its thermal and safety problems remain critical issue yet to be resolved, especially in the development of fast charging battery [2,3]. Thermal management is an important issue in Lithium-ion batteries, because the electrochemical process in the battery is vulnerable to the temperature variation. At high I_t-rate of charging or discharging, the exothermic heat generated in the cell and inadequate cooling eventually lead to thermal aging and thermal runaway [2]. Besides, uneven temperature distribution in the cell or module reduces the cycle life and charging capacity [3].

Insulation of the battery body is extremely important for a battery so that the positive and negative terminals are isolated. Good insulation is desirable to prevent any short circuit and sparks that occur when the cells are closely packed. In general, insulation material for the battery body is made of polymer such as Polyvinyl Chloride (PVC) or Polyethylene Terephthalate (PET) and a heat shrink is wrapped around the battery body as shown in Fig. 1. The thickness of the insulating film is about 0.2–0.3 mm. The polymer insulator must endure a harsh environment that composes of thermal cycling during charging and discharging cycle and corrosive environment which could cause insulator degradation, fracture

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Nomenclature

C_p	specific heat capacity of the battery, J kg^{-1} K^{-1}
E	emissivity
E_a	activation energy, kJ/mol
h	convective heat transfer coefficient, W m^{-2} K^{-1}
k_T	conductive heat transfer coefficient
L	thickness, m
R	universal gas constant, J mol^{-1} K^{-1}
T	surface temperature of battery, K
T_∞	free stream temperature, K
t	time, s
ρ	density of the battery, kg m^{-3}
r	radius of cell, m
σ	variance of the experimental results
σ_{sb}	Stefan–Boltzmann constant, W m^{-2} K^{-4}
$\bar{y}$	represents the average experimental results (y)

Subscript

eff	effective
i	different layer of active battery material
ang	angular direction
r	radial direction

or softening. These conditions are expected to be very challenging for the reliability of the polymer insulator. On the other hand, polymer insulator with poor thermal conductivity, together with high thermal contact resistance exist between the polymer insulator and battery metal casing that prevents the heat generated from the battery to dissipate effectively to the surroundings. The heat dissipation from the battery is realized by conduction across the actual contact area of the metal casing and polymer insulator and through conduction or radiation across the air gaps [4]. The contact area is normally small for rough surfaces. In addition, imperfect heat shrink process may introduce an air bubble being trapped between the battery metal casing and the insulator which leads to localized heat accumulation. During high I_t-rates of charging and discharging, the heat generated would be retained inside the cell. This is caused by thermal contact resistance between battery casing and polymer insulator, thus forming a large temperature gradient inside the cell under strong forced convection process [5]. Therefore, it is required to investigate these issues with insulator to ensure that the battery performs safely at all levels including electrical and thermal.

The properties of the metal surface could be changed by applying a layer of coating. The coating material properties could have an excellent thermal conductivity, good thermal insulating properties, electrically conductive or non-conductive [6]. Boron Nitride has a layer structure which is similar to graphite [7], and possesses a good thermal conductivity, electrical insulation, low dielectric constant and good thermal stability up to 1000 °C in the air [6]. Besides, Boron Nitride shows chemical inertness, high corrosion and erosion resistance. Due to these advantages, Boron Nitride has been used widely as release agents and protective coatings for dies/molds, glass making process, metal processing, sintering, welding, brazing, etc. Properties of Boron Nitride are shown in Table 1. There are various methods used for Boron Nitride coating such as chemical vapor deposition (CVD) [9–11], plasma assisted chemical vapor deposition (PACVD) [12–14], physical vapor deposition (PVD) [15–17], and spin coating [18]. However, studies on the Boron Nitride coating on the battery casing are rare. Moreover, most of the studies on the thermal analysis of Li-ion battery did not take the effect of the polymer insulator into account [19–23].

Taguchi technique is an experimental technique developed by Dr. Genichi Taguchi to dramatically improve the process, quality, product characteristics and simultaneously reduce the product development time and cost [24–26]. The principles of robust design are based on statistical methods to identify the parameters that affecting the performances. Besides, the optimum parameters determined from the laboratory level can be reproduced in the industrial conditions [27]. A full factorial design, which requires measuring all the design parameters, is costly and time consuming. However, by implementing Taguchi method, only a certain combination of parameters according to orthogonal array needs to be calculated and the target of the Taguchi method is to create a better parameter group and reduce the design period [25]. Hence, Taguchi method could be utilized to optimize the coating parameters effectively.

In the present study, the feasibility study to replace the polymer insulator of the battery with Boron Nitride coating will be investigated. A Taguchi method with orthogonal array L_9 (3^4) is used to optimize the coating parameters of the battery casing. Two factors, surface roughness of casing and coating thickness, which affect the coating quality are investigated. The target performance measure is used to determine the main control factors that largely affect the coating performance. The significance and contribution of each factor is analyzed using Analysis of Variance (ANOVA). Confirmation test is performed to validate the experimental design. Lastly, the influence of the conventional polymer insulator and Boron Nitride coating on the internal cell temperature distribution under various I_t-rates of constant current charging with forced convection will be discussed.

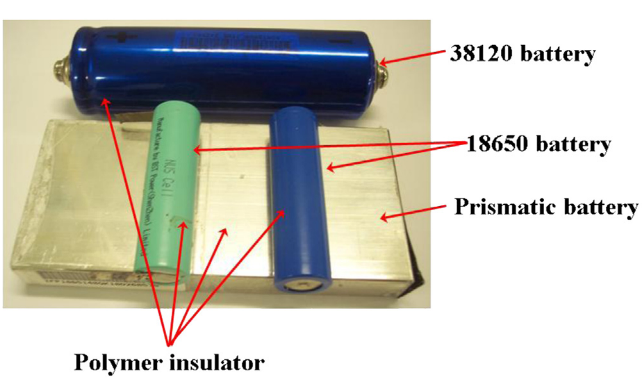

Fig. 1. Different types of Li-ion battery with polymer insulator.

Table 1
Properties of Boron Nitride [8].

Properties	Value
Crystal structure	Hexagonal
Color	White
Density, kg m^{-3}	1900
Maximum used temperature, °C	1800
Hardness, kg mm^{-2}	15–24
Elastic modulus, GPa	46.9
Thermal expansion coefficient (10^{-6}) (°C^{-1})	Parallel 11.9 Perpendicular 3.1
Thermal conductivity, W m^{-1} K^{-1}	Parallel 30 Perpendicular 33
Specific heat, J kg^{-1} K^{-1}	1610
Dielectric breakdown strength, ac-kV mm^{-1}	Parallel 95 Perpendicular 79
Vol resistivity, Ω cm	Parallel > 10^{14} Perpendicular > 10^{15}