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A safety study on internal short-circuit in Li-ion batteries for electric vehicles

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(Abstract) As the battery of electric vehicles becomes more energy-condensed, its safety level is more critical. To prevent unwanted thermal runway, we designed cell chemistries and finally achieved improved results of nail penetration test. By applying a coated functional separator and electrolyte additives, the heat generation decreased significantly and the cell temperature maintained under 150 ^{o}C.

1. INTRODUCTION

Recently, there has been much interest in electric vehicles (EV) due to their environmental friendliness as well as the depletion of fossil fuels. In EV, the power and energy provided by battery are the primary characteristics. However, as the capacity of the battery increases, the risk of fire or explosion becomes severe. There are numerous possible exothermic reactions in the battery cells up to 300^{o}C, where the dominant sources of heat generation are the reactions between electrodes and electrolytes. For IT application, materials that possess the ability to suppress the heat generation might improve the safety performances in terms of cell-level. However, in the case of large Lithium-ion battery (LIB) for EV application, it seems that there need additional devices to improve the safety level.

To simulate the intentional short-circuit environment inside the cells, the nail penetration test has been introduced. When the battery is penetrated by a metal nail, the internal cell temperature reaches over 300 ^{o}C in a very short period of time, which results in an unwanted thermal runaway. In this work, we found that if the energy density of the LIB cell is higher than 160Wh/kg, the amount of heat generated by excessive current tends to be uncontrollable meaning explosion. In such cases, it takes less than 0.4sec for the cell to reach up to 300 ^{o}C. To prevent this rapid temperature increase and maintain the cell temperature below 150 ^{o}C, we need to implement an approach to lower the shutdown temperature as well as the application of new additives by which the heat generation could be minimized..

2. RESULTS AND DISCUSSION

2.1 Separators possessing minimal heat shrinkage and improved shutdown characteristics

We have examined several separators for nail penetration tests. A polyethylene-based separator coated with two different thin and porous layers showed improvements in terms of the cell safety. One layer is to stabilize the dimension of the separator over the wide range of temperature and the other layer is to maintain the resistance up to the shut down temperature.

2.2 Additives for low heat generation by forming thermally stable SEI on the anode side

Several materials have been developed and evaluated to reduce the flammability of electrolyte. However, so far no noticeable improvement has been observed for the nail penetration test. Most of non-flammable additives do not always make a thermally stable solid electrolyte interphase (SEI). In this work, we focused on the stable anode SEI by which the heat generation under 100 ^{o}C can be minimized. From 50 to 150 ^{o}C, there are exothermic reaction peaks, which correspond to the destruction of SEI layer on the anode. If we could make a thermally stable SEI layer, within that temperature range, it would reduce the temperature increase by suppressing the reactions between the anode and the electrolyte. We introduced new additives which form a robust SEI layer containing inorganic moieties. Additives containing siloxane showed less heat generation on the anode which was proved by Differential Scanning Calorimetry (DSC) and Accelerated Rate Calorimetry (ARC) measurements.

3. CONCLUSION

The enhanced cell safety level for the nail penetration test for large format LIBs has been achieved. We believe that the adoption of coated separators and electrolyte additives improved the cell safety by reducing heat generation on the anode SEI as well as lowering the shutdown temperature of the separator.

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