Safety Assessment and Abusive Test of Lithium-Ion Battery in Electric Vehicles

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Abstract - *Lithium-ion batteries have become the lifeline of the modern technological world. These batteries have gained considerable attention due to their high energy density, high power density, low maintenance, an advantage that many other chemistries cannot claim. Owing to these properties Li-ion batteries are currently considered as the most suitable energy storage device for powering Electric Vehicles (EV's). All new technologies have their pros and cons, and LI-ion batteries are no different from them. Lithium-ion batteries suffer from performance barriers and technological barriers. Therefore, the safety of these batteries plays an important role in the operation of the Electric Vehicle system. This article discusses the abuse tolerance tests and evaluates the factors that affect the safety and performance of Li-ion batteries. Finally, new technologies and trends that will replace conventional Li-ion batteries in the future are also investigated.*

Key Words: Lithium-ion battery, Electric Vehicle, Safety, Failure.

1. INTRODUCTION

Electric Vehicles have gained global attention in the past decades. Reduced emission, immediate torque, fewer moving parts, silent drive are mainly the key features that shift the focus of people from conventional gasoline-powered vehicles to electric vehicles.
Europe secured approximately $60 billion in investment in 2019 to manufacture EV's & batteries, nineteen times more than in 2018. Sales of electric vehicles hit 2.1 million globally in 2019, according to the global EV outlook 2020. While 5.2% of China's cars are electric, Norway has 56% of its cars running on electricity [1]. Although India has an EV penetration of just 1% of India's total sales of vehicles, Hyundai, MG Motor, Mahindra Electric, and Tata have raced to take the lead in the four-wheeler category of EV. India is going to implement Faster Adoption and Manufacturing of Electric Vehicle (FAME) policy with a goal of reaching 30% of EV penetration by 2030.

2. LITHIUM-ION BATTERY

Lithium-ion battery pack plays a significant role in the EV system performance. The first commercial Li-ion battery was released by Asahi-Kasei in the year 1991. These batteries are low maintenance battery an advantage many other chemistries cannot claim [2]. They have a high energy density of about100-265 Wh/Kg. Modern EV's rely on these batteries, hence the safety of these batteries is a matter of great concern.

3. FAILURES IN LI-ION BATTERY PACK

Different studies have been investigating the safety and reliability of Lithium-ion battery packs over the past year. Here are some of the failures that occur in Lithium-ion batteries.

3.1 SEI Growth

For the stability of lithium-ion cells using graphite anode, a solid electrolyte interface is essential and these films have a thickness of up to 90nm [3]. During the initial charge-discharge cycle, the electrolyte reacts vigorously with the graphite anode. The SEI layer's role is to prevent further electrolyte decomposition. The electrolyte molecule cannot travel through these layers once the SEI layers are formed, so it cannot react with lithium ions and electrons. The growth of these layers thus increases the battery impedance, causing the battery to heat up and damage the battery.

3.2 Lithium Plating

Lithium plating is one of the degradation mechanisms in lithium-ion batteries which decline the lifespan of the battery [4]. If the charging voltage is increased beyond 4.2V, excessive current flows, and the transport rate of lithium ions to the negative electrode, graphite increases. Hence the lithium ions cannot be accommodated quickly enough between the intercalation layers of graphite and lithium ions accommodate on the surface of the anode as metallic lithium which results in the tearing of the separator that cause short circuit in the battery which leads to an explosion.

3.3 Temperature Effects

The performance of lithium-ion batteries will degrade below 0°C because below this temperature, the battery is soaked up like a sponge by porous graphite that makes up the anode [5]. The energy density of lithium-ion batteries was 100 Wh/L at 25°C and these values reduced to 5 Wh/L at -40°C. The chemical reaction rate decreases with temperature according to the Arrhenius equation. Low temperature affects the property of electrolytes. The decrease in temperature and will reduce the ionic conductivity. As a result, the internal resistance increases due to the impedance of the migration of ions and the current carrying capacity of the cell both for charging and discharging.

Operating at high temperatures results in the destruction of cells. According to the Arrhenius effect, the chemical reaction rate increases with increases in temperature [6]. But higher current gives rise heat dissipation. Unless this heat is removed faster than it is generated it results in thermal runaway.

Multiple stages are involved in the formation of thermal runaway. And they cause more damage to the cell. Due to overheating or physical penetration, the breakdown of the thin passivating SEI layer takes place at the anode. The initial overheating may be caused by excessive currents, overcharging, etc. Breaking of SEI layer starts at 80°C and once this layer is breached, the electrolyte reacts with graphite anode and shoots up the temperature. As the temperature builds up heat from anode reactions results in the breakdown of organic solvent in the electrolyte releasing flammable hydrocarbon gases. But no oxygen [7]. This typically starts at 110°C. The gas generation due to the breakdown of electrolytes causes pressure to build up inside the cell. At 135°C the polymer separator melts and causes a short circuit between the electrode. At 300°C the heat from the electrolyte causes the breakdown of metal oxide and the cathode releases oxygen which enables the burning of both the electrolyte & gases in the cell. A large amount of heat thus formed increases the temperature to 800°C or higher and cause a fire.

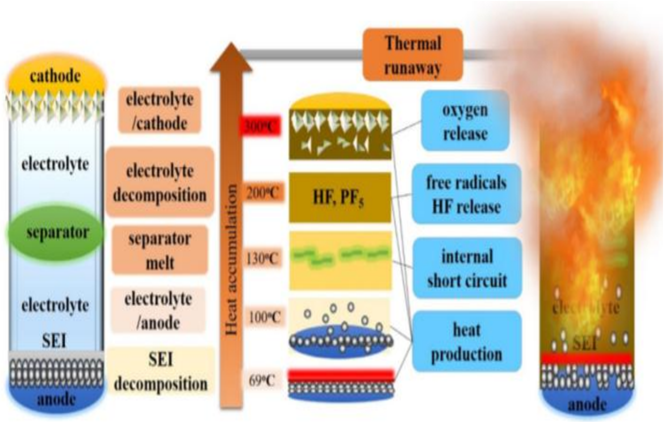

Fig -2: Thermal Runaway

4. ABUSE TEST

Abuse test shows the performance of a battery under varying conditions. These tests help in identifying the weak points and vulnerabilities the battery experience when it is subjected to extreme conditions or real-life off-normal conditions.

4.1 Thermal Abuse Test

This test takes place inside the thermal abuse test chamber. The inner chamber material is stainless steel 304. This machine operates at 220V and 50Hz frequency. The bottom part of the machine has wheels so that their movement is easy.

Now the battery is placed inside the chamber and the temperature is increased to 130 °C and is maintained at that temperature for up to 30 minutes [8]. If the battery doesn't catch fire or explode during the period of high-temperature exposure then it is considered to pass the test. When the battery is heated above 130 °C thermal runaway takes place and causes SEI breakdown, short circuit, separator melting, etc. The graph below shows the pass and fail the performance of the lithium-ion battery. If the cell can dissipate the internally generated heat, then its temperature will not increase significantly as shown in Fig 2 (b). But if more heat is generated than dissipated the cell temperature increases more and more and the thermal runaway takes place as shown in Fig 2(a).

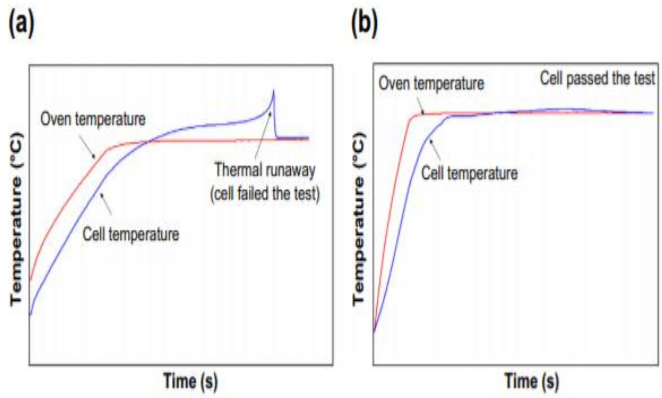

Fig 2: Thermal abuse test behavior of a Li-ion cell (a) cell failed the test that caused in thermal runaway and (b) cell passed the test

4.2 Nail Penetration Test

This test [8] is based on International Battery Standard SAE J2464 [9]. Here a sharp steel rod is "the nail" is forced through the battery at a speed of 8 cm/s [10], [11], [12]. Depending on the test level whether it is cell or module the depth of penetration and dimension of nail vary. In many of the cases, a 3mm diameter rod is required at the cell level and a 20 mm diameter rod is required for the module level. Depth of penetration is through the entire cell for cell level testing. Fig3(a) shows the schematic of a typical nail penetration test conducted for Li-ion cell. The voltage and temperature responses for Li-ion cells that pass or fail nail penetration tests are shown in Fig 3 (b) & (c). In both cells, there is an instantaneous steep voltage drop, as the nail penetrates through and the temperature rises. When the heating rate is low, the cell stops heating when the temperature is close to the separator shutdown temperature as shown in Fig(b). When the heating rate is very high, then the cell continues to heat so quickly that the heat generation far exceeds the heat dissipation and in most of the cases the cell fails the nail penetration test as shown in Fig(c).

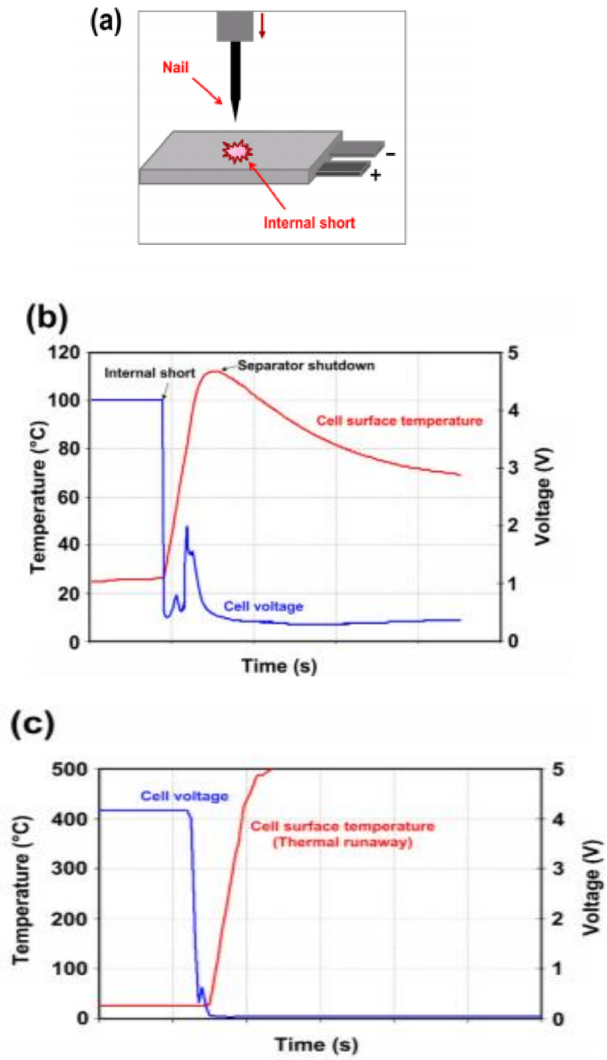

Fig-3: The behavior of a Li-ion cell with shutdown separator. (a) Schematic of nail test (b) voltage and temperature responses of a cell passing the test (c) voltage and temperature responses of a cell that failed the test

4.3 Fire Test

The aim of the test is to investigate any possible explosion risk. The fire test is carried out in a large fire test hall. The test setup that is the battery is placed on the grating table with a 25KW Propane burner positioned 20cm below the battery. During the test, the battery is exposed to flames from the propane burner. For safety reasons, the test setup was enclosed by a safety net cage. The test setup was placed under a 2MW calorimeter and the ventilation system was adjusted to provide a suitable flow rate in the hood making it possible in measuring the heat release rate continuously and to analyze the gases. The fire test showed that battery configuration, as well as the construction, affect the fire behavior of gas. The gas analysis of the fire effluents was conducted using Fourier Transfer Infrared spectroscopy and it was found that Carbon monoxide, Carbon dioxide, and Hydrogen Fluoride were the main fire gases produced. Out of these Hydrogen Fluoride and Carbon monoxide are important from a toxicological point of view. Fig. 4 shows hydrogen fluoride concentration as a function of time. A large number of cells increases the amount of hydrogen fluoride formed.

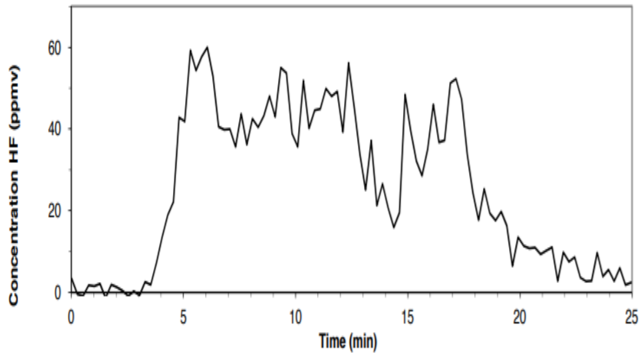

Fig-4: HydrogenFlouride Concentration VS Time

5. ANALYSIS

The pie chart below shows the prioritization of degradation modes' influence on reliability assessment of Lithium-ion batteries [14]. From the study, it is evident that loss of anode material degradation influences the safety and reliability of the battery more (28%) and the loss of electrolyte conductivity least affects the battery reliability (10%). Moreover, loss by electric contact (20%) and lithium plating (21%) are the effective factors that contribute to the anode material.

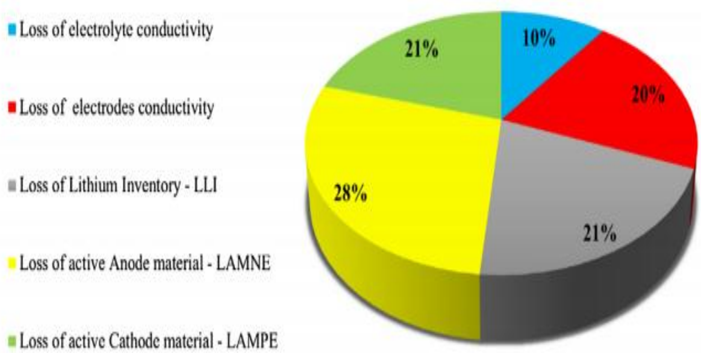

Chart-1: Prioritization of degradation

6. CONCLUSIONS

Electric Vehicle and their batteries are becoming a far larger business than most realize. The largest market for Lithium-ion batteries is and will remain electric vehicles. In these applications, they have the best compromise of performance, weight & size. Overcharge, short circuit, temperature range, the fire was found as the major factor that affects the safety and reliability of Lithium-ion battery. A new way of producing lithium-ion batteries will overcome the drawbacks affecting these batteries. A team from the Institute of Bio-Engineering in nanotechnology at Singapore is undergoing certain researches to produce anode materials which are ultrathin, 2D materials with excellent electrochemical and mechanical properties. Elon Musk promised that Tesla would soon be able to power electric cars for more than one million miles over their lifespan. Nawa technologies has designed and patented ultrafast carbon electrode which says, is a game changer in battery market. He says that they use vertically aligned carbon nanotube design. It can boost the battery power tenfold, increase the energy storage by a factor of three and battery life cycle five times. The company sees electric vehicle as being primary beneficiary it reduces the cost of battery production while boosting the performance. This technology could be in production by 2023.

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BIOGRAPHY

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