Flame Retardant Intumescent Sheet Molding Compound for Electric Vehicle Battery Cover Application

Steven Prascius

Teijin Automotive Technologies
255 Rex Blvd., Auburn Hills, MI USA 48326

Abstract

In recent years, the electric vehicle market has expanded rapidly and is expected to continue growing in the coming decade. While the adoption of electric vehicle technology provides many advantages over internal combustion engine vehicles, there are drawbacks. One such drawback is the potential danger of a thermal runaway event which is the uncontrolled increase in temperature and pressure due to damage to lithium-ion batteries that could lead to a battery fire. This danger has highlighted the increasing need for flame retardant materials for electric vehicle battery covers to help mitigate risk during such an event. One such material well suited for this challenging application is intumescent sheet molding compound (SMC).

Intumescent SMC meets the strict thermal requirements of OEMs and international standards for battery cover applications, while also meeting the physical requirements of traditional battery cover materials. This material provides superior insulative and flame-resistant performance with a <10 second after flame time in UL94-5VA and passing results in UL 2596 with a max panel temperature of < 370 degrees Celsius at 3 mm. In simulated thermal runaway testing, intumescent SMC has a max panel temperature of < 340 degree Celsius and a char strength of > 200 N after a 30-minute burn at 3 mm. Intumescent SMC has a tensile strength of > 110 MPa, a tensile modulus of >10 GPa, a specific gravity of 1.55 g/cc, and has proven automated production readiness.

1. Introduction

With the rapid expansion of the electric vehicle market in recent years, electric vehicle technology has shown many advantages over traditional internal combustion engine vehicles. With these advantages though, there come drawbacks that require additional efforts to help mitigate. One such drawback is the potential of a thermal runaway event that is associated with electric vehicle battery cells. A thermal runaway event is the uncontrolled increase in temperature and pressure inside a vehicle that stems from damage to lithium-ion batteries that could result in a difficult to extinguish battery fire. This danger has highlighted the increasing need for flame retardant materials for electric vehicle battery enclosures, including battery covers and battery trays, to mitigate risk during such an event.

Traditionally, two materials that have been considered for electric vehicle enclosures have been aluminum and steel. Although these materials fit the mechanical design requirements for this application, they have thermal limitations. Aluminum has a melting point of approximately 600 Celsius which is far below the ~1200 Celsius maximum temperature that can be observed during lithium-battery fire simulations. Steel has a melting point of between 1300 and 1500 Celsius, which will withstand the heat generated during a lithium-ion battery fire, but will also transport significant amounts of heat to nearby components due to the material's high thermal conductivity. As a result, materials that can not only withstand the initial heat of a lithium-ion battery fire, but also provide a sufficient insulative barrier are needed. One such material well suited for this challenging application is intumescent sheet molding compound (SMC).

Intumescent SMC is a thermosetting molding compound that incorporates intumescent technology that expands and forms a rigid, structural char upon exposure to high temperatures. The advantages of Intumescent SMC are that it can be processed in a similar manner to existing thermoset composites while providing a high degree of insulation at the elevated temperatures seen during a lithium-ion battery fire, while also maintaining rigidity and structure during and after flame exposure. Additionally, intumescent SMC provides mechanical and physical properties suitable for electric vehicle battery cover application. This paper will highlight the methods used to evaluate intumescent SMC for EV battery cover application.

2. Methods

2.1 Overview of Methods

The flame-retardant properties of intumescent SMC were assessed through three test methods: UL94-5VA, UL 2596, and an internal extended burn test. Each test method evaluated a component of flame retardancy deemed important to withstand a thermal runaway event.

2.2 UL94-5VA

The UL94-5VA test method was used to evaluate flame propagation on intumescent SMC and the material's ability to self-extinguish. The test samples were cut into 125 mm by 13 mm bars with a thickness of 3 mm and smoothed according to UL 94 procedure [1]. The samples were then attached to a fixture allowing for the inner blue cone of a UL 94 calibrated flame to be applied for five cycles to the corner of the specimen. The after flame and after glow time for each specimen was then recorded following the final flame application. The test set-up can be seen in figure 1.

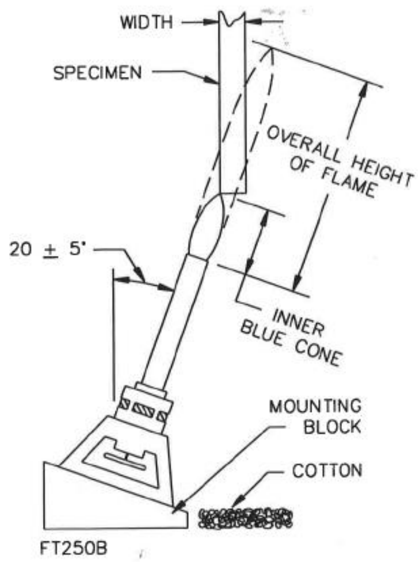

Figure 1. UL94-5VA vertical burning test

2.3 UL 2596

The UL 2596 test method was used to evaluate the thermal and mechanical performance of intumescent SMC in a simulated thermal runaway event. Three samples that were 305 mm X 305 mm X 3 mm were clamped to a 100 mm x 100 mm x 80 mm box containing a 5 x 5 array of 18650 lithium-ion NCA battery cells. The battery array was then ignited allowing for the attached sample to be exposed to the heat and pressure released from the cell array for five minutes, typically exposing samples to temperatures in excess of 1200 ^{o}C. The top side sample temperature was tracked throughout the test and the pressure was monitored to observe any yield through the sample thickness indicating burn through or a rupture. A diagram of the test set-up can be seen in figure 2 [2].

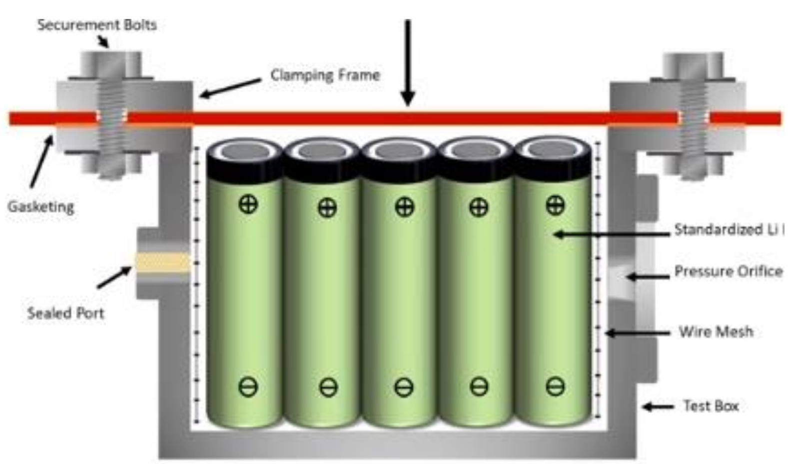

Figure 2. Diagram of UL 2596 test method

2.4 Internal Extended Burn Test

An internal extended burn test was also developed to assess the insulative performance of intumescent SMC and residual strength after burn, or char strength. Test samples were cut into 152 mm x 152 mm x 3 mm squares and were then suspended above a vertical UL 94 calibrated flame with an approximate temperature of 900 °C. The inner blue cone of the flame was then applied to the center of the test specimen for a 30-minute interval. During this interval, the topside panel temperature was recorded using an IR thermal camera. Once 30 minutes elapsed, the test specimen was allowed to cool to room temperature and then was tested for char strength by pushing a digital force gauge through the center of the burned region of the sample. The test set-up can be seen in figure 3.

Figure 3. Internal Extended Burn Test

2.5 Mechanical and Physical Properties

The tensile strength and young's modulus were measured with ISO 527. Dumb-bell shaped samples were prepared with a length of 170 mm, an inner width of 10 mm, an outer width of 20 mm, and a thickness of approximately 3 mm. These samples were tested with an Instron machine using an extension rate of 2 mm/min and a grip distance of 115 mm.

The density was measured with an internal procedure. Samples were cut to 2-inch x 2-inch specimens that were weighed using an analytical balance and then submerged in water using a hook apparatus and then re-weighed to calculate specific gravity.

3. Results and Discussion

The following results for UL94-5VA, UL 2596, and internal extended burn testing were generated using the methods described in the previous section.

3.1 UL94-5VA

UL94-5VA testing was used to determine the ability of intumescent SMC to self-extinguish when exposed to flame, a crucial property for battery cover materials to prevent the propagation of fire throughout a vehicle during a thermal runaway event. The results of this testing can be seen in table 1.

Table 1. UL94-5VA Results

Sample	After Flame Time (s)	Afterglow Time (s)	Thickness (mm)
1	< 1	< 1	3.0
2	< 1	< 1	3.0
3	< 1	< 1	3.0
4	< 1	< 1	3.0
5	< 1	< 1	3.0

UL94-5VA testing yielded results that were consistently less than 1 second for both after flame time and after glow time. A passing result requires a sample to stop burning within 60 seconds of the final application of flame and not have burn-through. The results for intumescent SMC show a strong ability to self-extinguish and prevent flame propagation when exposed to heat or flame.

3.2 UL 2596

UL 2596 was used to evaluate the ability of intumescent SMC to withstand the heat and pressure generated during a simulated thermal runaway event without having burn-through or a rupture through the material. The results of this testing can be found summarized in table 2 and in figure 4.

Table 2. Summarized UL 2596 Results

Sample	Thickness (mm)	Maximum Recorded Topside Sample Temperature (°C)	Peak Recorded Pressure (kPa)	Yield
1	2.87	338.7	269	No yield
2	2.89	361.9	266	No yield
3	2.95	367.8	372	No yield

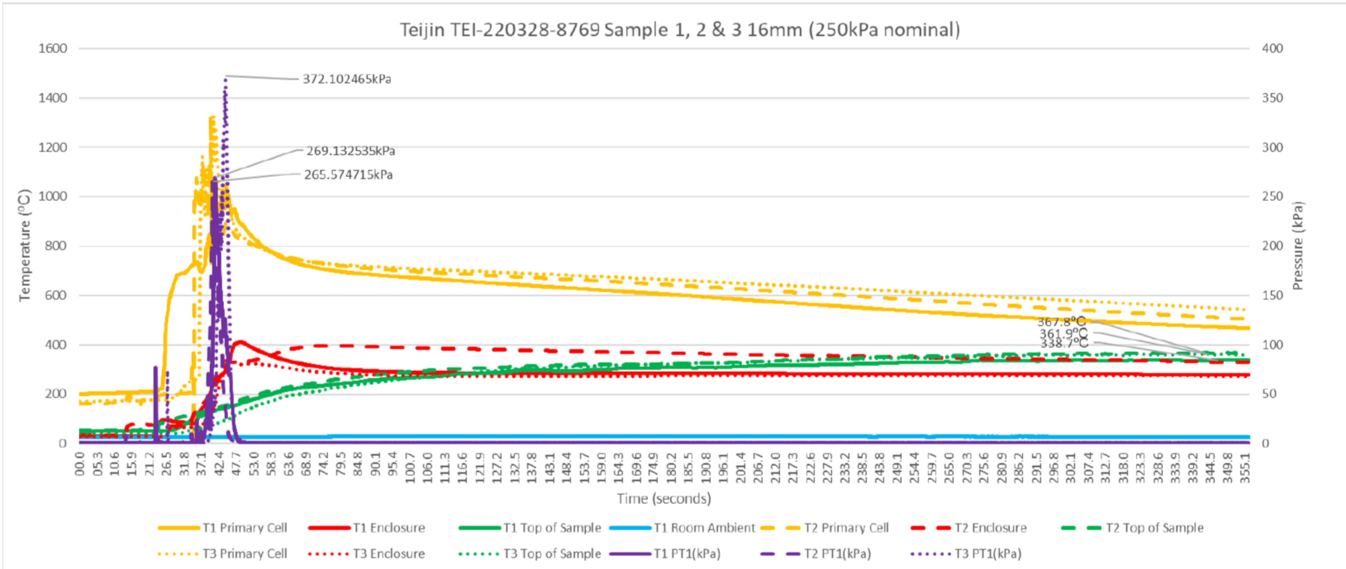

Figure 4. UL 2596 Results

UL 2596 testing showed passing results for all samples tested. The maximum temperature reached for the three samples remained below 370 °C for the duration of the testing. Additionally, the samples were able to withstand pressures in excess of 260 kPa without rupturing or yielding. The results show that intumescent SMC can withstand the energetic release of heat and pressure generated during a simulated thermal runaway event without burn-through or rupture. The results also show a high degree of insulation that prevents the high temperatures experienced by the bottom of the sample from radiating through the thickness of the material to the topside. Images of the tested samples can be seen in the following figures.

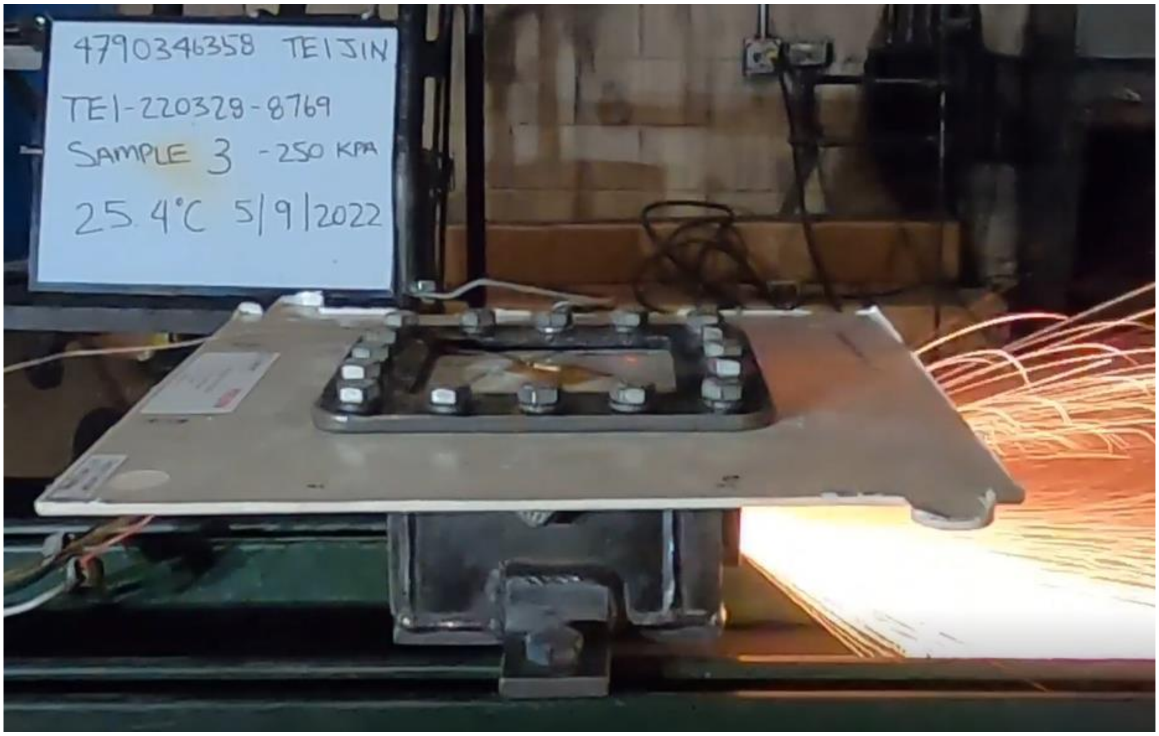

Figure 5. Intumescent SMC sample during initial battery cell ignition

Figure 6. Intumescent SMC sample after UL 2596 testing

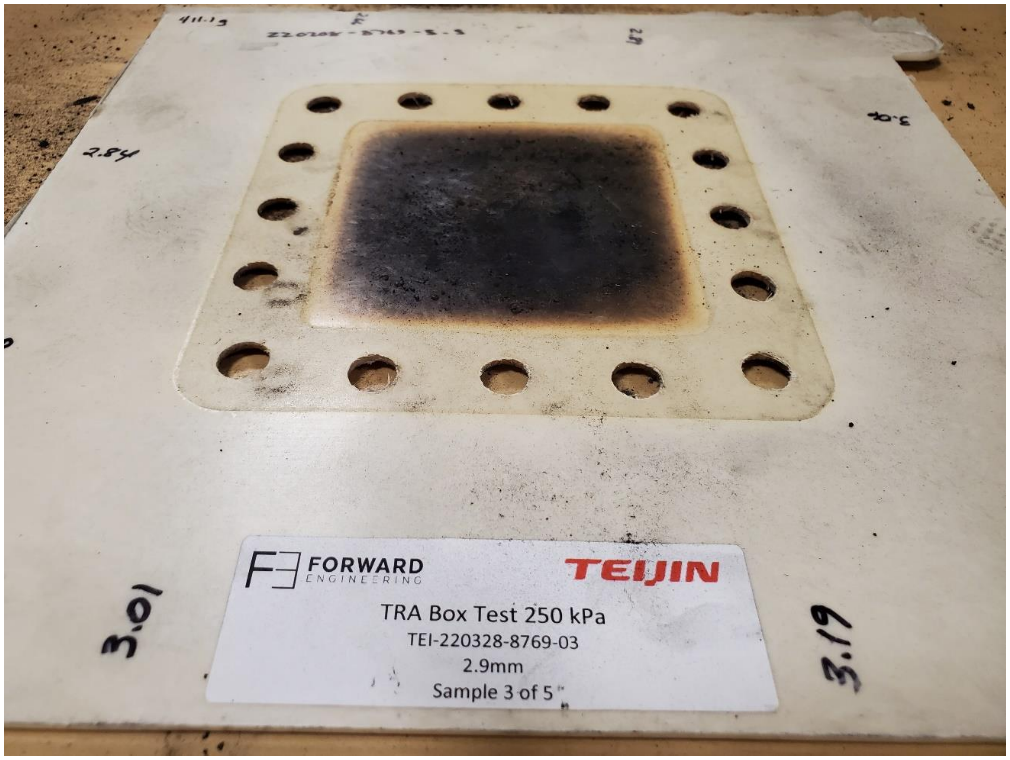

Figure 7. Top of sample after testing

Figure 8. Bottom of sample after testing

As seen in the above figures, a structurally strong char layer formed during testing which was able to prevent burn-through or rupturing of the sample. This property is important to prevent heat or physical matter from passing through a battery cover during thermal runaway which could cause additional damage. The internal extended burn test method was used to further evaluate the strength of the char layer and insulative ability.

3.3 Internal Extended Burn Test

Extended burn testing was used to determine the insulative properties of intumescent SMC and the residual strength of a burned sample at various thicknesses. The results of this testing can be seen in table 3.

Table 3. Internal extended burn test results

Sample	Thickness (mm)	Maximum Topside Sample Temperature (°C)	Char Strength (N)
1	2.6	385	114.8
2	2.9	356	195.0
3	3.2	349	273.6

Extended burn testing shows that thicker samples insulate better and have stronger char strengths than do their thinner counterparts. Additionally, the results show that when testing samples at a thickness of 3 mm and thicker, the maximum topside sample temperature can be limited to 360 °C or less with a residual char strength of approximately 200 N or greater. These results show the strong insulative ability and strong residual strength of intumescent SMC, which is important for preventing heat from spreading to nearby components inside a vehicle experiencing a thermal runaway event.

3.4 Mechanical and Physical Properties

The mechanical and physical properties of intumescent SMC are shown in table 4. Intumescent SMC provides tensile strengths and modulus deemed acceptable for battery cover application while having a density lower than common metal materials.

Table 4. Mechanical properties of intumescent SMC

Property	Intumescent SMC
Tensile Strength (MPa)	114.0
Modulus (GPa)	11.1
Density (g/cc)	1.55

4. Conclusion

As the electric vehicle market continues to grow, it is crucial to understand the limitations and potential dangers of this emerging technology. With the potential danger of a thermal runaway event established, it is important that materials that can withstand the harsh temperatures and pressures released during such an event are implemented to mitigate risk of further damage to vehicles or passengers.

Intumescent SMC has a proven ability to meet these strict demands through a variety of thermal testing. UL94-5VA testing shows a high degree of thermal resistance and the ability of the material to quickly self-extinguish after being exposed to flame. UL 2596 testing shows the ability to withstand the initial energic release of heat and pressure from a simulated thermal runaway test without burn-through or rupturing. Extended burn testing shows a high degree of insulative ability when exposed to prolonged flame and a strong residual strength after burn. Additionally, intumescent SMC has a tensile strength and modulus that meets battery cover requirements while having a density lower than common metal materials. As a result, it is apparent that this material is well-suited for this challenging application.

5. References

1. Fire Testing Technology Limited. “Users’ Guide for the UL94 - Tests Flammability of Plastic Materials for Parts in Devices and Appliances Testing” West Sussex, RH19 2HL, UK 2010.
2. “Electric Vehicle Battery Enclosure Material Safety (UL 2596).” n.d. UL Solutions. Accessed June 28, 2023. https://www.ul.com/resources/electric-vehicle-battery-enclosure-material-safety-ul-2596.