

Fire Fighting of Li-Ion Traction Batteries

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ABSTRACT

The number of full electric and hybrid electric vehicles is rapidly growing [1][2][3]. The new technologies accompanying this trend are increasingly becoming a focal point of interest for rescue services. There is much uncertainty about the right techniques to free trapped occupants after an accident. The same applies to vehicle fires. Can car fires involving vehicles with a lithium ion traction battery be handled in the same way as conventional vehicle fires? Is water the right extinguishing agent? Is there a risk of explosion?

There are many unanswered questions surrounding the topic of electric vehicle safety. The lack of information is a breeding ground for rumours, misinformation and superficial knowledge. Discussions on various internet platforms further this trend.

Tests were conducted on three lithium ion traction batteries, which were fuel-fired until burning on their own. The batteries were then extinguished with water, a surfactant and a gelling agent. The temperatures of the batteries and the required amount of water were recorded.

This paper presents the results of the tests and provides information which can be forwarded to fire schools and other educational authorities teaching rescue and police personnel. The results will also be of interest to vehicle manufacturers regarding the accessibility of the batteries in case of a vehicle fire and testing facilities.

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INTRODUCTION

The number of electric and hybrid-electric vehicles equipped with high voltage traction batteries is rapidly growing in most countries. Rising fuel prices, changing environmental awareness and political motives are some of the key reasons for this trend. To serve that growing market the automotive industry, the battery industry and utility companies are investing in research and development of such vehicles and the necessary infrastructure.

Even though the electric drive is nearly as old as the automobile itself, the last decade's developments justify referring to it as a new technology. As such, it has raised questions and even concerns. The electrical safety and fire safety of the electric drive are subjects of heated debate on internet platforms.

In view of the present low registration figures of electric and hybrid-electric vehicles, their involvement in accidents and fire events is accordingly small. Nevertheless, law enforcement agencies, emergency medical services, recovery services and, last but not least, fire departments need to be prepared.

Knowledge guides have been published by different organizations like the NHTSA [4], institutions for statutory accident insurance and prevention [5], and state fire schools [6]. Vehicle manufacturers provide vehicle specific rescue data sheets for fire services [7]. A lack of practical experience, especially with fire incidents, leads to interim guides, superficial information, and sometimes even instructions that are difficult to implement.

To gather additional information about the burning behavior of lithium ion traction batteries and the possibilities for fire-fighting, three tests were carried out within a test

series. The temperatures of the batteries and the amount of water required for fire-fighting were recorded. HD videos and extensive pictures were taken to generate schooling material.

The following chapters explain the test set-up, the selection of the extinguishing agents, the test results and the conclusions.

TESTS

A similar type of lithium ion traction batteries (hereafter referred to as LiB) has been used in all three tests. Different battery technologies, the design and position in a vehicle, the battery capacity and the fire scenario play significant roles during a fire. Thus, the results cannot be taken as universally valid. The generated data can be used to add to the pool of basic information.

The focus of the test series is to learn more about fire extinguishing of LiBs. The generated data can be used to develop teaching material for e.g. fire-fighters, emergency medical services (EMS) and law enforcement agencies.

Test Configuration

The batteries were placed in a support frame according to their mounting orientation in an electric vehicle (EV). The support frame was located inside a tray, [Figure 1](#). Two sides of the frame were covered to simulate the vehicles' chassis beams. The tray was filled with 45 litres (11.9gal) of n-heptane serving as an ignition source. The initializing fire burned for about 11 minutes, [Figure 2](#). The fire-extinguishing was started in minute 20.



Figure 1. Battery in the support frame placed in a tray



Figure 2. LiB completely surrounded by n-heptane fire to ignite the LiB

The LiBs were equipped with thermocouples. The temperatures were recorded. The amount of water used during fire-extinguishing was recorded. To collect some of the water run-off, sample-taking containers were kept at hand for analysis in a laboratory later on. After the tests the LiBs were stored in a container filled with the extinguishing mixtures used for the tests. All tests were filmed on HD video and photo documented.

Batteries

The tested batteries were identical. They were a product of Deutsche ACCUmotive. They are used on a current electric vehicle. The pouch cell batteries had a capacity of 17.6kWh and weighed about 175kg each. There is no metallic lithium in that type of battery. The state of charge (SOC) was at a level of 95%.

The LiB housing is made of two completely sealed body-sheet metal parts. The pan is 2.4 mm (0.09in) thick and the upper cover is 1 mm (0.04in) thick.

Temperatures

Type-K thermocouples (NiCr-Ni according to DIN 60584) were fixed on the LiB housings. The temperatures of the thermocouples were then recorded by a data acquisition system at a sampling rate of 1 Hz. The ambient temperature ranged between 20 °C and 26 °C (68°F to 79°F).

Each battery was equipped with 6 thermocouples, [Figure 3](#).

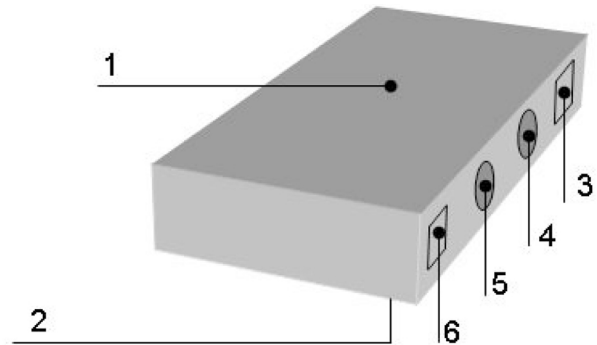


Figure 3. Location of the thermocouples

1. Top of battery housing
2. Bottom of battery housing
3. Electric connector
4. Right pressure release device
5. Left pressure release device
6. Control logic unit

The recording started just before igniting the n-heptane. It was stopped after the LiB-fires were extinguished. The cool-down process of LiB 2 and LiB 3 were additionally recorded overnight.

Extinguishing Agents and Nozzles

All three fires were extinguished by the same fully equipped, experienced fire-fighter.

With water being the extinguishing agent primarily used all over the world by fire brigades, LiB 1 was extinguished with water. The water was supplied through a standardized hydrant. An AWG type CM nozzle (DIN 14365) was used for delivery. The front limiter was fixed, limiting the water flow to a rate of 100 l/min (26.5gal/min) at maximum full jet. The water flow rate can be regulated continuously between 0 l/min and 100 l/min via a control lever. Full jet and spray jet are possible, [Figure 4](#).



Figure 4. Standardized CM nozzle used in Test 1

For LiB 2 the F-500 additive was used. This has shown good performance in vehicle fire-fighting and is recommended by the independent Baden-Württemberg State Fire School [6] for use in fighting fires involving LiBs. It uses an encapsulating technology and achieves good cooling performance. The water was supplied by the same hydrant as in Test 1. An AWG TurboSpritze 2000 Venturi 75 - C 2L, specially designed for F-500, was used for delivery. The nozzle, working on the venturi principle, has an attached 2l (0.5gal) container for the additive. The maximum water flow rate is limited to 75l/min (~20gal/min). The admixing ratio was set to 1%. The water flow rate can be regulated continuously between 0l/min and 75l/min via a control lever. Full jet and spray jet are possible, [Figure 5](#).



Figure 5. F-500 nozzle used in test 2

The Firesorb® additive was used for LiB 3. This has shown good performance in fire tests on small lithium ion tool batteries conducted by the Robert Bosch GmbH [8]. Mixed with water it forms a heat-shielding gel with a high cooling capacity and reduced water evaporation rate. An inline inductor Z2R according to DIN 14384 with a flow rate of 200l/min (~53gal/min) and an admixing ratio of 1.8% was used, [Figure 6](#), to add the additive. The same nozzle was used for delivery as in test one. The limiter was removed; the theoretical maximum flow rate was 200l/min (~53gal/min). Due to the increased friction (inductor + generated gel), the real flow rate was at a maximum of 90l/min (~24gal/min).



Figure 6. Inline inductor and additive canister

TEST 1: WATER

After igniting the n-heptane, it took about 8 minutes until the action of the LiB first became visible. A short circuit led to a small hole in the LiB housing with inflammable gas/steam escaping through it, [Figure 8](#). In the subsequent course of the fire, the pressure release devices (PRD) opened several times. The escaping gas led to a flash fire with flames about 200 cm (~80in) in length while the n-heptane was still burning. Short circuits led to bright white flames, comparable to welding flames. The LiB's housing was locally damaged by this, resulting in a few small holes. A few grams of liquid aluminum were discharged from the holes, coming up within a radius of less than 2 meters (~80in).

Once the n-heptane had been burnt away, after about 11 minutes, the LiB continued to burn in a self-contained fashion. The flames emerging from the pressure release devices were clearly smaller in this phase without the heptane fire. Flames up to 40 cm in length were permanently burning around the electric connector, at the holes in the housing, and at the bottom side at the cooling system's connection. Light-colored smoke was emitted by the burning LiB. The amount of smoke was far less than that emitted by burning gasoline or a burning vehicle.

Immediately after ignition of the n-heptane, the temperatures measured rapidly rose. The channel 2 sensor mounted under the LiB, and thus directly above the fire, measured temperatures around 750° C (1380°F). Influenced

by the wind, all measuring points showed changing values. With the n-heptane no longer burning, all temperatures decreased. The temperature characteristics of Test 1 are shown in full in [Figure 15](#) in the Appendix. [Figure 7](#) shows the characteristics of channels 1 and 2.



Figure 7. Test 1 temperature characteristics of channel 1 (blue) and channel 2 (red)

The battery was extinguished with water. The fire was extinguished in a well-directed manner using as little water as necessary. Starting in second 1,260, it took about 40 seconds and 70 liters (18.5gal) to extinguish the flames. Several short water pulses followed to cool the heavily smoking (white smoke) LiB. 144 seconds after starting to extinguish the fire, the LiB reignited. After extinguishing that fire the battery was cooled with reduced water flow within the next minutes to avoid repeat re-ignition. In this case, a reduction of white smoke was clearly visible. About 200 liters (~53gal) of water were used within the first 4 minutes. The LiB heated up and emitted large amounts of smoke again. Another 200 liters (~53gal) of water were necessary to cool down the LiB to a level of little smoke emission. The extinguishing process took 17 minutes and 30 seconds and 400 liters (106gal) of water were used.

The temperatures increased again, and channels 1 and 2 lined up at about 150° C (300°F). Smoke emission decreased to a very low level about 30 minutes after commencement of fire-fighting.

Three and a half hours after finishing the test, the LiB was placed in a tray filled with 180 liters (~50gal) of water. The LiB was completely immersed in water. Soon after dropping, large gas-bubbles became visible. This continued for several hours.

The extinguishing water run-off during fire-fighting was analysed in a laboratory. The values of fluoride (33 mg/l) and chloride (38 mg/l) were unusually high. Water with this level of contamination must be channeled into a wastewater treatment plant. An electrical conductivity value of 1.520μS/cm was measured.

The analysis of the water used for storage of the LiB for one night showed a fluoride concentration of 58 mg/l and a chloride concentration of 33 mg/l. An electrical conductivity value of 1.590μS/cm was measured.

The course of the test is shown in [Figure 18](#) in the Appendix.



Figure 8. Short circuit inside LiB 1 in minute 8 with the n-heptane still burning

TEST 2 - F-500

The burning behavior of the second LiB was very similar to that of test 1. Likewise, the temperature characteristic during the heating-up phase. A different picture was obtained for self-contained burning. From minute 9 to minute 10, several short circuits occurred and the pressure release devices were initiated several times, [Figure 10](#). The temperature registered by thermocouple 3 rose to about 1,300° C (2,372°F) for a few seconds. The channel 1 temperature was around the 400° C (750°F) line (100° C (212°F) above the test 1 values). At the same time, the channel 2 values dropped to about 150° C (300°F). The complete characteristics are shown in [Figure 16](#) in the Appendix. [Figure 9](#) shows the characteristics of channels 1 and 2.

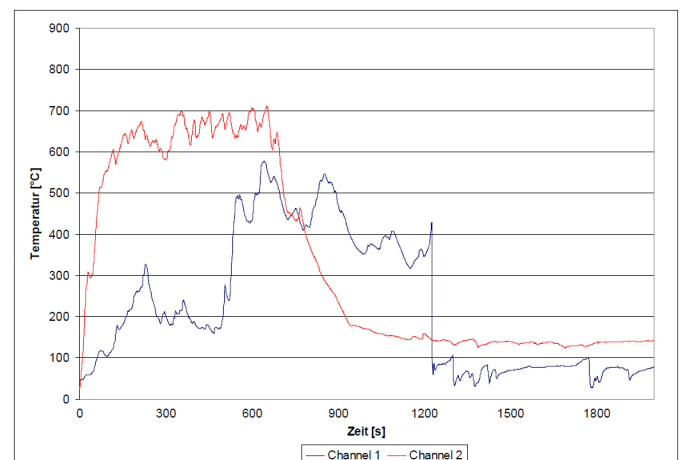


Figure 9. Test 2 temperature characteristics of channel 1 (blue) and channel 2 (red)