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Safety test methods for EV batteries

Karin Davidsson¹, Ingvar Karlsson¹, Peter Leisner¹, Magnus Bobert¹ and Per Blomqvist¹

¹SP Technical Research Institute of Sweden, Box 857, SE-501 15 Borås, Sweden
E-mail: first name.last name@sp.se

Abstract

The aim of the present paper is to share our experience in battery safety testing and risk analysis from a recent project called BLIXT, which had the objective to speed up the progress of the paradigmatic shift toward electric vehicles (EV). The batteries in question have been three different configurations of lithium-ion batteries (LiFePO₄). The tests have involved fire, crash tests and short circuit.

Keywords: Test methods, risk analysis, safety, lithium-ion, batteries.

1 Introduction

When introducing new technologies in vehicles, it is important to obtain at least the same degree of safety as for conventional vehicles, in order not to lose customers confidence. The safety risks of EVs differ considerable from conventional vehicles and an acceptable level of safety should be maintained during the whole life cycle of the vehicle (assembly, use, service, accident and recycling). This gives rise to a lot of questions concerning electric safety, fire safety, chemical risks and electromagnetic fields. Consequently, the main answer is that numerous new test methods are needed to secure right level of safety.

SP Technical Research Institute of Sweden (SP) was one of the partners in the BLIXT project. The project brought together parties from the Swedish automotive industry with the aims to accelerate and facilitate a Swedish production of EVs. Since the project aimed to speed up the process of a paradigm shift towards EVs, other design solutions were made compared to a project with longer time frames concerning design and development. One example was designing the

vehicle with the batteries in the crash zone. This was done to utilize available free space that arose when the ICE (internal combustion engine) and its peripheral equipment were removed. Even though accurate test procedures and standards are being developed [1, 2 and 3], the efforts within the present project have been performed regarding issues related to the unique placing of the battery.

In the SP laboratories the batteries have been fire- and crash tested, subjected to short circuit and compression tests. The tests have been performed to answer the questions what happens if there is a crash or a fire involving compressed batteries, short circuit or an explosion.

Figure 1 shows the most evident outcome of the project, a converted SAAB 9-3 cabriolet.



Figure 1. The most evident outcome of the BLIXT project: SAAB 9-3 cabriolet EV.

2 Management of chemical risks during safety tests of batteries

Batteries for EVs contain chemicals that are potential harmful to persons and/or the environment, or harmful chemicals could be formed by misuse, over-heating or fire. Therefore, already when carrying out electrical, mechanical and thermal testing of EV batteries, it is important to consider the risks from chemicals that might leak out. As an outcome of the project, guidelines were established for handling the chemical risks during testing. Such risk analysis will even be helpful input for risk assessment for batteries in EV.

In the present paper the chemical risks of Li-ion (lithium-ion) batteries with LiFePO₄ cathodes are evaluated in connection to destructive electrical and mechanical testing and during exposure to fire. Batteries made of Fe (iron) based cathode chemistry are more stable than Co (cobalt) based chemistry, which are responsible for some accidents in portable electronic devices that have received major media attention [4 and 5]. The improved stability by using Fe based cathode chemistry is obtained to the cost of reduced energy capacity. Furthermore, the solvent for the electrolyte consist of several flammable organic compounds that will ignite when exposed to external fire.

The chemical compound in the battery that causes most concern is the lithium hexafluorophosphate of the electrolyte. Hexafluorophosphates are toxic and corrosive, and forms hydrofluoric acid by hydrolysis in contact with water [6 and 7]. The rate of formation of hydrofluoric acid by hydrolysis of hexafluorophosphate increases with

temperature. Hydrofluoric acid is volatile and vapour is extremely dangerous to inhale and in contact with eyes. Likewise, skin contact should be avoided. Even in diluted solution hydrofluoric acid is harmful and has the ability to penetrate skin and cause injury deeper in the body.

Due to the chemical risks discussed above, both during and after abuse testing, batteries are considered as potential dangerous to humans. Therefore, all tests were carried out in either a fire testing laboratory or in a laboratory for testing explosion protection of products, both with proper ventilation. Furthermore, personal protection equipment was used to avoid any physical contact between the operator and any eventually leaking chemicals. After testing all batteries were treated as toxic waste.

3 Short circuit test

Safety issues concerning high voltage batteries in EVs have been in focus during this project. A traffic accident could expose both passengers and rescue party to new hazards. One example could be a short circuit in the battery pack caused by a deformation of the chassis. In the beginning of the project the knowledge about the consequences when performing the tests was limited. During the project experience proved that since the results are so unforeseeable it is utterly important to follow adequate safety precautions during the tests. Short circuit tests have been performed on three different configurations of batteries.

3.1 Test setup

All short circuit tests were performed outdoors. The test setup consisted the test object (one battery cell) placed inside a 180 liters sheet steel cabinet with a front made of transparent polycarbonate. The short circuit was achieved by a contactor with a current limit of 10 000 A. During the tests the current, voltage and temperature were registered. The test setup can be seen in Figure 2 and Figure 3.



Figure 2. The test setup for short circuit test.



Figure 3. Short circuit test during performance.

3.2 Test results

All three test objects behaved differently. One reason is the differences in the construction. One of the batteries had an enclosure made of hard plastic and this type built up a very high internal pressure and finally, after a few minutes, the whole battery bursted into pieces. Another type of battery had an enclosure made of metal foil and this battery expanded in a controlled way to three times its initial thickness and finally the enclosure got punctured. The third battery with metal casing did not seem to be affected at all.

The initial current from each battery were measured during the short circuit tests. High current were registered from two of the batteries (3200A and 1800A). The battery which did not seem to be affected at all had a current of 200A.

Figure 4,

Figure 5 and Figure 6 show the initial current for the three tested batteries at the first second after short circuit.

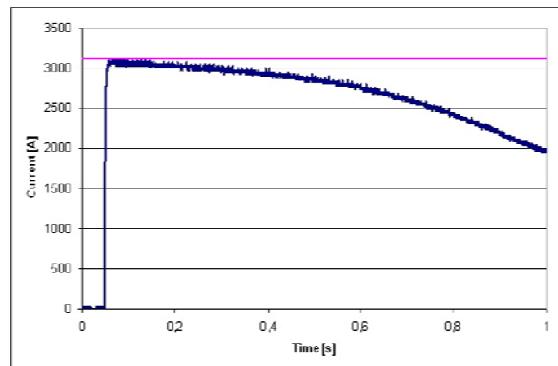


Figure 4. Battery type 1 (hard plastic): Initial current in Li-ion batteries during short circuit test.

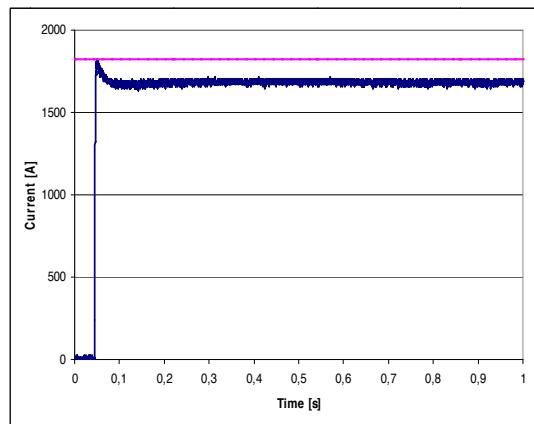


Figure 5. Battery type 2 (metal foil): Initial current in Li-ion batteries during short circuit test.

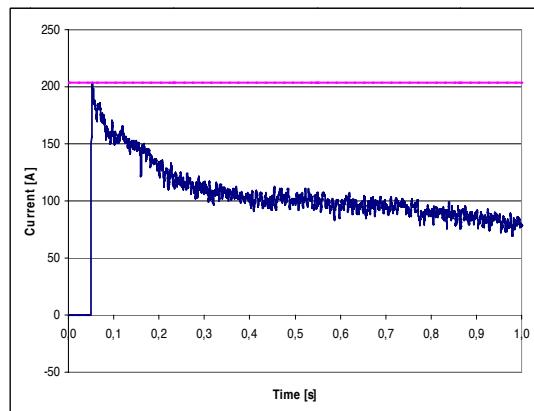


Figure 6. Battery type 3 (metal casing): Initial current in Li-ion batteries during short circuit test.

4 Fire test

A number of fire tests were performed, with different battery configurations. They varied from single battery cells directly exposed to flames to battery modules consisting of cells packed in casings of plastic or stainless steel. The aim of the fire tests was to investigate any possible explosion

risk, the emissions from a fire with a battery, and how fire is developed in different battery configurations when it is exposed to flames from an external fire. Further, the aim of the performed fire tests was to form a base for a suitable fire test method.

4.1 Test set-up

The fire tests were carried out inside SPs large fire tests hall. The test set-up consisted the test object (battery or battery module) placed on grating table with a 25 kW propane burner positioned 20 cm below the test object. During the test the test object was directly exposed to flames from the propane burner. For safety reasons the test set-up was enclosed by a safety net cage (without roof), see Figure 7.

The test set-up was placed under a 2 MW furniture calorimeter and the ventilation system was adjusted to provide a suitable flow rate in the hood, 6000 m³/h, making it possible to measuring the Heat Release Rate (HRR) continuously and to analyses the gases.



Figure 7. The test set-up during a fire test. The test set-up was enclosed with a safety net cage and the HRR, i.e. the power in kW from the fire, was measured using a 2 MW furniture calorimeter.

4.2 Test results

The fire tests showed that the battery configuration as well as the construction of each cell considerable affects the fire behavior of the battery. Depending on the cell construction as well as the casing, the cell was exploding or was limited to a rather short increase of the fire when each battery cell was contributing to the fire. The modules using casing of stainless steel showed that the time for the cells to be involved into the

fire was increased considerable. Figure 8 and Figure 9 shows a battery under fire and after the test.



Figure 8. Lithium battery on fire.



Figure 9. The same battery as in Figure 8, after performed fire test.

During most tests the heat release rate (HRR) was measured during the fire test. In one test gas analyses of the fire effluents was conducted using FTIR¹. The diluted fire effluents collected by the furniture calorimeter were continuously sampled to the FTIR. The sampling equipment and the FTIR measurement cell were all heated to avoid condensation of water and losses of gas species. The analysis showed that carbon dioxide (CO₂), carbon monoxide (CO) and hydrogen fluoride (HF) were the major fire gases produced. Of these gases CO and HF are most important from a toxicological point of view.

¹ FTIR = Fourier Transfer InfraRed spectroscopy

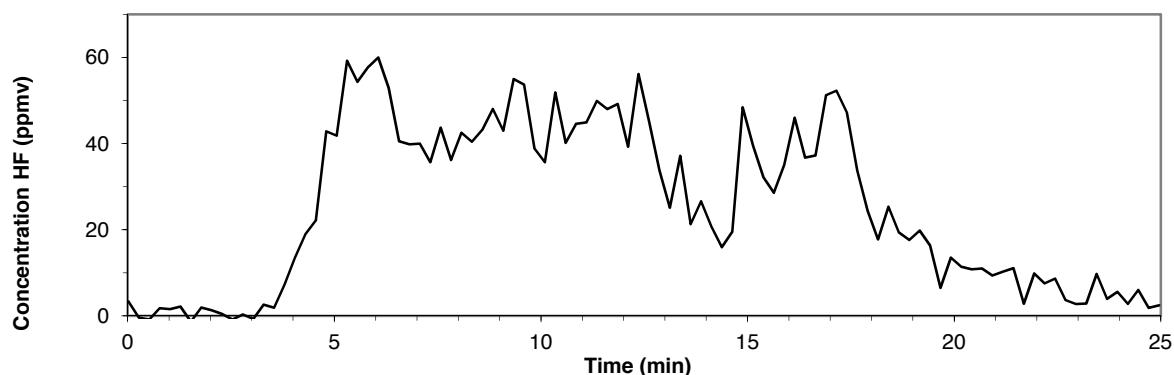


Figure 10. The figure shows the diluted HF (hydrogen fluoride) concentration as a function of time during a fire test with a battery module.

weight of the battery. This type of data could be used as input for a risk assessment of toxic emissions in a certain fire scenario.

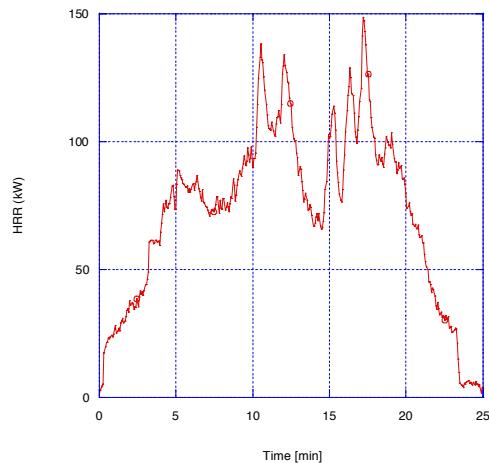


Figure 11. Heat release rate (HRR) as a function of time for battery modules. Six cells are packed together without casing. Note the different time scale in Figure 11 and Figure 12.

The gas analyzes showed high concentrations of HF in the combustion gases from the battery. See Figure 11 - Figure 12. Note that the concentration of HF shown in Figure 10 is in the diluted fire effluents collected by the furniture calorimeter in the test. The concentration in the undiluted smoke from the battery was thus considerably higher and the absolute concentration in a real accident scenario would be dependent on dilution volume and dispersion. Alternative methods to present the production of toxic species from a material in a fire are to use production rates or yields. Both production rates (mean and max) and yields of HF and CO from the battery test are presented in Table 1. Yields are here calculated as the quotient of the total amount of toxic specie produced and the initial

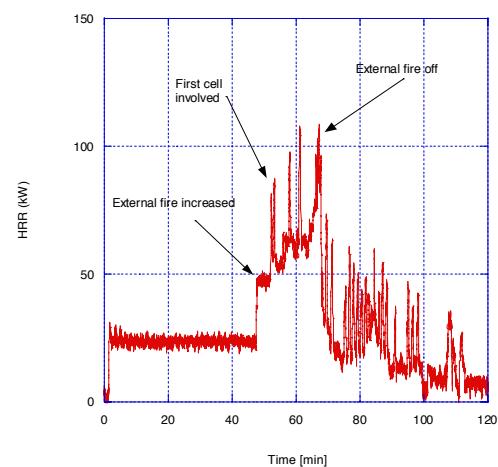


Figure 12. Heat release rate (HRR) as a function of time for battery modules. 31 cells packed into a casing of stainless steel. Note the different time scale in Figure 11 and Figure 12.

Table 1. Production data of major toxic gases measured in a battery test (6 battery cells).

Production data of major toxic gases	Gas	
	Carbon monoxide (CO)	Hydrogen fluoride (HF)
Production rate, mean (g/s)	0,030	0,035
Production rate, max (g/s)	0,17	0,072
Yield (g/g)	0,0038	0,0045

4.3 Future fire test method

The fire tests performed within the project have mainly been performed in order to increase the knowledge of the behavior of Li-ion batteries (LiFePO_4) during exposure to fire. However, the principles for the test procedure used within the project could be used as a base for future development of a standardized fire test method. The future work should be focused on defining the test-setup. It is also advisable to define the test object and to distinguish between a battery as a component and a battery as a part of the system, i.e. the vehicle. An external fire in a real situation will affect the battery depending on the installation in the vehicle.

5 Discussion

In the project, Li-ion batteries with LiFePO_4 cathodes, from three different suppliers, were tested. Even though, the chemistry of the three batteries in principle were the same, results in different tests differs a lot. The general observation is that the overall design of the battery is essential for its safety performance. The battery might have build-in fuse functions that switch off the battery by, e.g. external short-circuit and overheating or vents that relief pressure in a controlled way. In fire situations the casing of the battery cells in to modules could be very important in order to protect the battery cells from an external fire.

It is utterly important to identify the risks involved in testing high voltage batteries. This is a must for the operator who shall perform the tests in the future. In this project it was of great importance to handle the tests in a safe way and perhaps sometimes the safety concerns worked against a rational and effective working procedure.

In conclusion, one cannot rely on test results from other batteries than the actual battery in question, and it is relevant to test the battery on different levels of packaging (cell, module and battery pack).

Acknowledgment

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Authors

Dr. Karin Davidsson

SP Technical Research Institute of Sweden, Box 857, SE-501 15 Borås, Sweden
 Tel: +46105165184 Fax: +4633125038 Email: karin.davidsson@sp.se
 Karin Davidsson (Dr.), manager Battery and Hybrid Vehicle Systems at SP Technical Research Institute of Sweden. Ph.D. in industrial electrical engineering (2005), Lund University, Sweden.



B. Sc. Ingvar Karlson

SP Technical Research Institute of Sweden, Box 857, SE-501 15 Borås, Sweden
 Tel: +46105165190 Fax: +4633125038 Email: ingvar.karlson@sp.
 Ingvar Karlson is working at the Safety section at SP Technical Research Institute of Sweden. B. Sc. in Electrical Engineering (2000), University of Borås, Sweden.



Professor Peter Leisner

SP Technical Research Institute of Sweden, Box 857, SE-501 15 Borås, Sweden
 Tel: +46105165000 Fax: +4633125038 Email: peter.leisner@sp.se
 Peter Leisner (Prof. Dr.), head of the electronics department at SP Technical Research Institute of Sweden and Professor in Embedded systems at Jönköping University, Sweden. M.Sc. in electrochemistry (1989) and Ph.D.in process technology (1992), Technical University of Denmark. Received the Swedish degree of Docent in Electronic Production (2001), Linköping University, Sweden.



M. Sc. Magnus Bobert

SP Technical Research Institute of Sweden, Box 857, SE-501 15 Borås, Sweden
 Tel: +46105165190
 Email: magnus.bobert@sp.
 Magnus Bobert is working at the Fire Dynamics section at SP Technical Research Institute of Sweden. M. Sc. in Engineering Mechanics (1995), The Royal Institute of Technology (KTH), Sweden.



Dr. Per Blomqvist

SP Technical research Institute of Sweden, Box 857, SE-501 15, Borås, Sweden
 Tel: +46 10 516 56 70 Fax: +46 33 41 77 59
 Email: per.blomqvist@sp.se
 Per Blomqvist (Dr.), senior research scientist at the department of fire technology, SP Technical Research Institute of Sweden. M.Sc. in analytical chemistry (1990), Göteborg University, Sweden. Ph.D. in fire technology (2005), Lund University, Sweden.

