

Research on the behaviour of a LiFePo₄ prismatic cell subjected to mechanical stress

Szabo I, Kocsis L *, Mariasiu F,

Technical University of Cluj-Napoca, Automotive Engineering and Transports
Department, Bd. Muncii 103-105, Cluj Napoca, Romania

levente.kocsis@auto.utcluj.ro

Abstract. Numerous models of electric vehicles in the automotive market are clear proof of being a solution for the massive reduction of greenhouse gases, caused by the high number of the internal combustion engines in the transport sector. It was observed that by developing and using electric vehicles, the quantities of harmful emissions in large cities can be significantly reduced. The convenience of users of electric vehicles have pushed the researchers to study in more detail and attention the storage of energy in the energy sources used in the construction of electric vehicles. Several researchers have used the resulted data to develop finite element models, therefore it is necessary to study their behaviour. The article presents an experimental research, regarding the analysis of the behaviour and prismatic cell of type LiFePo₄ at different mechanical stresses, including three-point bending, lateral bending, indentation with hemispherical punch and pinch indentation. The cell was tested at ambient temperature at 90% SOC.

1. Introduction

Researches regarding the behaviour and stability of electric cells under different and various mechanical stresses is an important issue, given the increase in the number of electric vehicles on the roads. The general aims of researches are to improve energy sources in electric vehicles from the design stage, which correspond to the requirements related to their use and operation in maximum safety and reliability. There are several standard requirements that vehicle manufacturers must take into account regarding the use of energy sources on electric vehicles [1], [2].

The probability that the vehicle's energy source will cause fire risks is high in the event of an accident or damage to the module as a result of improper operation. This phenomenon is directly proportional to the number of electric vehicles in traffic. Therefore, manufacturers can prevent or at least significantly reduce the possibility of damage from the design stage, using CAD design.

Therefore, the article studied the behaviour of a prismatic cell subjected to various mechanical demands. Multiple researches have been conducted by researchers, respectively on different models of lithium-ion cells to study their response to external mechanical abuses [3]. Generally, the results and conclusions shown that always is a correlation between mechanical deformation on cells and short circuit.

In present article, experimental alleged methods included three-point bending on cells, penetration with a hemispherical head, respectively axial and lateral plane compression to determine the moment short circuit starts. Cell voltage and temperature were monitored throughout the experiment.

2. Methods and results

In order to determine the effects of mechanical stresses on the battery cells that equip the electric vehicles, it is necessary to build an experimental stand. The measurements performed also imply the need for measurement and monitoring equipment to immortalize and measure the processes and results of the experimental test. After a detailed analysis of the results obtained, they were passed in a structured form in the paper, respectively in the last part the interpretation of the results. The stand was configured

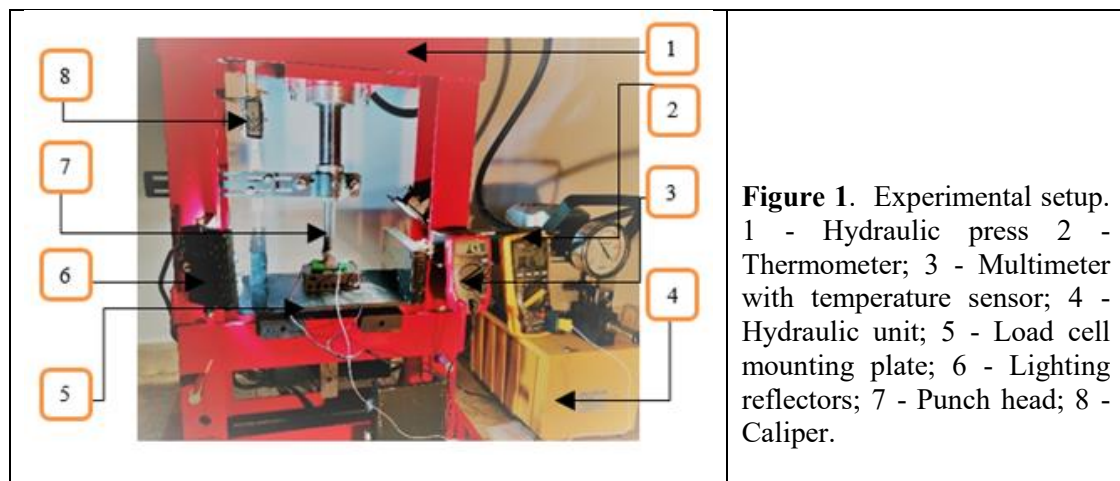
from a 10-tons commercial hydraulic press and a hydraulic unit equipped with an electric motor and the related hydraulic installation. The hydraulic unit is equipped with a simple manual oil flow control valve, to adjust the oil flow to 0.52 - 2.5 L / min. The working pressure of the hydraulic unit varies between 50-600 bar. The entire auxiliary equipment for the test was designed using a CAD software and was welded mechanically. At the same time, this was made according to the execution drawings elaborated according to the necessity and utility within the project.

All the indentation heads were made of steel, where for the bending head was used a $\phi 25.10$ mm rod and a $\phi 12.5$ mm for hemispherical head. Also, the pinch head indentation tip has a length of 30 mm. Every loading case was performed with a cylinder speed of 3mm/min.

Table 1. Apparatus and devices used to perform experiments

Experimental stand	Hydraulic press	10 T
	Hydraulic unit	50-600 bar
	Ball valve, hydraulic connections	
	Load cell mounting plate	1 x
	Lighting reflectors	3 x
Measuring instruments	Load cell	0-20 kN
	Multimeter with temperature sensor	0-1300 °C
	AXIOMET Multimeter	0-600 V
	Caliper	0.01 mm
Cell type	4 X Prismatic Battery Cell	3.2 V
Used punches	T punch head	25 mm
	Hemispherical head	12.5 mm
	Pinch indentation	

To reach consistent and relevant conclusion, test parameters and special demands had to be established. The main test parameters are displacement, voltage, temperature and pressing force. The simulated demands are three-point bending, lateral bending, hemispherical sharp pinch head indentation. All the tests were performed on 11 Ah LiFePo₄ cathode material pouch cells, with a SOC= 90%.



Experimental setup for the three-point bending test of the prismatic cell is shown in figure 2. Two support rollers were placed on the stand, over which the cell was placed, and with the bending head attached to the head holder, and the load was applied using this configuration. The cells were larger and relatively more robust compared to cylindrical cells, and the experiment lasted for 200 seconds.

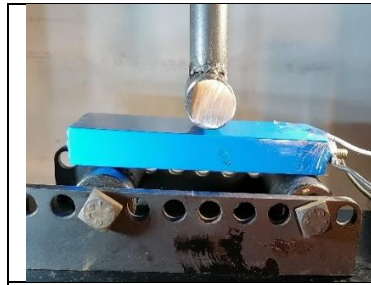


Figure 2. Three point bending experimental setup.

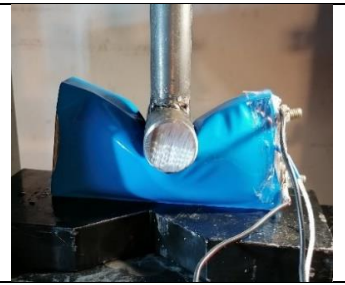


Figure 3. Lateral bending experimental setup.

On the cell terminals, electric wires from the multimeter were attached, to monitor the cell temperature and voltage at a load force of about 15 kN, the cell having a nominal voltage of 3.2 V was short circuited and the voltage dropped to 0 V.

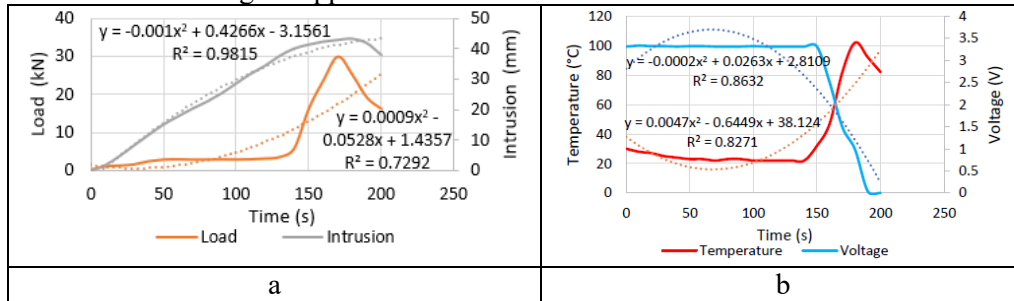


Figure 4. Three-point bending results: a- variation of force and displacement. b- temperature and voltage variation.

In order to perform the lateral bending experiment on the prismatic cell, it was necessary to mount the bending head in the support, also the prismatic cell was placed on the stand table to perform the experimental test. The connection, to monitor the cell voltage was made using the terminals provided on the cell, and the thermometer sensor was attached to the aluminium casing of the cell. Experimental setup can be seen in figure 3.

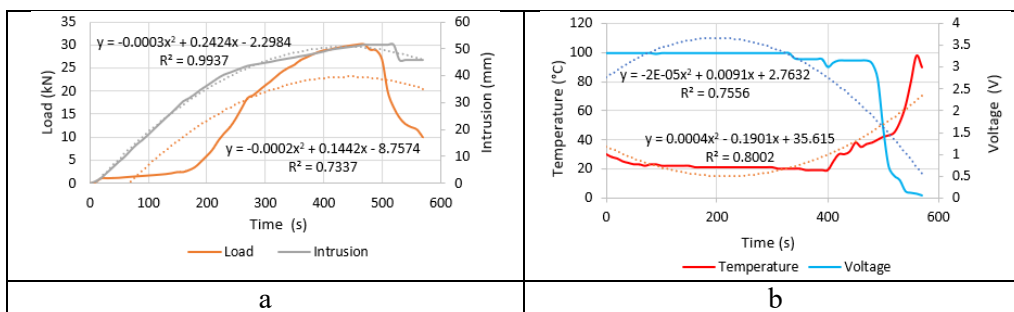
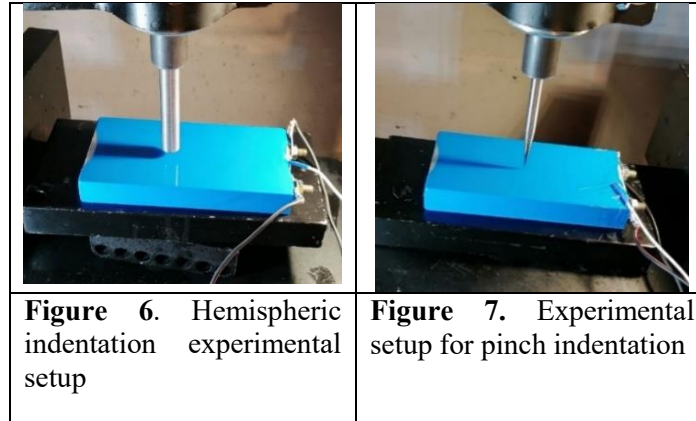


Figure 5. Lateral bending results: a - variation of force and displacement; b- temperature and voltage variation.

Due to the strength of the cell structure the force exerted by the press was greater, compared to the other cells, according to Figure 5, it reached a maximum of 30 kN. Since this experiment was performed on the side of prismatic cell, given the geometrical width of the cell of 75 mm, the intrusion is more than 66% of the cell (50 mm), as seen in figure 3.

At the same time, the width of the cell also influenced the duration of the experiment, which lasted almost 600 seconds.

The next experiment on the prismatic cell was performed with the hemispherical head with a radius of 6 mm. On the existing terminals the conductors of the multimeter were attached to measure cell voltage and the heat sensor was placed on aluminium casing to monitor the cell temperature as figure 6 shows.



As shown in figure 7, by actuating the piston, the pinch head deforms the cell, short circuit being induced. To monitor the voltage, the electric conductors from the multitester were attached to the cell terminals. The results for the hemispherical head indentation experiment can be found in figure 8. The short circuit occurred at a deformation of 6 mm, from which the temperature began to rise as a result of the applied load deformation. In the last experiment on the prismatic cell, we have the same configuration with the flat plate on the frame, respectively the pinch head was mounted in holder. The voltage variation is represented in figure 9. After the cell case protrusion, a short circuit occurred. The voltage variation in figure 9 b shows that from second 40 the voltage drops to close to 0 V and the temperature rises to 120 °C. The variation of force and deformation can be found in figure 9 a.

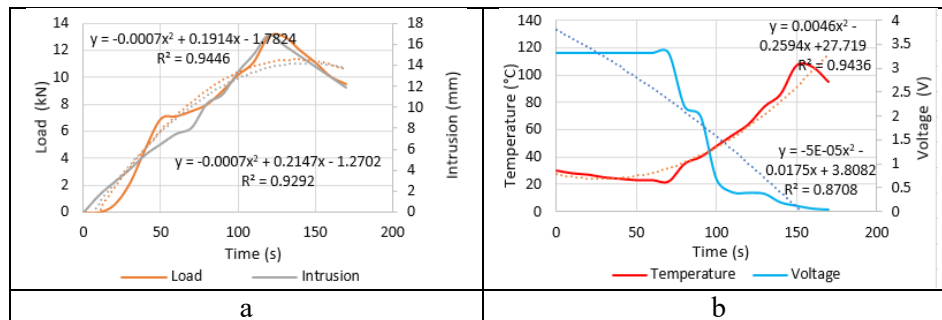


Figure 8. Hemispherical test results: a - variation of force and displacement; b- temperature and voltage variation.

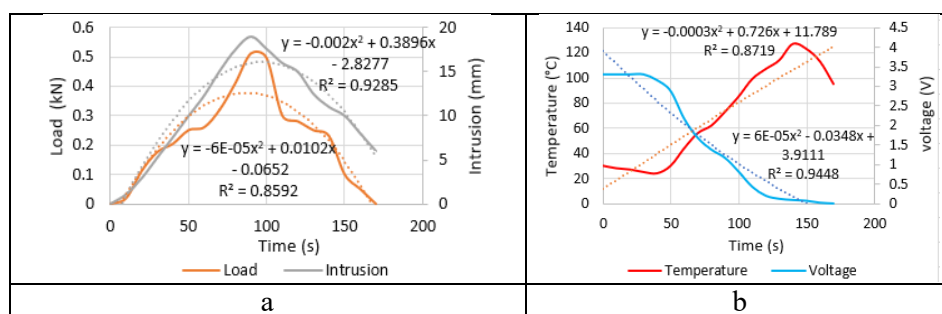


Figure 9. Results of pinch indentation test: a - variation of force and displacement; b- temperature and voltage variation.

3. Discussions

Prismatic cells are widely available in electrical constructions for vehicles and even for testing the effects of different mechanical stresses experimental tests have been performed with different forms of stressing equipment.

From the point of view of the negative effects, it is understood that the most negative effects are obtained for the use of the carcass tightening equipment, for all the mechanical force it is concentrated in a single point and a relatively easy penetration of the carcass is achieved after 38 seconds). However, this test was necessary because there is a high probability that the battery of an electric vehicle will be penetrated by a screw or a thin round profile (as well as debris from the road) during driving / operation.

The other experimental tests performed show the behaviour of prismatic cells in the simulation conditions of a frontal impact accident. By considering the time of the short circuit production as main criteria, it is observed that the best positioning of the prismatic cells inside a battery would be with the smallest side oriented towards the front of the vehicle.

4. Conclusions

Through this configuration of the stand and with the help of testing devices, the test parameters were analysed in terms of the influence of mechanical stresses on the prismatic cell to understand the mechanical behaviour under mechanical loads applied to the cell.

At all four experimental tests at the beginning of the short circuit the voltage decreases, and the temperature increases to values of over 100 ° C.

The results also shows that if the diameter of the indentation head is larger the short circuit it is triggered later, compared with the smaller diameter indentation head tests.

It is recommended that the data obtained in the paper be compared and validated by the finite element method. However, the results can be used as input information for modelling new energy cells used in the construction of electric vehicles.

References

- [1] Miller P, Dobedoe T, Duncan G, Pike T, Sharred D and Smout P, Surge Transport and its Role in Technology Transfer of Environmental Awareness in the Transport Sector, IEE Seminar on Automotive Electronic Standards, IET London, Savoy Place, UK, 1999, Ref. No. 1999/206, pp. 4/1–4/8
- [2] Miller P, IEEJ Transactions on Industry Applications, 2008, **128**, (7), 880
- [3] J. Zhu, T. Wierzbicki, W. Li, A review of safety-focused mechanical modeling of commercial lithium-ion batteries, *Journal of Power Sources* 378 (2018) 153–168
- [4] Sahraei, E.; Campbell, J.; T., Wierzbicki, Deformation and failure mechanisms of 18650 battery cells under axial compression. *Journal of Power Sources* 336 (2016) 332–340.
- [5] Golriz K., E. Sahraei; 2017 Review: Characterization and Modeling of the Mechanical Properties of Lithium-Ion Batteries, *Energies* 10 (11), 1730
- [6] Li, W., Xia Y., Chen, G. et al. 2018 Comparative study of mechanical-electrical-thermal responses of pouch, cylindrical, and prismatic lithium-ion cells under mechanical abuse. *Sci. China Technol. Sci.* 61, 1472–1482.
- [7] Xia Y, Chen G, Zhou Q, et al. 2017 Failure behaviours of 100% SOC lithium-ion battery modules under different impact loading conditions, *Engineering Failure Analysis* 82: 149–160

Acknowledgments

This research was funded by the Program “POCA1-A1.2.3-G-2-15 Partnerships for Knowledge Transfer, no. financing contract: 6/16.01.2018, project title: Intelligent Urban Intelligent Vehicle Technologies URBIVEL, ID: P_40_333, MySMIS: 105565”.