Research on the behaviour of a $LiFePo_4$ pouch cell under mechanical stress

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Abstract. In this article, research has been done regarding the behaviour of the pouch cell under the action of mechanical abuse, in order to improve pouch battery cells design. Four types of indentations were performed on pouch cell respectively, three-point bending, lateral bending, indentation with hemispherical head and pinch indentation. Contemporary electric vehicles are a solution in terms of environmental pollution, that is why the large vehicle manufacturers also have different models of electric vehicles. Also, a major problem for electric vehicles customers is the autonomy of a vehicle. That forces major electric vehicle manufacturers to invest in in-depth research into storing electricity in energy cells. Li-ion cells seem to be a viable solution at present, and that is why the paper presented a pouch-type cell subjected to specific mechanical stresses. Also, the internal short circuit can be observed in all four tests performed, and its effects are destructive in the case of lithium-ion pouch cells.

1. Introduction

Pouch cells as an energy source are used in the electric vehicle industry, also in various applications that require portable energy sources. Obviously, there is a global spread of the trend of owning an electric vehicle, being subject to many mechanical stresses that occur during their operation. At the same time, numerous researches perform connection with this important aspect, and some researches will be presented in a brief form in the following chapters.

Extensive research on $LiFePo_4$ pouch type cells were conducted by Wei L. research group and collaborators, in order to establish the behaviour at different loads and mechanical stresses [1]. Experiments were done what included mechanical stresses on the cell with the bending head, the punch was performed with a sharp steel rod head, to determine the short circuit start moment. In parallel, the voltage was monitored with a voltmeter and the cell temperature with a temperature sensor was measures. Also, other researches have also been conducted by Sahraei and collaborators regarding the behaviour of the pouch cell under a certain mechanical stress, among others showing that in some conditions it is enough 1 mm intrusion in the cell and that may introduce soft short circuit, what can lead to serious consequences [4], [5].

In this article, 4 tests were performed with different mechanical stresses on the pouch cell, respectively with the 10 Ah $LiFePo_4$ cathode material, with SOC = 80% (similar cells were used in the manufacture of the Nissan Leaf and Chevrolet Volt [6]).

2. Methods and results

In the realisation of experimental study regarding the structural stresses on the cells that equip the electric vehicles, it was necessary to develop a test stand whose components and devices used were listed in table 1.

The tests were performed with the help of three test heads made especially of steel with S355JR quality. In the figures 2, 3 and 6, 7 the indentation heads are shown. The T bending head has dimension of ϕ 25.10 mm, ϕ 12.5 mm hemispherical head. The pinch head with length of 30 mm of sharp tip. The cylinder speed was set to 4 mm • min^{-1}, and all four experiments were performed under this condition.

Table 1. Devices used in tests.

Experimental stand	Hydraulic press	10 T
	Hydraulic unit	50-600 bar
	Ball valve, hydraulic connections	
	Load cell mounting plate	
	Lighting reflectors	
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 Pouch Cell LiFePo4 H - 3210	3.2 V
Used punches	T punch head	25 mm
	Hemispherical head	12 mm
	Pinch indentation	

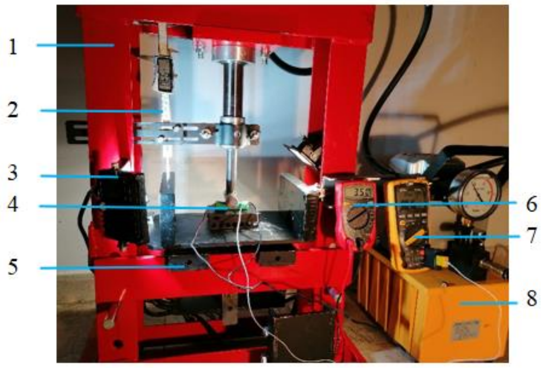


Figure 1. Experimental stand setup. 1 - Hydraulic press; 2 - Calliper; 3- Lighting reflectors; 4 – Punch head; 5 - Load cell mounting plate; 6 - Multitester; 7- Multitester with temperature sensor; 8 – Hydraulic unit.

The auxiliary mechano-welded parts used in the construction of the stand were designed in a CAD design program. Figure 1 includes the configuration of the stand where a 20 kN force load cell was also included, with the help of which the applied force on the cell was monitored. The force was measured and graphically displayed using a dedicated software installed on laptop. The experiments were also filmed using video camera to help in further analyses of obtained results.

Table 2. Summary of the testing parameters and indentation tests

Testing parameters	Intrusion	mm
	Voltage	V
	Temperature	° C
	Load	kN
Indentation tests	Three-point bending	25.1 mm
	Lateral bending	25.1mm
	Hemispherical head indentation	12.5 mm
	Pinch indentation	

Figure 2 shows the configuration of the stand for the three-point bending experiment. On the support with two rollers the pouch cell was placed, with an attached temperature sensor. The three-point bending head with the diameter of Ø 25.10 mm was used as the deformation device. The voltage measurement was performed using multimeter with the terminals attached to the cell terminals.

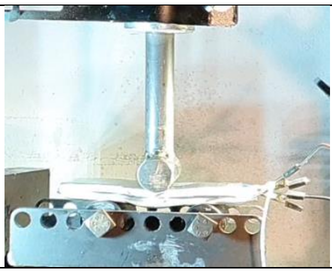


Figure 2. Experimental stand setup for pouch cell three-point bending.

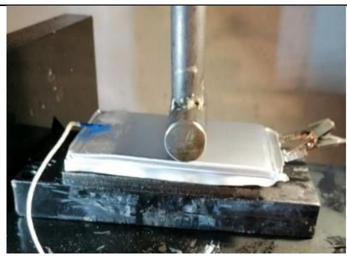
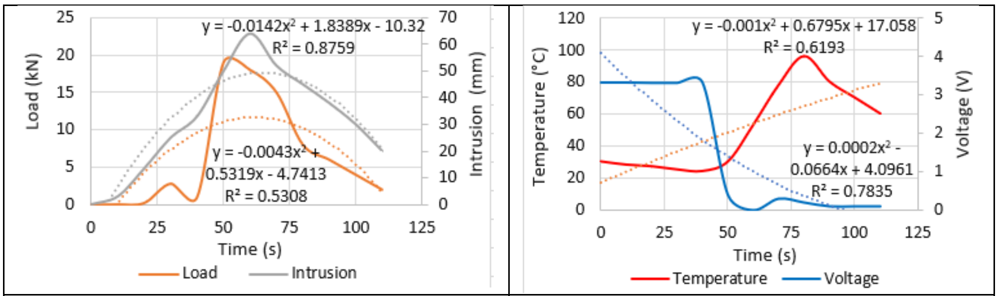


Figure 3. Experimental stand setup for pouch cell lateral bending.

The obtained results were centralized, where the variation of force and deformation appear in figure 4 and the variation of temperature and voltage in figure 4 b.



a | b

Figure 4. Pouch cell three-point bending test results: a- variation of force and displacement; b- temperature and voltage variation.

In the case of simple bending, the pouch cell was placed on a flat steel on the stand frame, figure 3 includes the respective configuration. As in the previous experiment, the T head was used in the test. A multimeter was also used to monitor the voltage and a thermometer with a sensor was used to monitor the cell temperature. The obtained results are centralized in figure 5.

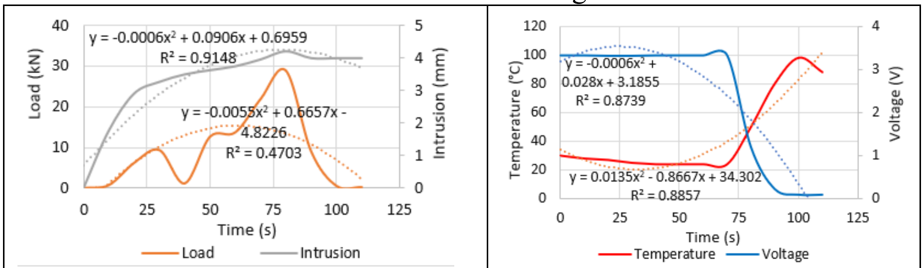


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Figura 5. Pouch cell lateral bending test results: a- variation of force and displacement; b- temperature and voltage variation.

In the tests performed with the hemispherical head, the configuration is found in figure 6, where the cell was placed on the flat surface on the press frame. To measure the voltage variation in Figure 8 b, the terminals on the multimeter were attached to the terminals of the energy cell. The variation of the temperature measured on the cell surface during the experiment is also found in the graph in figure 8 b. The maximum temperature that was measured is approximately 105 ° C.

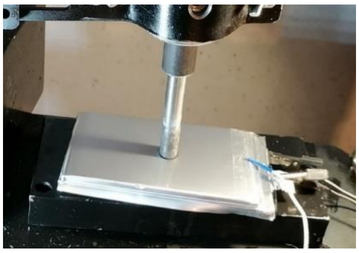


Figura 6. Experimental stand setup for pouch cell hemispherical head indentation.

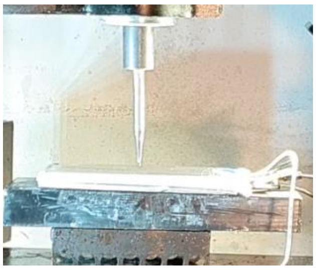
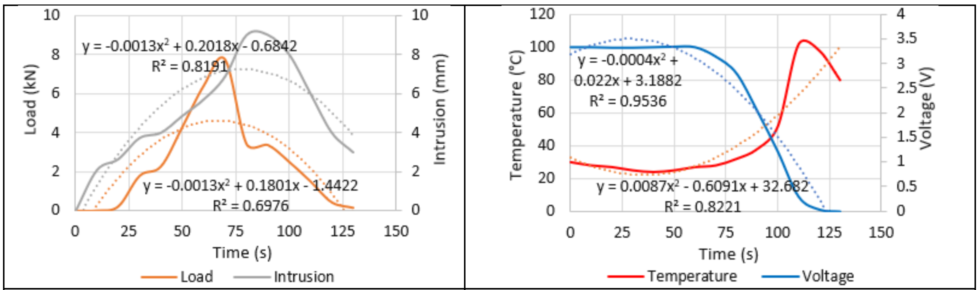


Figura 7. Experimental stand setup for pouch cell pinch head indentation.

The positioning of the pouch cell in the case of the pinch test was done on a flat surface according to figure 7. The penetrating pinch head is mounted on the device support, and the multimeter was connected with electric wires to the pouch cell terminals.

The applied force on the cell when the short circuit is induced by the applied load is 6 kN. The variation of the force appears in the curve represented in figure 8, where the maximum force exerted on the cell was 7 kN.



a b

Figura 8. Pouch cell hemispherical indentation test results: a- variation of force and displacement; b- temperature and voltage variation.

The force variation is represented in figure 9, where in the second 20 is the value of the penetration force of 0.2 kN when the short circuit was induced. The variation of voltage is shown in figure 9 a where it is observed that in the second 20 the voltage starts to decrease due to the tripping of the short circuit. After penetration, the temperature rises to 100 ° C in 100 seconds, as shown in Figure 9.

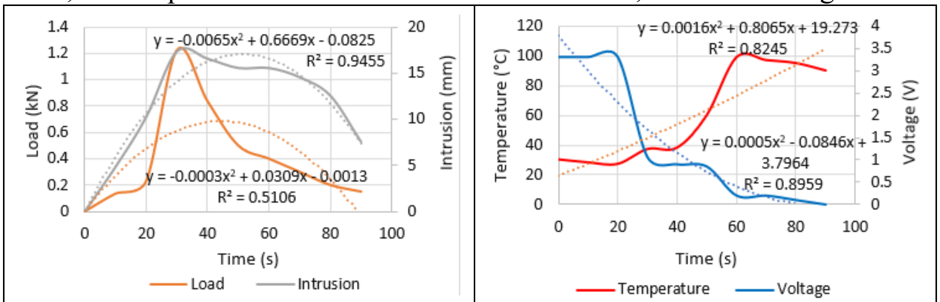


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Figura 9. Pouch cell pinch indentation test results: a- variation of force and displacement; b- temperature and voltage variation.

In the case of the three-point bending experiment, the pouch cell case being malleable, the pressing force increases exponentially. The start of the short circuit was at 30 seconds after the start of experiment where the displacement was over 30 mm and the voltage decreases.

The simple bending experiment was also performed for 125 seconds, and the graphs in Figure 5 show that starting with 65 seconds, the short circuit was triggered.

The onset of the short circuit in the case of the hemispherical indentation it was induced from the second 60, and the applied force with 6 kN and with a displacement of 6 mm. From second 75 the temperature rises exponentially according to the graph in figure 8.

3. Discussions

Pouch-type electric cells are by their construction the most fragile type of cells used in batteries (energy storage sources) and therefore special attention must be paid to the possible effects of mechanical tests and stresses that may occur in their operation. Through the tests performed, the primary results obtained are necessary to be applied further in the possible development and construction of a battery housing (consisting of this type of cell and with specificities for this type of cell). Because the determination of the puncture effect of the pouch-type cells is made only on one dimension, it cannot be stated with certainty what is the optimal position of their placement within the construction of a battery. Also, an important role in their positioning has the uniform distribution of the electrolyte in the composition of the bag type cells, which requires additional researches on this issue.

4. Conclusions

The tests performed on the pouch type cell show that the onset of the short circuit does not appear even from the first moments of the application of the global force. By the action of force, the displacement occurs where the deformation is directly proportional to the displacement.

This technical approach can be applied to any battery cell type to study the short circuit starts moment under the action of mechanical stress.

The internal short circuit in the cell is the result of several abuses of a mechanical nature, it is also a topic that must be studied further.

It is also recommended to validate the experiments by the finite element method, and with the help of the results it is possible to obtain and bring cellulite and modules that correspond to the clients' requirements.

References

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Acknowledgments

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