RESEARCH RROJECT

Stack Compression in Li-ion Battery Cells

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ABSTRACT

As the demand for electrical vehicles rises along with their positive impact on climate change, many studies are conducted on fuel cells and Li-ion battery cells to improve their performance and life cycle. This research project investigates current studies about stack compression in Li-ion battery cells as it significantly impacts the degradation and capacity fading of the cells. Since stack compression is relatively a new topic for Li-ion battery cells compared to for fuel cells, solutions or strategies to balance between its benefits and drawbacks on overall cell performance have not been proposed largely. This project also discusses the available approaches in utilizing stack compression in Li-ion battery cells, especially in the cylindrical format.

INTRODUCTION

The transportation industry has always been one of the major fields in causing global carbon dioxide (CO_2) emissions, as shown in Figure 1. Switching to electrical vehicles using Li-ion batteries and Hydrogen fuel cells is a promising solution to reduce CO_2 emissions, at least within the transportation sector. According to the Energy Technology Perspectives 2020, with the current development of electrical vehicle market, by 2070, passenger cars and buses will be consuming zero fossil fuel, meaning zero CO_2 emission (Fig. 2).

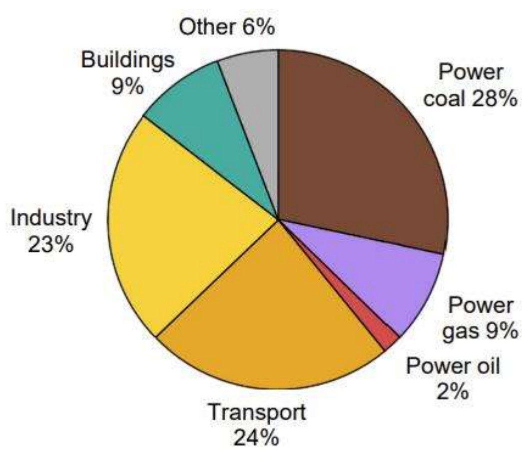

Figure 1 – Global energy-related CO2 emissions by sector in 2019[1]. *Note: Transportation is the second biggest sector.*

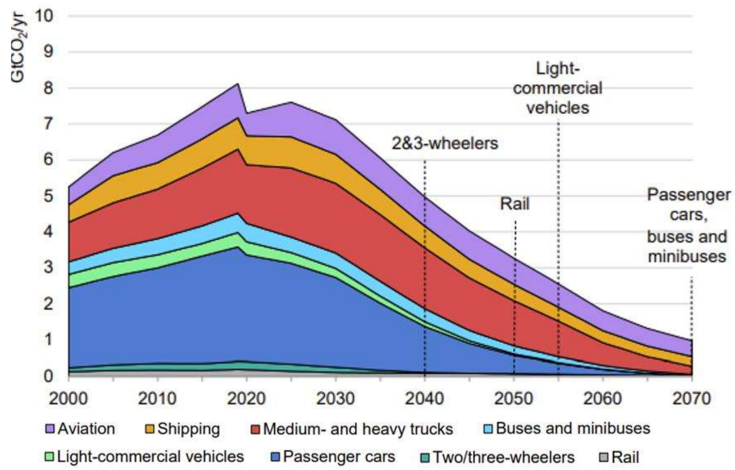

Figure 2 – Global CO_2 emissions in transport by mode following the Sustainable Development Scenario in 2000-2070[1]. *Note: The dotted lines indicate at the corresponding years, the corresponding transport modes have mostly stopped using fossil fuels and emitting CO_2.*

Having discussed the positive impact of electrical vehicles on reducing CO_2 emission, improving the performance and life cycle of Li-ion batteries and Hydrogen fuel cells is of great interest. One of the major concerns is the dimensional changes of the cell components during usage which leads to significant degradation and fading in capacity. This issue can be addressed with the introduction of stack compression pressure.

Stack compression pressure has been proved to improve proton exchange membrane (PEM) fuel cell's performance and durability if applied properly[2]. The dimension changes, membrane swelling, and thermal expansion are the factors causing the stack compression pressure. Since a non-uniform pressure profile can damage the membrane electrodes assembly (MEA) or gas diffusion layers (GDL), maintaining a constant and uniform compressive stack pressure has been demanding, but challenging. A possible solution is to increase the shear modulus of the GDL. Similarly, a stack compression pressure also exists in Li-ion battery cells, especially in pouch ones, and is debated to be useful in controlling the degradation and capacity fading[3]. However, compressive stack pressure in Li-ion battery cells has not been studied as well as in fuel cells. It is currently successfully applied only under testing circumstances using external compression systems. Therefore, questions regarding how stack compressive pressure can be applied internally in Li-ion battery cylindrical or pouch cells are concerned and will be studied in this project.

ANALYSIS

Stack compression in fuel cells

Investigation into how stack compressive pressure exists in fuel cells would further support the understanding of how it should be applied in Li-ion cells.

A PEM fuel cell consists of a membrane electrode assembly (MEA), a gas diffusion layer (GDL), and a bipolar plate. When the cells are stacked together, a compressive contact pressure is applied to maintain adequate gas sealing and reduce contact resistance[4]. Overly applied compression can lead to MEA's puncture, GDL pore structures' crushing, and bipolar plate's crack. Therefore, a constant and uniform compressive stack pressure is desired between the MEA and GDL. Besides the initially applied external compressive pressure, the membrane's swelling and thermal expansion in all components are studied to responsible for the internal stack compressive stress profile[2]. The significant dimensional changes caused by these two factors can lead to a 30% over compression and 23% loss in a single operating cycle. Figure 3 demonstrates how these factors impact the compression load between MEA and GDL.

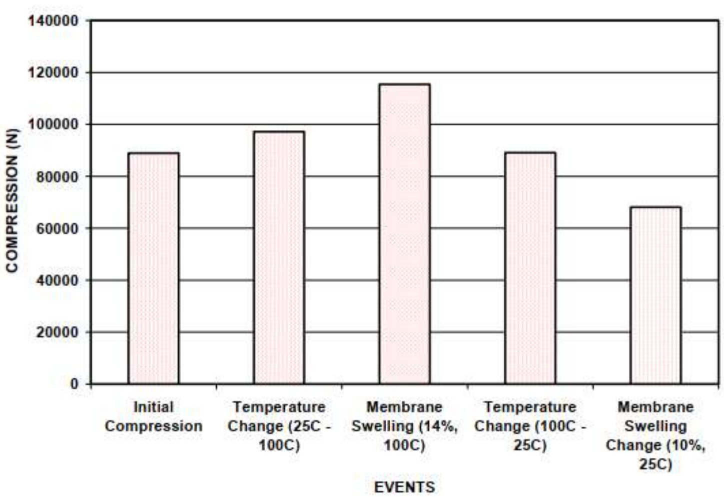

Figure 3 – Compression profile of a PEM fuel cell stack[2].

The thermal expansion factor can be addressed by alternating materials of each cell component. However, the membrane swelling issue does not have a straightforward solution. The membrane is designed to have an incredible water intake capability, and hence its swelling ratio is significant. To study the effect of the swelling onto stack compression changes, Lai & Trabold built a spring model and a finite element (FE) model. Both models output similar results where the swelling ratio of the membrane in the thickness direction is most significant, such that a compressive force is generated by the swelling and buckle the membrane. Refer to Figure 4 for the illustration.

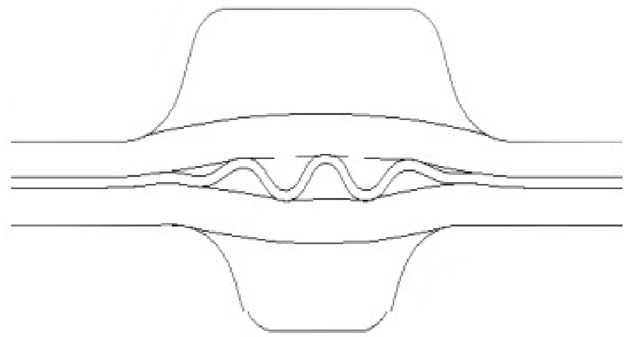

Figure 4 – Buckling of membrane between two GDLs[2].

This buckling behavior directly leads to the loss of thermal conductivity throughout the channel due to the loss of contact area. In the observation of this buckling behavior, it is argued that not only the swelling of membrane is responsible but also the insufficient compressive pressure between the MEA and GDLs. While the swelling can hardly be interfered with due to the desired water intake capability of the membrane, increasing the compressive pressure between the layers without additional external pressure is necessary. The first approach is to decrease the distance between 2 GDLs which would limit the gas flow. The second approach is more achievable, which is to increase the shear modulus of the GDLs (Fig. 5).

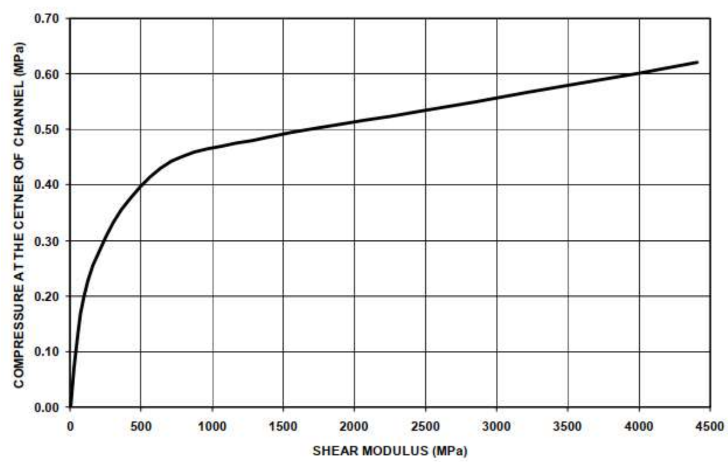

Figure 5 – Impact of GDL's Shear Modulus on stack compression pressure[2].

To conclude, an internal stack compressive pressure exists within a fuel cell stack besides an initial external one. Increasing the Shear Modulus in the GDLs would be the efficient solution to the non-uniform stack compression issue. This finding helps improve one of the most significant concerns in fuel cells' lifetime and performance.

Stack compression in Li-ion battery cells

The structure of fuel cells and Li-ion battery cells differ significantly. For example, if Li cells have different materials for the anode and cathode, fuel cells have symmetrical structure. This means stack compression applied externally and generated internally in fuel cells and in Li-ion cells is completely different. However, one common fact is that stack compression is also proved to improve the performance and cyclable lifetime of Li cells[3]. Otherwise, current studies on stack compression in Li-ion cells only investigate externally applied mechanical pressure[5]. There has been little to no evidence on how compressive pressure can be generated internally in Li-ion battery cells like in fuel cells. The complete dependence on external pressure limits the approaches to apply stack compression on Li cells. How stack compression effectively improves Li cells' performance and how it can be applied, both internally and externally, will be discussed under this section.

Pouch cells

In experimenting with Li-ion Si/C pouch cells, a flexible compressed configuration, a fixed one, and an uncompressed/free of compression one are used. Overall, Muller et al found that compression enhances the electrical contact in anode during delithiation and improves the reproducibility in aging tests[3]. However, under the most compressed configuration, the fixed compression, Li pouch cells experience the most significant inhomogeneity in stress distribution. This occurs due to the difference in thermal characterizations of Li cells, where higher current density associated with higher local temperature happens near the current collector. These localized hotspots can have a pressure of up to 6 times larger than the initially applied one by the test module. Moreover, the inhomogeneous stress profile can lead to localized pore closure – a main factor causing capacity fading. This study provides more insight into the design of Li-ion pouch cells, and the remaining questions are how to apply a homogenous compressive pressure such that the benefits gain exceed the drawbacks, and how can this study apply to the Li cylindrical models. As the cylindrical model is more consumed than the pouch one within the transportation industry, it is crucial to study how stack compression is applied and affects the performance in cylindrical models.

Cylindrical cells (1865)

Interestingly, the study of external stack compression in pouch cells is fundamental to understanding the internal compressive pressure in the jelly roll structure of cylindrical cells.

During the experiment, three locations were investigated: the outside, center, and inside of the jelly roll (Fig. 6). The current collector tabs and the distance between the jelly roll and the housing are reasons why a nonhomogeneous current distribution is observed. This leads to a non-uniform pressure distribution, where the pressure increases towards the inside of the jelly roll. The outside part of the roll is considered as a pouch cell being in an uncompressed or weakly compressed configuration due to the space of free expansion. The center of the jelly roll, constrained by the expansion of both the inside and outside parts, is like be under a fixed compression model. Therefore, this is how pouch cell study is related to cylindrical one. Hence, based on the study on pouch cells, different aging mechanisms or different capacity fading mechanisms throughout the jelly roll in cylindrical cells are expected.

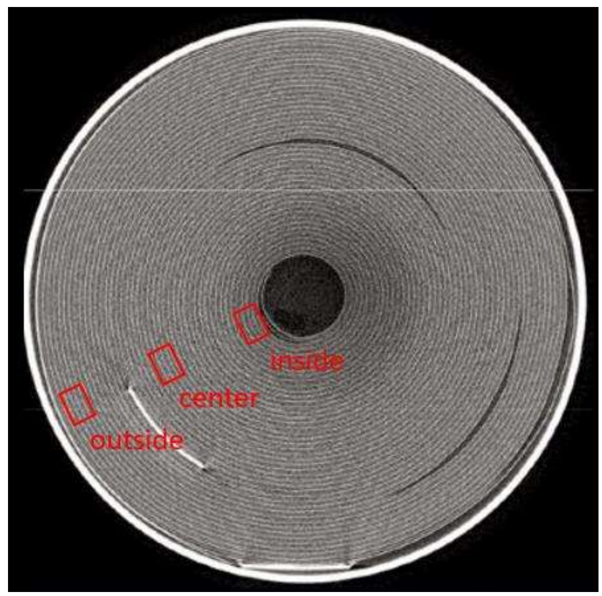

Figure 6 – Cross-sectional area of Li-ion cylindrical cell (jelly roll)[6]

Stack compression does occur internally in Li-ion cylindrical cells without an initial external mechanical pressure. Although it brings certain benefits in increasing electrical contact between layers, its non-uniform distribution causes degradation and capacity reduction. Unlike in fuel cells, where internal stack compression can be adjusted by increasing the Shear Modulus of the GDLs, the self-generated internal stack pressure in cylindrical cells is challenging to control. Possible solutions will be discussed accordingly.

Possible solutions for Li-ion cylindrical cells

An extensive study on stress analysis in jelly roll of a Li-ion battery cell is conducted by Chen et al[7]. It is agreed that the jelly roll is subjected to compressive stress. As degradation occurs due to many reasons, mostly because of the compressive stress profile, the failure of electrode materials, such as buckling and wrinkle, can happen. A size comparison shows that with the same cylindrical format, a larger size cell experiences less internal compressive stress (radial stresses), and therefore is less likely to fail (Fig. 7). This study provides a crucial point of view on how to reduce internal stack compression within Li-ion cells. Many electrical vehicle companies that use Li-ion battery cells are switching to larger cell size due to multiple reasons in cost, capacity, and performance.

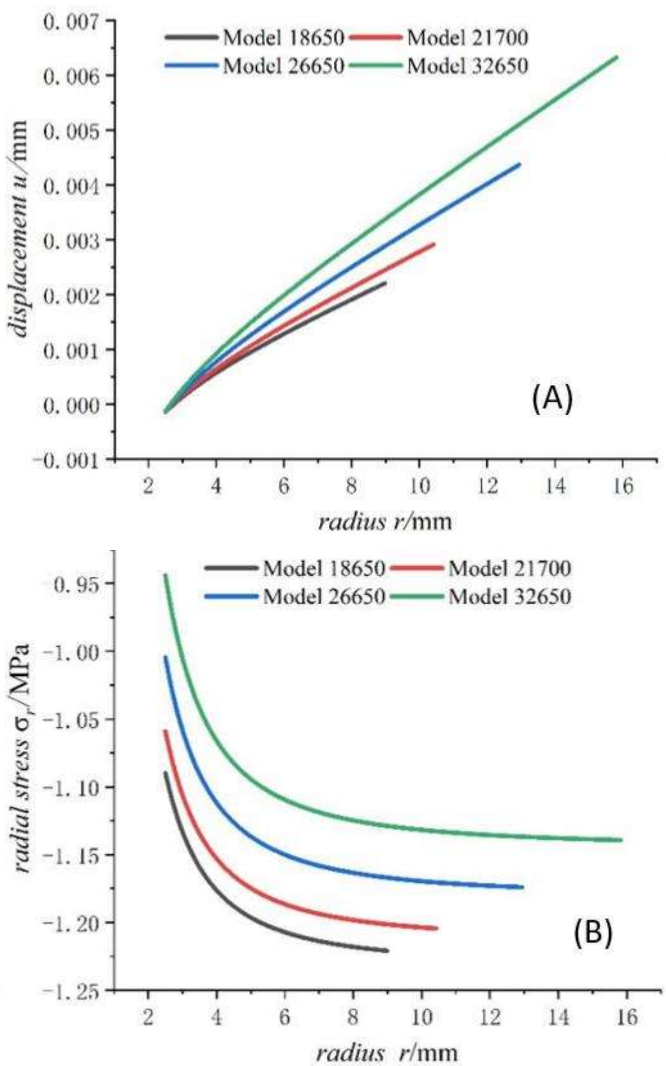

Figure 7 – Analysis results based on cell size[7].

Decreasing the Li-ion concentrations obviously decreases the compressive stress as well, but clearly this is not a desirable solution[7].

CONCLUSION

This research project aims to investigate the status of how stack compression within Li-ion battery cells is studied to minimize the cells degradation and capacity fading. In pouch format, to examine how stack compressive stress affects the cell life cycle, mechanical compressive stress has to be applied externally under different modes. In cylindrical format, stack compression is generated internally and is different throughout the jelly roll radius, causing different aging mechanisms. This difference is mimicked by the pouch cell study under different compression modes. Existed analysis suggests that increasing the cell size would reduce the stack compression pressure or stress concentration to a certain level and therefore, improve the battery's life. However, overall, there have not been many proposed solutions on how to take advantage of this stack compression in Li-ion cells as in fuel cells.

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REFERENCES

[1] Energy Technology Perspectives. *International Energy Agency (IEA)*, 2020. [CrossRef]

[2] Lai, Y. H.; Trabold, T. A. Stack Compression of PEM Fuel Cells. *The 2nd International Conference on Fuel Cell Science, Engineering and Technology*, **2004**. [CrossRef]

[3] Muller, V. et al. Effects of Mechanical Compression on the Aging and the Expansion Behavior of Si/C-Composite|NMC811 in Different Lithium-Ion Battery Cell Formats. *Journal of The Electrochemical Society*, **2019**. [CrossRef]

[4] Mathias, M. et al. Diffusion media materials and characterization. *PEM Fuel Cells: Materials and Design Development Challenges, Springer*, **2003**, 46. [CrossRef]

[5] Cannarella, J.; Arnold, C. B. Stress evolution and capacity fade in constrained lithium-ion pouch cells. *Elsevier*, **2013**. [CrossRef]

[6] A peek inside a Lithium-Ion battery. *Qnovo*, **2014**. [CrossRef]

[7] Chen, J. et al. Stress and Displacement of Cylindrical Lithium-Ion Power Battery during Charging and Discharging. *Energies*, **2022**. [CrossRef]