

The Preeminent Importance of Separator Resistance & Li Ion Conductivity on Electrochemical Performance Capabilities & Safety of Li Ion Cell Designs

Kirby W. Beard, Jay M. Forlino, Jamie L. Owens

Porous Power Technologies, LLC, 5115 Campus Drive, Plymouth Meeting, PA 19462
484-351-8316, kbeard@porouspower.com, www.porouspower.com

Abstract: Porous Power Technologies' (PPT's) novel microporous polymer separator provides the potential for vastly improved lithium ion battery performance. The unprecedented high level of porosity and pore uniformity along with small, well-controlled pore size provide enhanced power and efficient lithium ion cell cycling under a wide range of conditions. Past publications have documented the ability of the PPT separator to provide up to 4 times capacity at high discharge rates plus extended cycle life in lab cells. Current data, using full size cells, confirms the cell power capabilities but also shows over double the cycle life under low rate cycling, compared to typical commercial polyolefin separators. Additionally, under various extremely abuse conditions (oven/hot box testing and abusive over-charge) PPT separators outperform the shut-down, "safety" separators.

Keywords: polymer; separator; lithium; ion, battery

Introduction

Prior Cell Testing: Various cell designs in up to 20 Ah sizes have shown the ability of PPT separator to provide higher power capabilities, better charging rates, reduced capacity fade and less cell polarization than conventional commercial polyolefin separator. However, despite such remarkable performance results with these high porosity PPT separators, conventional wisdom has led to the supposition that less porous, more robust separator layers are pre-requisite in providing adequate cell safety. Unfortunately, this technical approach detracts from cell power and cycling capabilities. Other unintended consequences of separators with reduced porosity, barrier layers or non-optimized pore structure include excessive internal heat generation, low coulombic efficiency and decomposition reactions for both the electrolyte and the active electrode materials. Such ill-advised trade-offs between performance and safety result in sub-optimal outcomes. New strategies for enhancing both the energy efficiency and the safety of lithium cells are still a major requirement for the industry.

Optimized Cell Designs: A new technical approach for cell design that builds upon the ability of PPT's high porosity separator to provide both high performance and exceptional safety characteristics has now been validated. Specifically, the high conductivity afforded by the use of the novel PPT separators creates a lower thermal signature across most all operating regimes and even under extreme abuse conditions. Lithium ion cells with PPT separators have now demonstrated improved safety in short circuit, over-charge, over-heating and mechanical abuse testing compared to current conventional polyolefin separators. The theoretical basis for this unexpected result derives from the reduced ionic resistance and the uniformity of the PPT separators. Typical commercial polyolefin separators develop and retain higher levels of heat during use and abuse, but also suffer from severe inconsistencies in properties and performance that prove to be fatal flaws. Supporting data showing the enhanced capabilities of PPT separator are detailed in the sections below.

Symmetrix[®] Separator and MAS[™] Production Technology: PPT's unique intellectual property enables enhanced cell performance as well as high production efficiencies:

- **Symmetrix[®] Separator:** High porosity, uniform pore structure, improved cycling efficiency, high power output and low thermal profiles in use/abuse
- **MAS[™] Production Technology:** High volume, simple, low cost manufacturing, low cost separators and fast, reliable electrode lamination/stacking technology

The benefits of these technologies include the following,

- Enhanced ion conductivity/thermodynamics:
HIGH POWER/ENERGY EFFICIENCY
- Negligible internal cell impedance build-up:
STABLE LONG TERM CYCLING
- Low internal heat generation in normal use and abuse:
SUPERIOR SAFETY PERFORMANCE ENVELOPE

Production Grades/Types of PPT Separator: Table 1 lists properties, features and benefits of various PPT separators.

Table 1. Properties and Applications of Various PPT Symmetrix[®] Separators

CODE	FILM TYPE	POWER/HANDLING	COSTS	CELL TYPES
HP	Highest porosity (70-80%)	Highest power, but weakest	Lowest	Pouch cells w/ special assembly
HPX1	High void (65%), stronger	High power in reinforced version	Very good	Pouch cells/maybe other types
HPX2	Good strength/voids (60%)	Moderate power/strength/handling	Good	Pouch & some wound/laminated
HPX3	High strength, (55% voids)	Fair power with higher robustness	Fair	Pouch/wound/folded/laminated
HPX4	Highest strength/reliability	Most robust/strong/reliability/safe	Comparable	Potentially good for any usage

Cell Capacity and Cycling Test Data

Baseline Separator C-rate Performance: Discharge capacity's of standard PPT separator grades are shown in Figure 1, below.

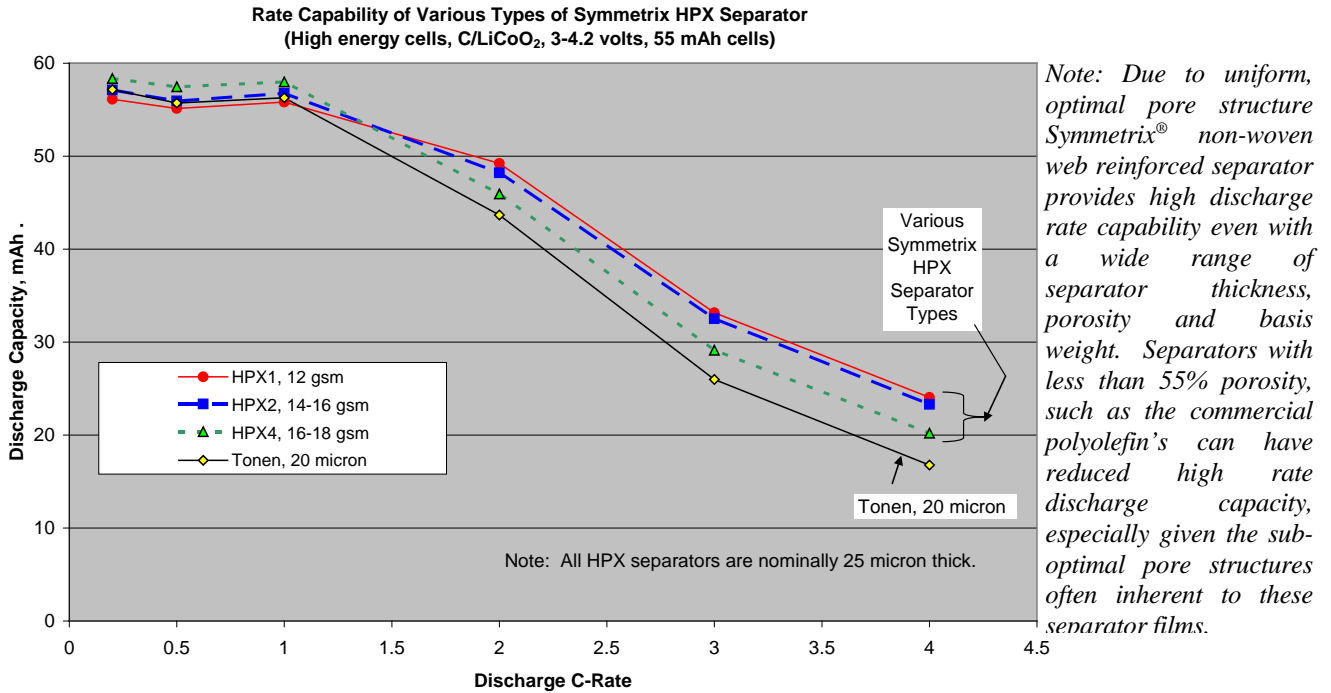


Figure 1. Comparison of C-rate Capabilities of Various PPT Separators with Tonen Separator.

Baseline Separator Cycling Performance: Figure 2 below shows cycling capacity for various PPT separator grades.

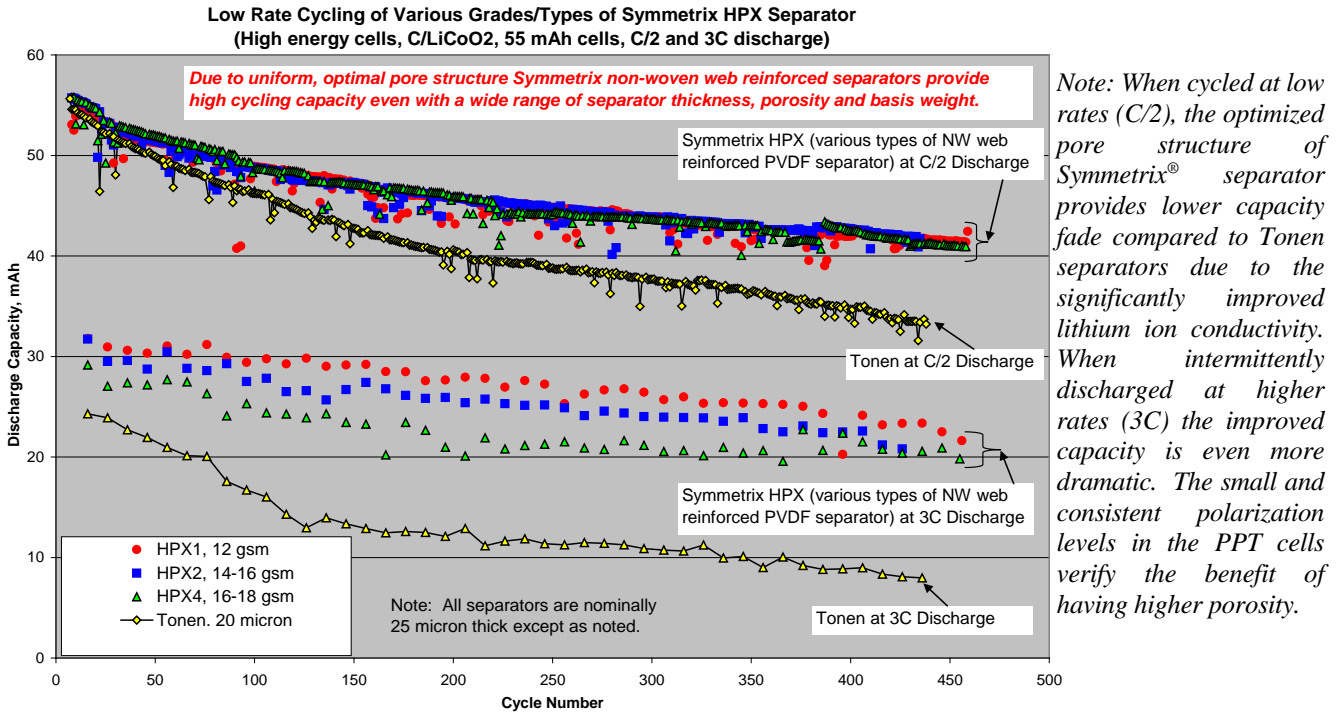


Figure 2. Comparison of the Cycling Discharge Capacity of Various PPT Separators with Tonen Separator.

Long Term Cycling of Baseline Separators: PPT's HP (high porosity) separator shows excellent capacity over extended low rate cycling compared to conventional commercial polyolefin separators, especially when intermittently discharged at just moderate power (Figure 3).

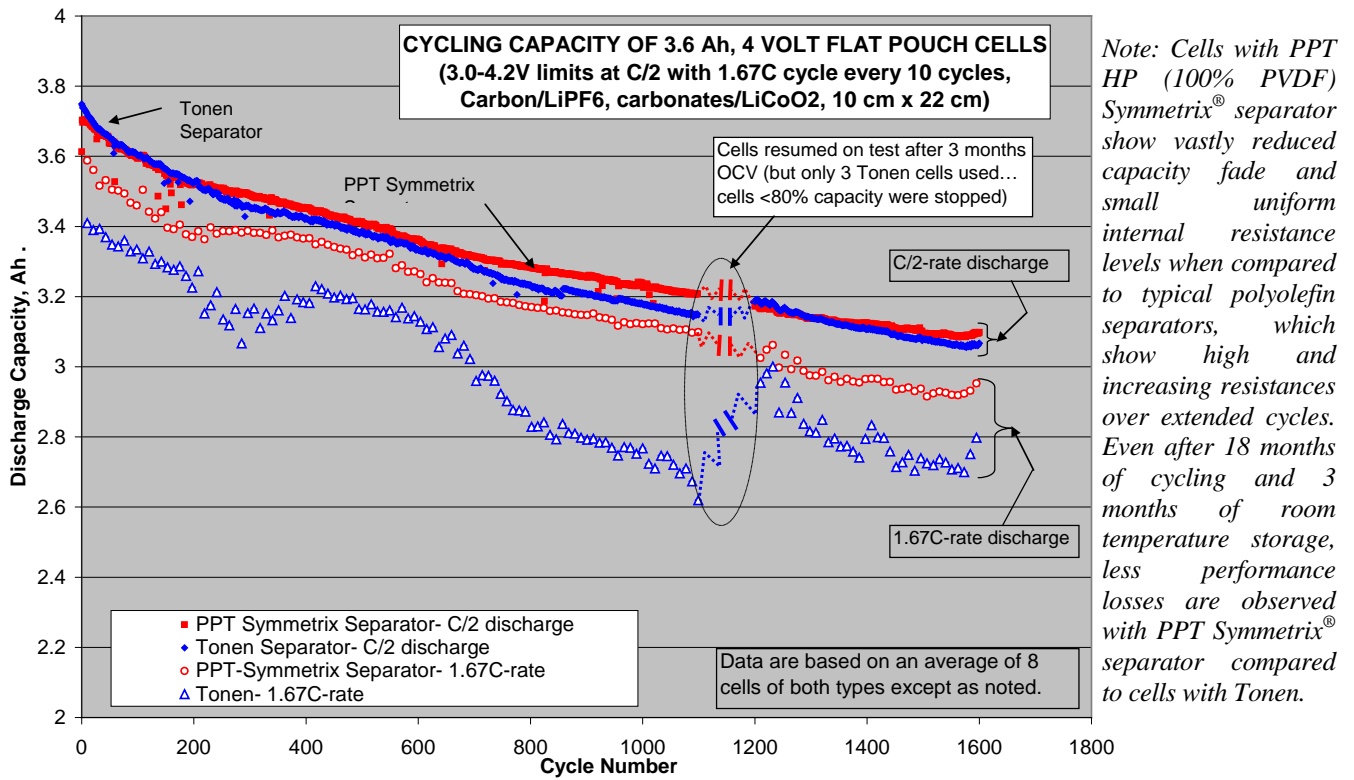


Figure 3. Comparison of the Cycling Discharge Capacity of Full Size Cells with PPT's HP Separator

Cell Safety Test Data

Overcharge Testing of Tonen Separators: When subjected to just moderate levels of overcharge, Tonen cells can readily fail.

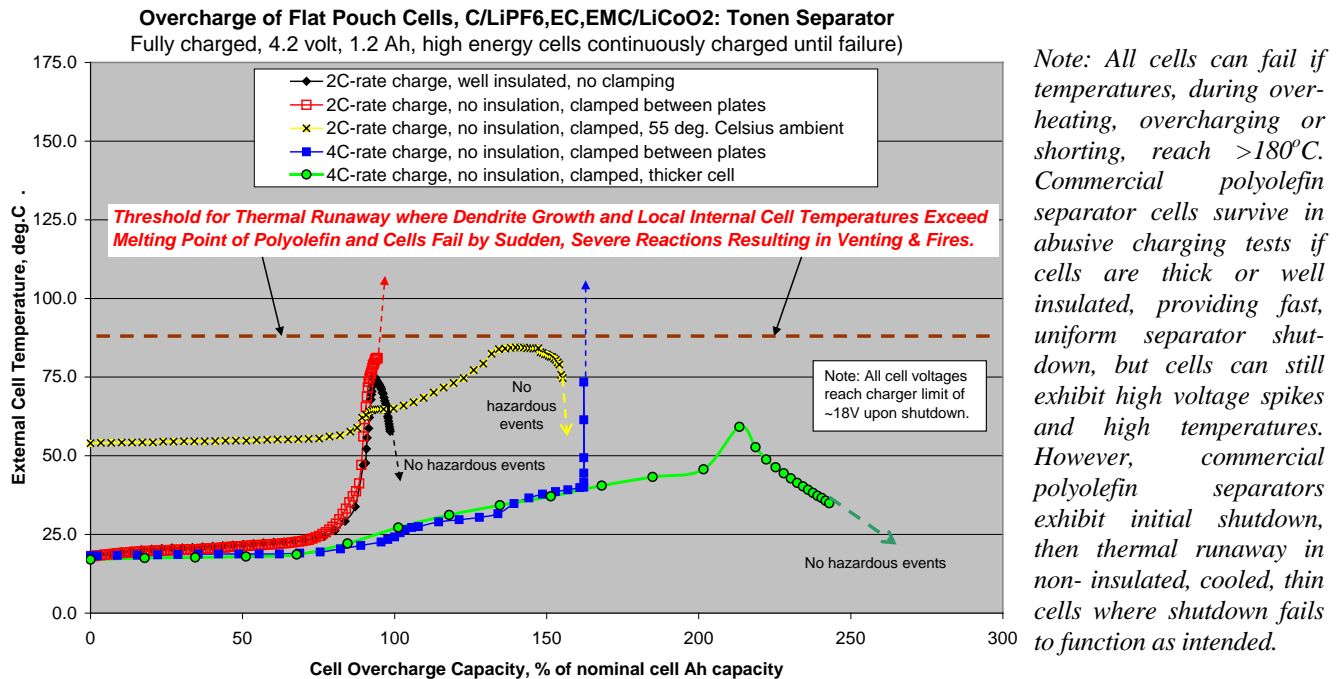
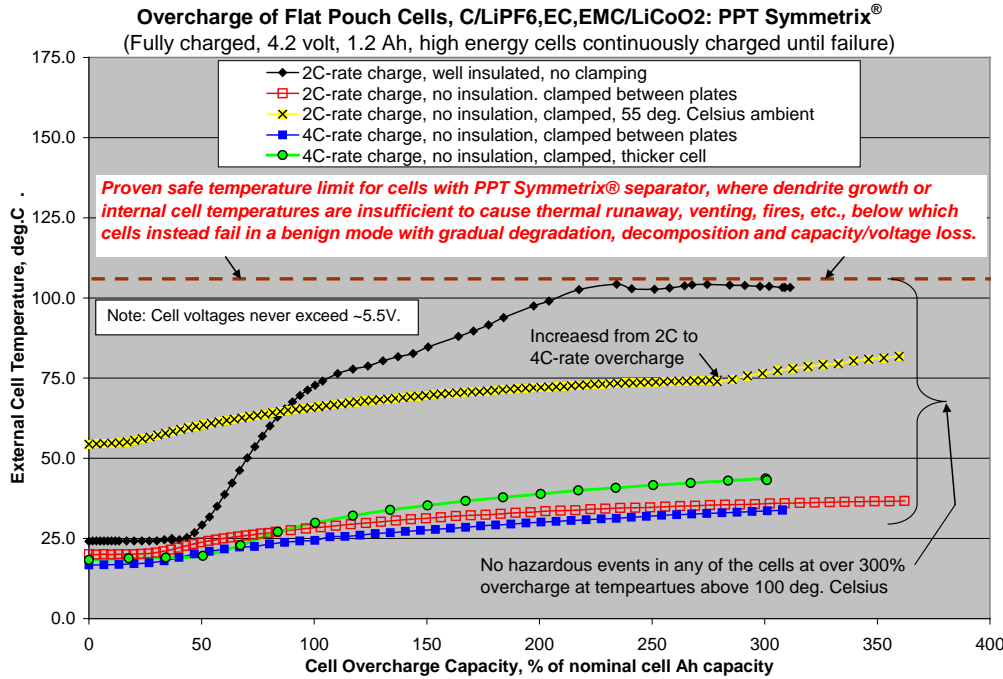


Figure 4. Abusive Over-Charge Testing of Cells with Tonen Separator

Overcharge Testing of PPT Separators: When subjected to various levels of overcharge, PPT Symmetrix® separator cells are able to survive.



PPT Symmetrix® separator shows the ability to withstand high temperatures in the oven overheating and shorting test comparable to cells with Tonen separator. However, unlike cells with Tonen separator, the cells with PPT separator, when overcharged, all show uniform, soft shorting with moderate, well controlled temperature rise and benign failure mode (<5.5 volts at full current to >300% charge capacity) over the full range of abusive heating, charging, internal/external shorting.

Figure 5. Abusive Over-Charge Testing of Cells with PPT's Symmetrix® HPX Separator

Performance Envelope for Various Separators: When overcharge and heating test data are plotted together, the PPT separators show a wide stable range of acceptable performance, while the Tonen separator shows failures when cells are not able to shut-down.

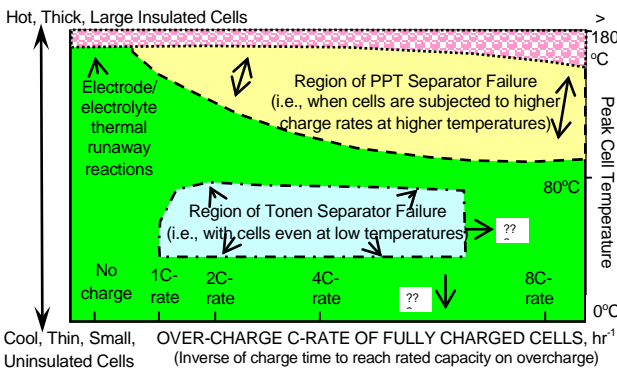


Figure 6

Conclusions and Summary

Performance Capabilities of PPT Separators: Repetitive cell lot testing, using both high power and high energy cell designs with cell capacity's ranging from 50 mAh up to 20 Ah and in electrode plate sizes going from 10 cm² up to 200 cm², have continued to demonstrate exceptional PPT separator performance (power, cycle life and safety) compared to conventional polyolefin separators. Various established cell producers have verified the results depicted in the sections above and are now qualifying the separator for commercial production. Proven benefits are as follows,

- Improved Discharge Output/Cycle Life Capabilities
- Improved Cell Operation (i.e., energy efficiency)
- Higher Discharge Voltage Levels/Lower Charge Volts
- Improved Safety under Various Extreme Abuses: NO THERMAL RUNAWAY WITH Symmetrix®
- No Known Major Deficiencies: Storage, Cell Crush, Temperature Limits, Charging, Voltage Decay, etc.
- No Performance Losses in Bonded/Laminated Cells
- Vastly Improved Cost and Performance Compared to Typical Conventional Commercial Separators
- Ability to adapt for use in high speed, automated, reliable cell production processes (MAS™ process)

Summary: Overall, PPT separator films offer potential for dramatic improvement in electrochemical cell technology.

References

- Beard, K.W., "Electrochemical, Thermal and Safety Characteristics of High Power, High Efficiency Lithium Ion Cells Constructed with Novel, High Performance Separators," *Proceedings of the 26th International Battery Seminar*, Ft. Lauderdale, FL, March 19, 2009,
- Beard, K.W., "Performance Characteristics of High Power, High Efficiency Li Ion Cells Constructed with High Performance Separators and the Effects of Varied Separator Thickness and Laminated Cell Designs on Rate Capability and Safety," *Proceedings of the 27th International Battery Seminar*, Ft. Lauderdale, FL, March 17, 2010