

CASE STUDY

Tensile Testing on Battery Thin Films

Introduction

A battery separator is one of the most important — and least appreciated — components inside a lithium-ion battery. Even though separators look like basic plastic film, they are actually one of the most critical engineered components in the entire battery. The battery separator is the porous membrane between the anode and cathode that allows lithium ions to flow through while blocking the passage of electrons. If electrons were able to travel through the separator, the battery can short circuit, possibly leading to thermal runaway. In fact, separator failure is one of the classic pathways to battery fires. The separator's job is deceptively simple yet completely crucial: The separator keeps the two electrodes from touching each other while still allowing lithium ions to pass through. If it fails at this job, the results can be catastrophic.

In jelly-roll style batteries, the anode, separator, and cathode are ultra-thin layered materials — often only a few tens of microns thick — that are stacked together and tightly rolled into a cylindrical structure.



Figure 2: Illustration of a jelly-roll style battery.

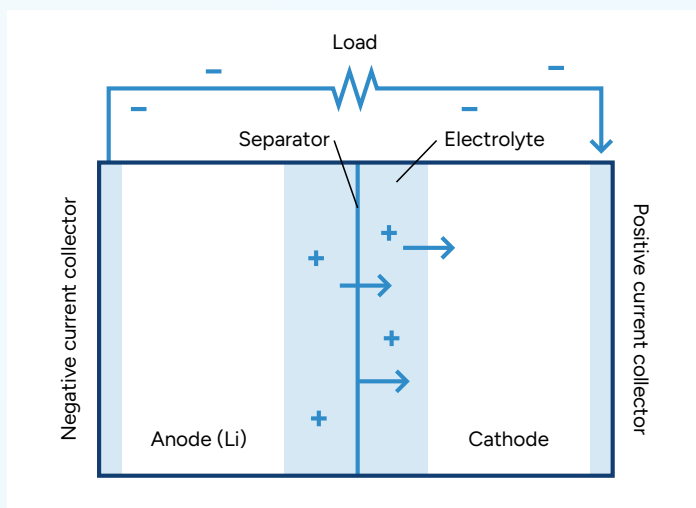


Figure 1: A simplified diagram of a battery.

Separators are made thin because this allows for lower resistance for lithium ions, which means better battery performance. It also allows maximum energy density because more electrode layers fit into the same battery volume. However, these ultra-thin polymer films must still maintain sufficient mechanical integrity to survive high-speed manufacturing and long-term battery operation.

During electrode winding, stacking, calendaring, and assembly, the separator experiences tensile stress, compression, bending, and localized

deformation despite often being only a few tens of microns thick. If the separator tears, punctures, shrinks, or deforms excessively, the electrodes can come into direct contact and create an internal short circuit, potentially leading to overheating or thermal runaway.

In addition to separators, lithium-ion batteries also rely on ultra-thin metallic current collectors. These current collectors — typically aluminum foil on the cathode side and copper foil on the anode side — act as the conductive backbone of the battery. Their job is to collect electrons from the active electrode materials and transport electrical current into and out of the cell during charging and discharging.

Like separators, current collectors are engineered to be extremely thin in order to maximize energy density and reduce overall battery weight. Modern current collectors may only be a few microns thick, yet they must still survive demanding manufacturing processes and battery operation.

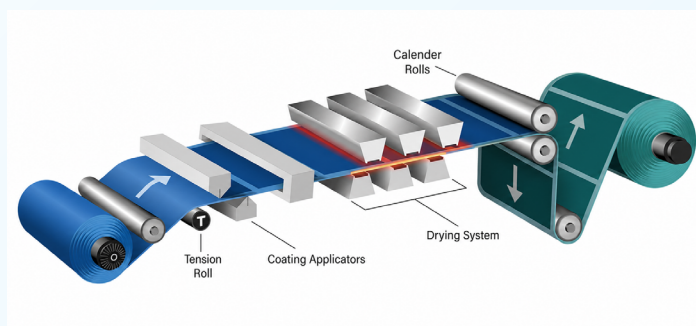


Figure 3: Diagram demonstrating roll-to-roll battery thin film manufacturing.

One of the major advantages of tensile testing is that these mechanical properties directly influence how battery materials behave during manufacturing. Modern lithium-ion battery

production involves high-speed roll-to-roll handling, coating, calendaring, stacking, and winding processes that continuously place thin films and foils under mechanical stress. Because separators and current collectors are often only a few microns thick, even subtle differences in stiffness or yield behavior can significantly affect manufacturing performance.

Elastic modulus is especially important because it influences how a material responds to tension, bending, wrinkling, and dimensional changes during processing. A separator with a modulus that is too low may stretch excessively during winding or stacking, potentially leading to misalignment, wrinkling, or uneven layer spacing inside the battery. Conversely, a separator with a very high modulus may become too stiff and less tolerant to localized deformation, increasing the likelihood of tearing or puncture during handling.

Yield strength is equally important because it defines the stress level at which permanent deformation begins. During manufacturing, stress concentrations can develop at edges, defects, or contact points. If the applied stress exceeds the material's yield strength, permanent stretching or deformation may occur even if the material does not immediately fracture. Over time, these small dimensional changes can contribute to defects, poor layer registration, localized thinning, or long-term reliability issues inside the finished cell.

For metallic current collectors, understanding modulus and yield behavior is particularly critical because the foils must remain dimensionally stable while supporting electrode coatings and maintaining reliable electrical pathways. Excessive deformation or wrinkling in current collectors can propagate into coating defects,

uneven current distribution, or localized heating during battery operation.

By quantitatively measuring properties such as elastic modulus and yield stress, manufacturers can better optimize material selection, process conditions, winding tension, calendaring pressure, and handling parameters. This enables tighter process control, improved manufacturing yield, and ultimately safer and more reliable battery designs.

Mechanical integrity is especially important in the finished cell because defects in current collectors can propagate into electrode damage, poor electrical contact, localized heating, or long-term reliability issues. As battery manufacturers continue pushing toward thinner and lighter designs, accurately characterizing the tensile behavior of both separators and current collectors becomes increasingly important.

Materials Testing at Covalent

Using ASTM-compliant tensile testing and high-precision non-contact strain measurement, battery manufacturers can quantitatively evaluate the mechanical integrity of ultra-thin separator films and current collectors with exceptional accuracy and repeatability.

In this case study, we evaluate tensile properties of two battery thin film materials, a separator and a current collector.

The separator evaluated in this study, a 25µm thick multilayer PP–PE–PP (polypropylene–polyethylene–polypropylene) separator, is a common architecture in commercial lithium-ion batteries. In this design, the polypropylene outer layers provide mechanical strength and dimensional stability, while the polyethylene

core serves as a thermal shutdown layer. If the battery overheats, the PE layer can soften and collapse its porous structure, reducing ion transport through the separator and helping slow or prevent thermal runaway. This illustrates how modern battery separators are not simply passive plastic films, but carefully engineered multilayer materials designed to balance ion transport, mechanical durability, manufacturability, and safety simultaneously.

The current collector evaluated in this study was an ultra-thin aluminum foil, which serves as the cathode-side current collector in many lithium-ion battery designs. While current collectors are often overlooked compared to active battery materials, they play a critical role in transporting electrical current into and out of the electrode coatings. These foils must balance high electrical conductivity with extremely low thickness and weight, all while surviving coating, calendaring, slitting, and high-speed winding operations without tearing or deforming.

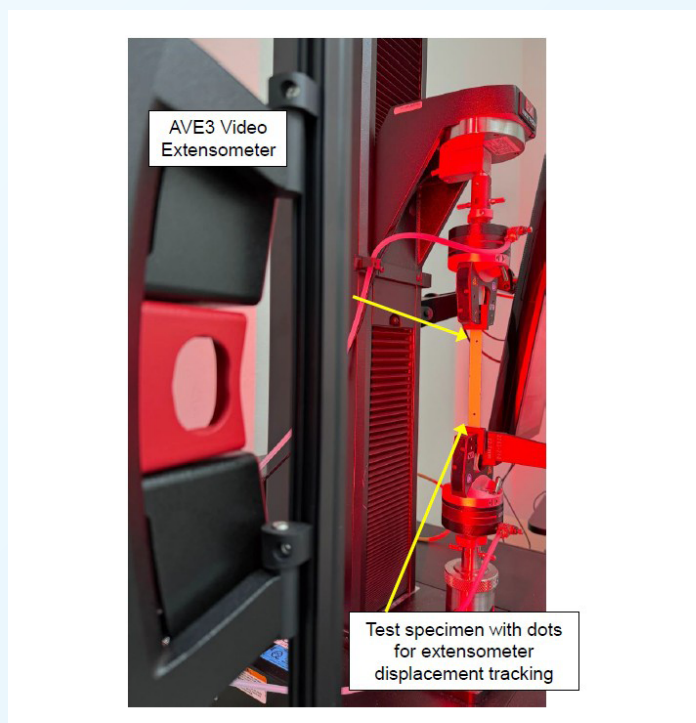


Figure 4: Instron AVE3 video extensometer set up.

Tensile data is collected using an Instron tensile tester with an Instron AVE3 video extensometer. In this setup, the specimen is physically clamped at its ends using carefully controlled pneumatic grips while the center gauge region of the sample remains untouched. As the Instron applies a precisely controlled tensile displacement, the AVE3 system uses a high-resolution camera to optically track small markers placed on the specimen surface, allowing strain to be measured without physically contacting the delicate film or foil. This non-contact approach is especially important for battery separator films and current collectors that may only be 10–25 μm thick, where a traditional clip-on extensometer could damage the sample or alter its true mechanical response. By isolating the measurement region from the grip region, the system accurately captures material behavior including elastic modulus, yield stress, tensile strength, and strain at break while minimizing measurement artifacts caused by gripping or handling.

Interpreting the Data

The output of tensile testing is a stress vs strain curve.

Stress is the force being applied to the material, normalized by its cross-sectional area. In tensile testing, the Instron machine is pulling on the sample and measuring how much force it takes.

Strain is how much the material deforms relative to its original length — basically how much it stretches.

The stress–strain curves are really the fingerprint of how each material mechanically behaves as it is stretched.

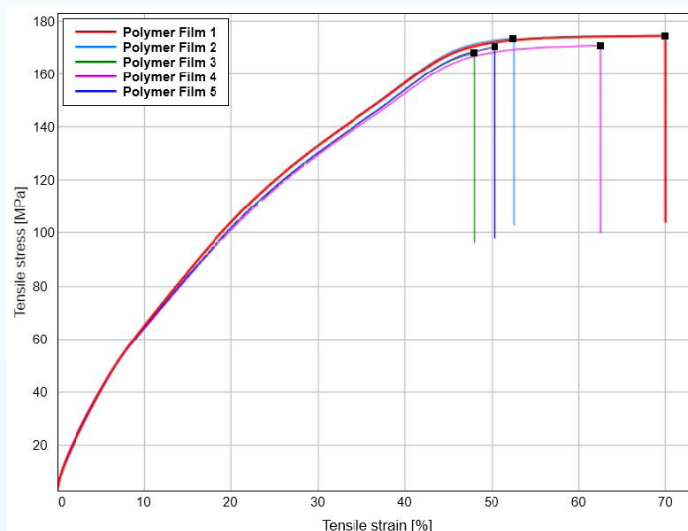


Figure 5: Stress-strain curve for the polymer film.

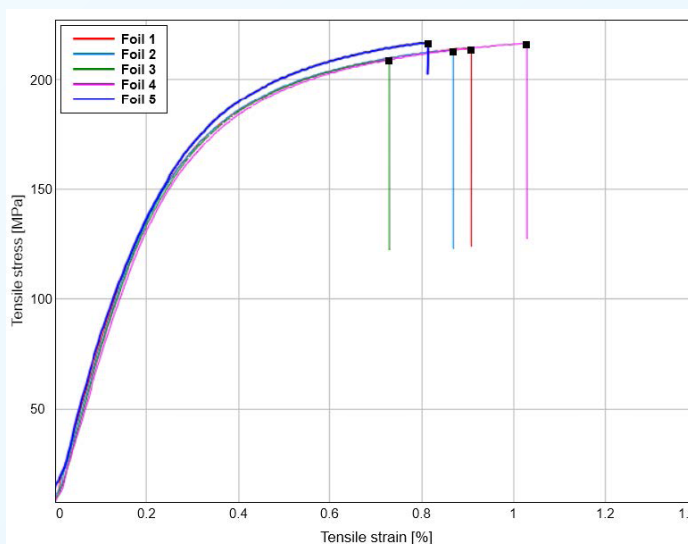


Figure 6: Stress-strain curve for the aluminum foil.

At the beginning of the curve, both materials show an approximately linear region where stress increases proportionally with strain. This is the elastic region, where the material deforms reversibly and would return to its original shape if the load were removed. The slope of this region corresponds to the elastic modulus, which tells us how stiff the material is. The aluminum foil shows a much steeper slope than

the polymer separator, immediately revealing that the foil is far stiffer and less compliant.

As the curves progress, the materials begin behaving very differently. The polymer separator exhibits significant elongation after yielding, continuing to stretch over a large strain range before failure. This extended plastic deformation region indicates a ductile material capable of absorbing mechanical strain during battery manufacturing and operation. In contrast, the aluminum current collector reaches high stress quickly but fractures after very little elongation. Its curve is much shorter horizontally, showing that the foil tolerates minimal strain before failure despite its relatively high strength.

The curves also reveal the consistency of the measurements. The replicate curves closely overlap for both materials, indicating highly repeatable mechanical behavior and precise strain measurement from the AVE3 video extensometer system. This kind of repeatability is especially important for ultra-thin battery materials where even small variations in mechanical performance can influence manufacturability, yield, and long-term reliability.

The tables below extract key mechanical properties from the stress–strain curves. The elastic modulus is determined from the slope of the initial linear region of the curve, which reflects the material’s stiffness. Yield stress is identified at the point where the curve begins deviating from linear behavior, indicating where the material stops deforming elastically and begins deforming permanently. Tensile strength is taken from the highest point on the stress–strain curve and represents the maximum stress the material can withstand before catastrophic failure begins.

Replicate	Modulus of Elasticity [MPa]	Yield Stress, 0.2% offset [MPa]	Tensile Strength [MPa]	Strain at Break [%]
1	591.48	35.60	174.57	69.92
2	585.96	36.19	173.68	52.51
3	588.17	33.32	168.07	47.92
4	585.83	33.43	170.88	62.44
5	585.42	33.54	170.35	50.34
Mean	587.37	34.42	171.51	56.62
Std. Dev.	2.53	1.37	2.63	9.26

Figure 7: Tensile metrics from the polymer film.

Replicate	Modulus of Elasticity [GPa]	Yield Stress, 0.2% offset [MPa]	Tensile Strength [MPa]	Strain at Break [%]
1	75.53	190.93	214.24	0.91
2	69.50	193.77	213.08	0.87
3	71.52	192.67	208.71	0.73
4	68.93	192.53	216.35	1.03
5	70.23	197.21	216.67	0.81
Mean	71.14	193.42	213.81	0.87
Std. Dev.	2.64	2.35	3.22	0.11

Figure 8: Tensile metrics from the aluminum film.

The tensile testing results reveal an important reality of lithium-ion battery design: not all ultra-thin battery materials are engineered to behave the same way mechanically. Although both the separator and current collector are only a few tens of microns thick, their roles inside the battery require dramatically different mechanical behavior.

The polymer separator film demonstrated relatively high flexibility and ductility, reaching an average strain at break of approximately 56.6% with a tensile strength of 171.5 MPa. This behavior is critical because separators must survive bending, winding, stacking, and long-term dimensional changes during battery operation without tearing or puncturing. A

separator that is too brittle could fail during manufacturing or develop defects over time that ultimately allow the electrodes to contact each other and create an internal short circuit.

The aluminum current collector foil behaved very differently. While the foil exhibited higher stiffness and strength — including a modulus of approximately 71.3 GPa and tensile strength of 211.9 MPa — it failed at only about 0.85% strain. In other words, the current collector can withstand very high stress but tolerates very little stretching before failure occurs. This highlights an important challenge for battery manufacturing: ultra-thin metallic foils must remain dimensionally stable and electrically conductive while enduring coating, calendaring, slitting, and high-speed winding operations that can introduce localized stress concentrations, wrinkles, or micro-tears.

The study also demonstrated the value of high-precision, non-contact strain measurement. Despite testing extremely delicate materials, the Instron AVE3 video extensometer produced highly repeatable tensile data with exceptionally low variability between replicates. For the separator film, the measured elastic modulus standard deviation was only 0.4% of the average value, while the aluminum foil yield stress standard deviation was just 0.8%. These results demonstrate that modern tensile testing systems can quantitatively characterize the mechanical reliability of ultra-thin battery materials with remarkable precision and repeatability.

Conclusion

Modern lithium-ion batteries rely on an intricate balance of electrochemistry, manufacturing precision, and materials engineering. Components such as separators and current collectors may appear simple, but this study demonstrates that these ultra-thin materials are highly engineered structures with demanding and fundamentally different mechanical requirements. The separator must remain flexible and ductile enough to survive winding and long-term cycling without tearing, while the metallic current collector must maintain electrical conductivity and dimensional stability despite being only a few microns thick.

As battery manufacturers continue pushing toward higher energy density, faster charging, lighter weight, and lower cost, these materials are becoming thinner and more mechanically demanding than ever before. In high-volume battery manufacturing environments, even small improvements in mechanical consistency can translate into significant gains in process yield, throughput, reliability, and safety. Subtle defects, process variations, or insufficient mechanical robustness can ultimately influence manufacturing yield, battery lifetime, and safety.

This case study highlights how modern ASTM-compliant tensile testing combined with high-precision, non-contact strain measurement can quantitatively characterize the mechanical behavior of delicate battery materials with exceptional repeatability. By understanding how separators and current collectors respond to stress, strain, and deformation, battery developers can make more informed decisions about material selection, process optimization, and long-term reliability.

In the race toward safer, higher-performance batteries, understanding the mechanical behavior of ultra-thin battery materials is no longer optional — it is a critical part of battery engineering itself.



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