Researchers discover a surprising way to jump-start battery performance

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Giving lithium-ion batteries their first charge at high currents before they leave the factory is 30 times faster and increases their lifespans by 50%. Credit: Greg Stewart/SLAC National Accelerator Laboratory

A lithium-ion battery's very first charge is more momentous than it sounds. It determines how well and how long the battery will work from then on—in particular, how many cycles of charging and discharging it can handle before deteriorating.

In a study published today in *Joule*, researchers at the SLAC-Stanford Battery Center report that giving batteries this first charge at unusually high currents increased their average lifespan by 50% while decreasing the initial charging time from 10 hours to just 20 minutes.

Just as important, the researchers were able to use scientific machine learning to pinpoint specific changes in the battery electrodes that account for this increase in lifespan and performance—invaluable insights for battery manufacturers looking to streamline their processes and improve their products.

The study was carried out by a SLAC/Stanford team led by Professor Will Chueh in collaboration with researchers from the Toyota Research Institute (TRI), the Massachusetts Institute of Technology and the University of Washington. It is part of SLAC's sustainability research and a broader effort to reimagine our energy future leveraging the lab's unique tools and expertise and partnerships with industry.

"This is an excellent example of how SLAC is doing manufacturing science to make critical technologies for the energy transition more affordable," Chueh said. "We're solving a real challenge that industry is facing; critically, we partner with industry from the get-go."

The results have practical implications for manufacturing not just lithium-ion batteries for electric vehicles and the electric grid, but for other technologies, too, said Steven Torrisi, a senior research scientist at TRI who collaborated on the research.

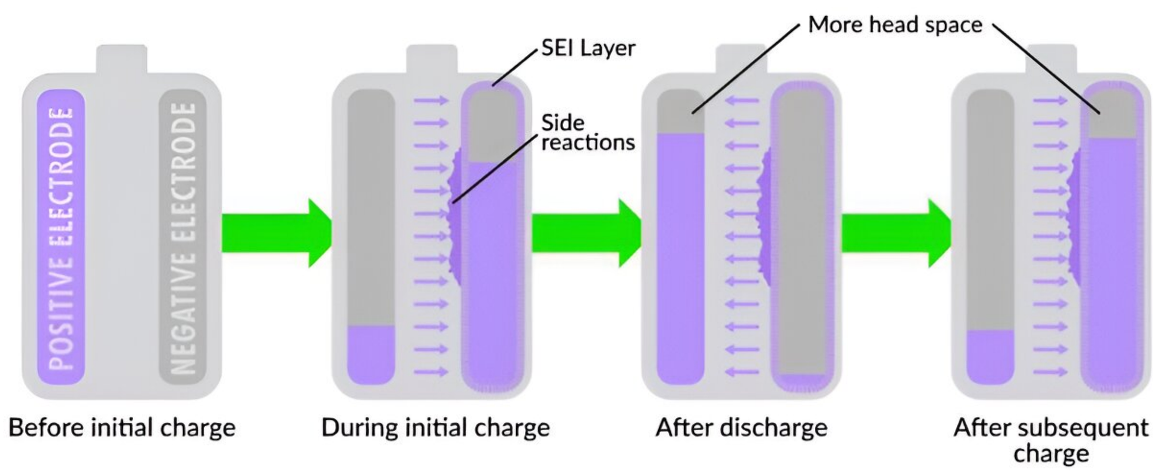
"This study is very exciting for us," he said. "Battery manufacturing is extremely capital, energy and time intensive. It takes a long time to spin up manufacturing of a new battery, and it's really difficult to optimize the manufacturing process because there are so many factors involved."

Torrisi said the results of this research "demonstrate a generalizable approach for understanding and optimizing this crucial step in battery manufacturing. Further, we may be able to transfer what we have learned to new processes, facilities, equipment and battery chemistries in the future."

A 'squishy layer' that's key to battery performance

To understand what happens during the battery's initial cycling, Chueh's team builds pouch cells in which the positive and negative electrodes are surrounded by an electrolyte solution where lithium ions move freely.

When a battery charges, lithium ions flow into the negative electrode for storage. When a battery discharges, they flow back out and travel to the positive electrode; this triggers a flow of electrons for powering devices, from electric cars to the electricity grid.



Factory-charging a new lithium-ion battery with high currents significantly depletes its lithium supply but prolongs the battery's life, according to research at the SLAC-Stanford Battery Center. The lost lithium is generally usually used to form a protective layer called SEI on the negative electrode. However, under fast charging conditions, lithium ions are also consumed during side reactions at the negative electrode. This creates additional headspace in both electrodes and helps improve battery performance and lifespan. Credit: SLAC National Accelerator Laboratory

The positive electrode of a newly minted battery is 100% full of lithium, said Xiao Cui, the lead researcher for the battery informatics team in Chueh's lab. Every time the battery goes through a charge-discharge cycle, some of the lithium is deactivated. Minimizing those losses prolongs the battery's working lifetime.

Oddly enough, one way to minimize the overall lithium loss is to deliberately lose a large percentage of the initial supply of lithium during the battery's first charge, Cui said. It's like making a small investment that yields good returns down the road.

This first-cycle lithium loss is not in vain. The lost lithium becomes part of a squishy layer called the solid electrolyte interphase, or SEI, that forms on the surface of the negative electrode during the first charge. In return, the SEI protects the negative electrode from side reactions that would accelerate the lithium loss and degrade the battery faster over time. Getting the SEI just right is so important that the first charge is known as the formation charge.

"Formation is the final step in the manufacturing process," Cui said, "so if it fails, all the value and effort invested in the battery up to that point are wasted."

High charging current boosts battery performance

Manufacturers generally give new batteries their first charge with low currents, on the theory that this will create the most robust SEI layer. But there's a downside: Charging at low currents is time-consuming and costly and doesn't necessarily yield optimal results. So, when recent studies suggested that faster charging with higher currents does not degrade battery performance, it was exciting news.

But researchers wanted to dig deeper. The charging current is just one of dozens of factors that go into the formation of SEI during the first charge. Testing all possible combinations of them in the lab to see which one worked best is an overwhelming task.

To whittle the problem down to manageable size, the research team used scientific machine learning to identify which factors are most important in achieving good results. To their surprise, just two of them—the temperature and current at which the battery is charged—stood out from all the rest.

Experiments confirmed that charging at high currents has a huge impact, increasing the lifespan of the average test battery by 50%. It also deactivated a much higher percentage of lithium up front—about 30%, compared to 9% with previous methods—but that turned out to have a positive effect.

Removing more lithium ions up front is a bit like scooping water out of a full bucket before carrying it, Cui said. The extra headspace in the bucket decreases the amount of water splashing out along the way. In similar fashion, deactivating more lithium ions during formation frees up headspace in the positive electrode and allows the electrode to cycle in a more efficient way, improving subsequent performance.

"Brute force optimization by trial-and-error is routine in manufacturing–how should we perform the first charge, and what is the winning combination of factors?" Chueh said. "Here, we didn't just want to identify the best recipe for making a good battery; we wanted to understand how and why it works. This understanding is crucial for finding the best balance between battery performance and manufacturing efficiency."

More information: Data-Driven Analysis of Battery Formation Reveals the Role of Electrode Utilization in Extending Cycle Life, *Joule* (2024). DOI: 10.1016/j.joule.2024.07.024.
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