Supplementary Materials: Coupling Analysis and Performance Study of Commercial 18650 Lithium-Ion Batteries under Conditions of Temperature and Vibration

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1. Test Incubator for Controlling Temperature

An Indelb T12R test incubator (Indelb, Zhongshan, China) is used for controlling temperature in this paper. By heating generation with a resistance and cooling with a DC compressor refrigeration, it can provide a temperature range of 55 °C to −18 °C, which can simulate the high and low temperature environmental conditions in the actual operation of the battery. The Indelb T12R test incubator is shown in Figure S1. The relevant technical specification is shown in Table S1.

Figure S1. Indelb T12R test incubator.

In order to study the battery temperature performance, it is considered to divide the ambient temperature into five temperature gradients for experimental research. That is, (1) Low temperature icing environment: −15 °C to −10 °C, which is recorded as a temperature gradient *L*; (2) Low-normal temperature environment: 0 °C to 5 °C, recorded as temperature gradient *LN*; (3) Normal temperature environment: 15 °C to 20 °C, recorded as temperature gradient *N*; (4) Normal high temperature environment: 30 °C to 35 °C, recorded as temperature gradient *NH*; (5) High temperature environment: 45 °C to 50 °C, recorded as temperature gradient *H*.

Table S1. The specifications of the Indelb T12R.

Performance Index	Specifications
Heating range	25 °C to 55 °C
Heating work mode	Resistance heating
Cooling range	10 °C to −18 °C
Cooling work mode	DC compressor
Heating/cooling power	60 W / 55 W
Capacity/size	12 L, 354×250×155 (mm) effective workspace

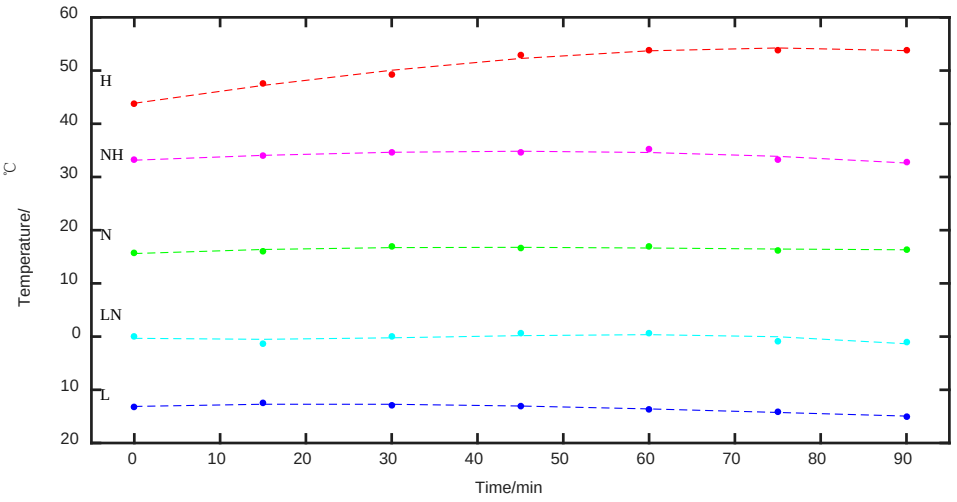

Figure S2. The five temperature gradient.

As shown in Figure S2, the test was carried out in five gradients in the experiment. The scatter plot is the temperature value recorded by the high precision HT-9815 industrial digital display thermocouple thermometer (XINTEST, Beijing, China), and the fitted temperature profile.

2. Vibration Test Bench

A ZD/LX-XTP-VT700 test bench (Huayi Technology, Shanghai, China) which features fully automatic six-degree space electromagnetic absorption bench, which is composed of an electric vibration table, a power amplification unit, an acceleration sensing unit and a vibration control unit. The vibration control unit dynamically adjusts the power amplification unit through the signal fed back by the acceleration sensor to control the vibration parameter of the electric vibration table. Sinusoidal vibration, random vibration, fixed-frequency vibration, sweeping vibration, etc. are generated in three directions of X/Y/Z. The vibration test bench is shown in Figure S3, and the related technical specifications are shown in Table S2.

Table S2. The specifications of the vibration test bench.

Performance Index	Specifications
Frequency range	1 Hz ~ 600 Hz
Amplitude	0 ~ 5 mm (adjustable range mmp-p)
Maximum acceleration	20 g
Vibration direction	Vertical + horizontal + front and rear
Vibration waveform	Sinusoidal, random, fixed-frequency, sweeping, etc.

The standard SAEJ2380 is based on the actual measured random vibration curve of an electric car driving 100,000 miles, so it is more suitable for battery vibration testing. The standard SAEJ2380 can better reflect the actual vibration of lithium-ion batteries for vehicles, so this article refers to the SAEJ2380 standard. The vibration test conditions in the vertical, longitudinal and lateral directions are shown in the Table3.

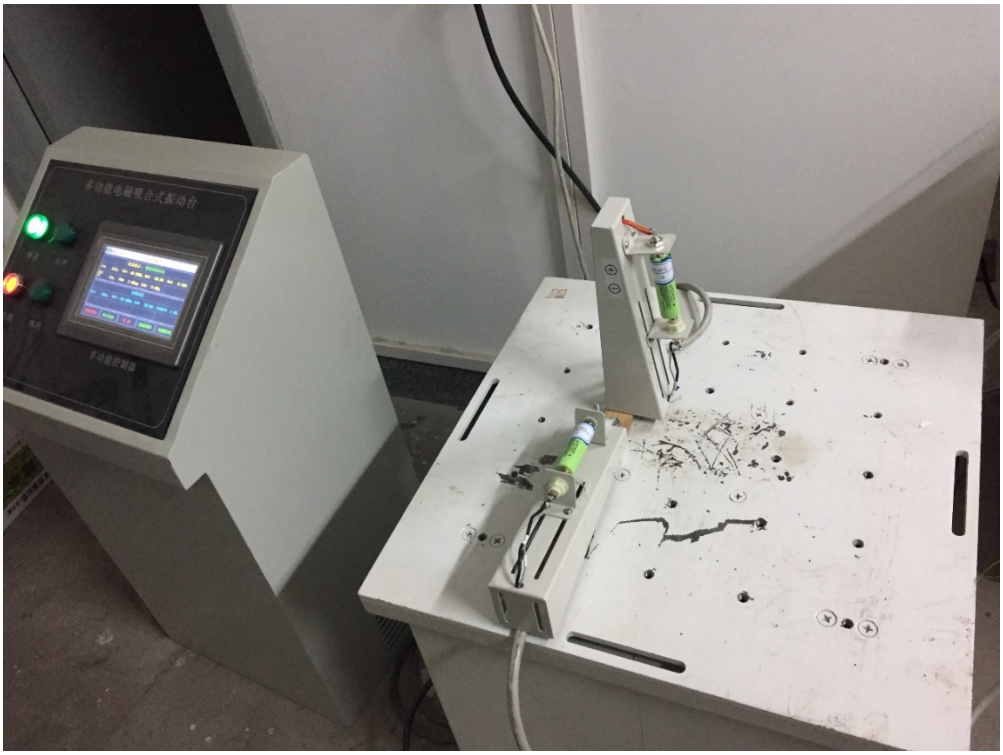

Figure S3. The vibration test bench.

Table S3. The test schedule of vibration.

Test Conditions Vibration Spectrum	Test Conditions SOC (%)	Alternative Test Acceleration (G rms)	Alternative Test Time (h)	Alternative Test Cumulative Time (h)
Vertical Axis	100	1.9	0.15	0.15
	100	0.95	3.5	3.65
Longitudinal Axis	100	1.5	0.09	3.74
	100	0.75	6.7	10.44
Lateral Axis	100	1.5	0.09	10.53
	100	0.75	6.7	17.23