

## Investigation on the Impact of Coating Thickness Setting and Calendering on the NMC 811 Cathode Performances for Lithium-Ion Batteries

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### ABSTRACT

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The need for energy in various activities around the world is increasing. Batteries come as an important energy solution, among others, for various applications, such as electric vehicles, mass storage for utilities, gadgets, etc. Lithium-ion batteries that are able to produce superior performance are needed. The battery cathode is an important key to the performance of lithium-ion batteries. The battery cathode fabrication factor is one that affects the quality of the battery produced. The thickness of the coating material will determine the amount of active material contained in the cathode, while the calendering process is needed to compress the material in the cathode so that the lithium-ion transfer process in the battery can run more effectively. Based on the research results, the thicker the coating material on the cathode, the greater the capacity value produced. With a coating thickness of 300  $\mu\text{m}$ , the resulting capacity reaches 180 mAh/gr. However, in the life cycle and rate capability tests, the performance stability is not better than the thickness of 100  $\mu\text{m}$  and 200  $\mu\text{m}$ . As for the calendering level, the battery with an optimum decrease in dry thickness is able to have the best performance in terms of capacity, life cycle, and rate capability.

## 1. INTRODUCTION

Lithium-ion batteries are one type of rechargeable battery or secondary battery that can be recharged [1]. Nowadays, lithium batteries are widely applied such as in laptops, smartphones [2], and electric vehicles such as electric bicycles [3] and electric cars [4]. The advantages of Li-ion batteries are lightweight, excellent energy storage stability [5], high charge storage capacity [6], higher operating voltage, good cycle endurance, high energy density [7], long cycle life, high energy capacity, and low impact on the environment [8],[9].

Lithium-Ion Battery (LIB) is composed of four main parts, which are the negative electrode (anode), positive electrode (cathode), electrolyte, and separator [10]. The cathode in a lithium-ion battery is an important component because it affects the charging and discharging process when there is an exchange of  $\text{Li}^+$  ions which will determine battery performance [11]. Lithium Nickel Manganese Cobalt Oxide ( $\text{LiNi}_x\text{Mn}_y\text{Co}_z\text{O}_2$  or NMC) is one of the most commonly used cathode materials in lithium-ion batteries [12]. The combination of nickel-manganese-cobalt elements can make the battery have high performance, such as high capacity, high heat and current stability, and long cycle life [13].  $\text{LiNi}_{0.8}\text{Mn}_{0.1}\text{Co}_{0.1}\text{O}_2$  (NMC 811) cathode is an NMC cathode composition that can produce high capacity, making it suitable for application in equipment that requires high energy such as electric vehicles [14],[15]. When applied as battery electrodes, NMC cathodes are given additional conductive materials to improve their electrical conductivity so that the batteries have superior performance and are suitable for equipment that requires high current capability [16]. Acetylene Black (AB) is

an additional conductive material that has long been used because of its low price and superior characteristics [14],[17]. Graphene is a carbon-based material that offers advantages in terms of surface area to increase the contact area between the cathode material and the electrolyte which is expected to help the performance of the cathode active material [18],[19], [20]. The addition of a combination of these two conductive materials in the NMC 811 cathode is expected to further enhance the ability of the NMC811 cathode to be applied to various equipment that requires lithium-ion batteries with superior performance [21].

The performance characteristics required by batteries to meet various equipment needs include high capacity, long cycle life, and resistance to high currents or good rate capability [22]. Battery fabrication factors are one of the important factors that determine battery performance [23], [24]. In electrode design, electrode thickness which determines the active material content or mass loading, electrode porosity, and chemical composition are important parameters that affect the energy and power capabilities of the cell. Electrode energy density can be affected by electrode thickness, electrode porosity, and the content of inactive materials such as binders and conductive additives [25]. Calendering is a compacting process of the Li-ion electrodes to reduce their porosity which improves the particle contact and consequently may contribute to the enhancement of the battery energy density [26]. Optimal porosity values are necessary because too low porosity values can also reduce battery cell performance [27]. In batteries, the electrode compaction process is considered very important because

volumetric energy density can be an important characteristic in energy storage systems [28]. The energy density in lithium ion batteries can be increased by minimizing the space required per electrode mass [29]. Calendering is a simple process to determine the physical properties of electrodes in order to increase the bond strength between the electrodes and the current collector [30]. Calendering of battery electrodes can increase capacity retention, reduce contact resistance, and improve cycling performance significantly [31],[32]. Therefore, optimization in battery fabrication including electrode coating thickness and calendering process are important factors in battery performance.

The effect of lithium ion battery cathode thickness and calendaring process has been tested in several previous studies, including the lithium ion battery cathode type  $\text{LiFePO}_4$  (LFP) [23],[33],[31],  $\text{LiNi}_{0.33}\text{Mn}_{0.33}\text{Co}_{0.33}\text{O}_2$  (NMC 111) [33],[34], and  $\text{LiNi}_{0.6}\text{Mn}_{0.2}\text{Co}_{0.2}\text{O}_2$  (NMC 622) [25]. The importance of the calendaring process on battery cathodes has also been studied, where battery cathodes that go through the calendaring process have better performance than cathodes that are not calendared [31]. The appropriate cathode thickness and calendaring process on the cathode of LFP-type lithium-ion batteries have been shown to improve battery characteristics. Batteries with thinner cathodes due to the calendaring process to achieve a 37.5% reduction in thickness showed a trend towards improved performance [23]. Research on the effect of thickness and calendaring for NMC materials with high nickel content such as NMC 811 has not been done much, even though its ability to store high energy is very much needed in various equipment. When the ability of NMC811 is compared with NMC111 by theoretical mechanical methods, it shows that NMC811 material is physically weaker, so it needs further research for its electrode ability [35]. Preparation of NMC811 cathode with SWCNTs and gum binder showed that the cathode with thickness up to 101 mg/cm<sup>2</sup> produced a high specific capacity of 203.4 mAh/g [36]. NMC811 produced by the water-based process with poly acrylic acid (PAA) binder with calendaring level up to 30% showed improved performance [37]. For NMC811 cathode was added with CB conductive material with 30% calendaring, which resulted in a 7.87% decrease in capacity up to 2C current [38]. This shows the calendaring process on the NMC811 cathode is very necessary to meet the required conductivity, but too strong a level of calendaring can also cause electrode damage so that further investigation is needed for the right level on the NMC811 cathode [39]. This study tested the NMC 811 type lithium-ion battery cathode with conductive AB and graphene additives in various coating thickness variations and calendaring variations up to a 60% thickness reduction to determine the optimum point of pressing the NMC cathode in the fabrication process that can produce the best performance for lithium-ion batteries. Performance testing carried out includes testing capacity, life cycle, and rate capability up to 3C current to support the needs of lithium-ion batteries that require batteries with high charging and discharging current capabilities.

## 2. METHODS

Testing of the initial cathode material was carried out to determine the quality of the raw materials used. Morphological testing with a Scanning Electron Microscope (SEM) with JEOL JSM-6510 LA (Japan) was carried out on the cathode

material and cathode coating results. The first step was to prepare the cathode by mixing NMC 811 powder, conductive materials (graphene and acetylene black), and PVDF with a mass ratio of 87:8:5 using NMP solvent at 1000 rpm for 4 hours. Then the slurry was coated on aluminum foil with coating thickness variations of 100, 200, and 300  $\mu\text{m}$ . The cathode sheet was then dried overnight at 90°C.

The second stage is to evaluate the effect of the calendaring process on the cathode. The calendaring process was carried out on one of the cathode coating thickness variations (200  $\mu\text{m}$ ) which was then compacted until it decreased in thickness by 30%, 45%, and 60%. Then the cathodes were fabricated into 18650 cylindrical cells with each cell composed of a cathode measuring 12 cm x 5.6 cm and graphite as the anode. The assembled battery cells were then filled with 1 M LiPF<sub>6</sub> electrolyte in a volume ratio of EC: EMC = 3:7 for further electrochemical testing. Performance evaluation was conducted for cathode thickness variation and calendaring process variation using NEWARE Battery Analyzer and BTS program. The tests carried out are determining the capacity of battery cells by testing with a current of 0.1C for charging-discharging to determine the capacity produced, life cycle testing to determine the durability of the battery if used for a long time, and rate ability testing to determine the ability of battery performance at various high charging and discharging currents.

## 3. RESULTS AND DISCUSSION

Initial testing was done by looking at the morphology of the battery cathode used. Figure 1(a) shows the NMC 811 particles used in this study. The particles are uniformly sized around 10-20  $\mu\text{m}$  with good and regular morphology and do not contain many impurities, so it can be said that these particles are in good condition to be used as raw materials [40]. Figure 1(b) is the result of the NMC cathode coating on the current collector. The binder and conductive material around the NMC particles are clearly visible enveloping the NMC active particles that bind to each other which still have a large enough distance. The cavity around NMC particles can be further reduced by the process of compaction of electrodes through the calendaring stage [28]. The denser particles are expected to facilitate ion transfer in the charging and discharging process which can improve the performance of lithium ion batteries [41].

Battery fabrication factors are one of the important factors that determine battery performance. Specific energy and specific power per weight and per volume are the major challenges among many requirements for lithium ion batteries for electric vehicle use. In electrode design, electrode thickness (mass loading), electrode porosity, and chemical composition are important parameters that affect the energy and power capabilities of the cell [24]. Electrode energy density can be affected by electrode thickness, electrode porosity, and inactive material content (polymer binder and conductive carbon) [42]. Therefore, optimization in battery fabrication including electrode coating thickness and calendaring process are important factors in battery performance.

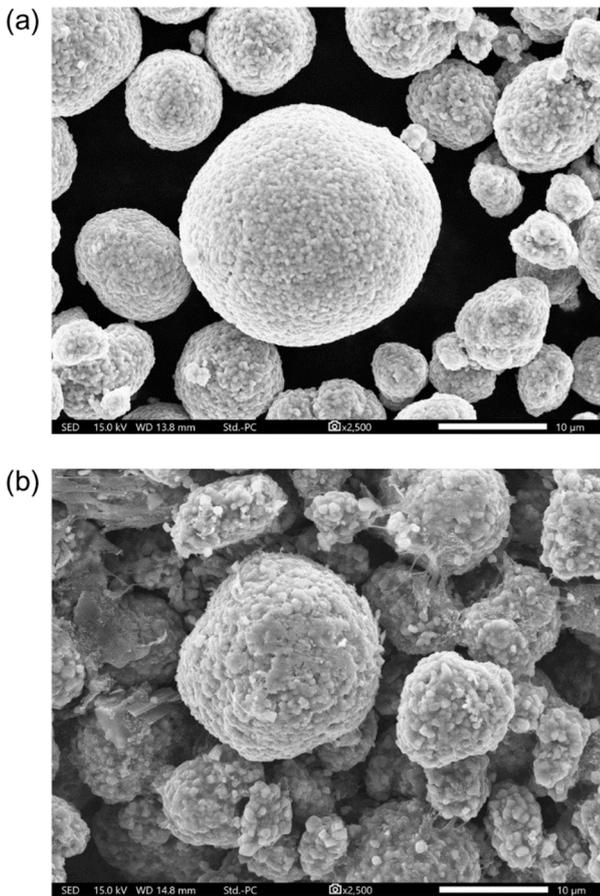


Figure 1. SEM test results (a) NMC 811 material and (b) cathode coating products

### 3.1 Effect of cathode material coating thickness

The coating thickness variation is carried out to determine a good fabrication technique, in terms of the best cathode material coating thickness for NMC 811 batteries that can produce the most optimum performance. In this study, coating thickness variation was carried out on the cathode with variations in thickness settings of 100 µm, 200 µm, and 300 µm in the coating process. This thickness setting is the thickness adjustment when coating the cathode material on one side of the Al foil sheet, which is then done in the same way for the reverse side.

The thickness of the coating on the cathode affects the resulting battery capacity. More active material will be contained if the coating material is thicker. The amount of active material contained in the cathode sheet affects the number of ions that can move to the anode, thereby affecting its capacity. The resulting cathode dimensions are shown in Table 1. Based on these data, the thicker the coating material, the greater the active material content per cm<sup>2</sup>. This can result in a larger capacity battery with the same cathode length and thickness.

Table 1. Cathode dimensions based on thickness variations

Coating adjustment	Thickness (µm)		Mass (gr)		Mass loading (gr/cm <sup>2</sup> )
	Dry cathode	Calendered cathode	Cathode sheet	Active material	
100	130	70	1.50	1.042	0.0155
200	180	99	1.88	1.373	0.0204
300	210	117	2.58	1.982	0.0295

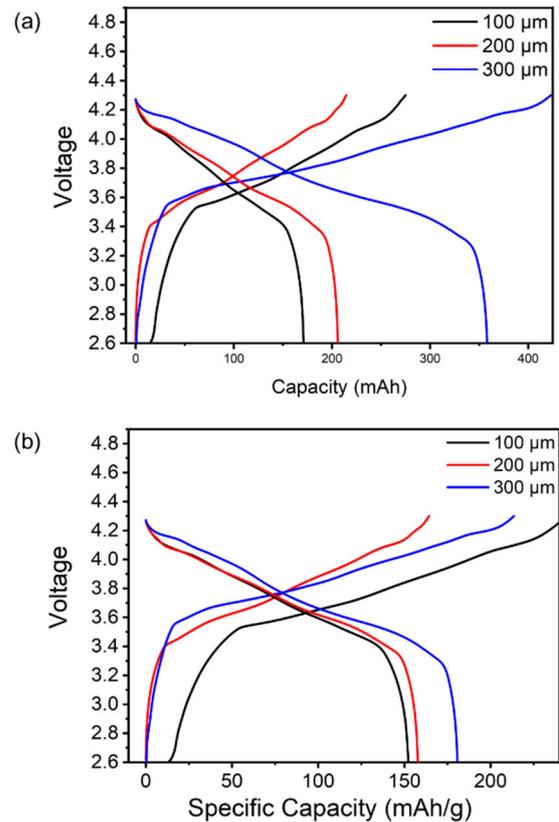
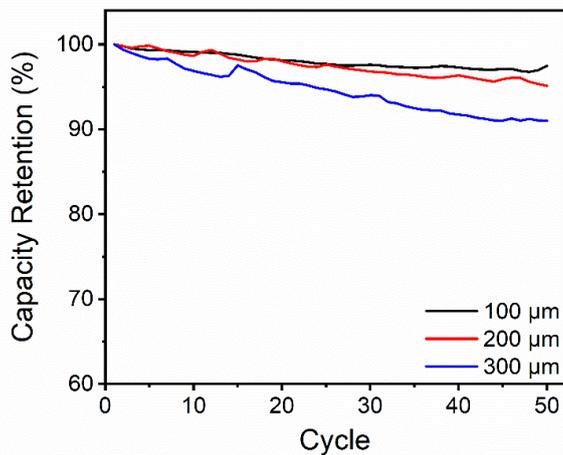


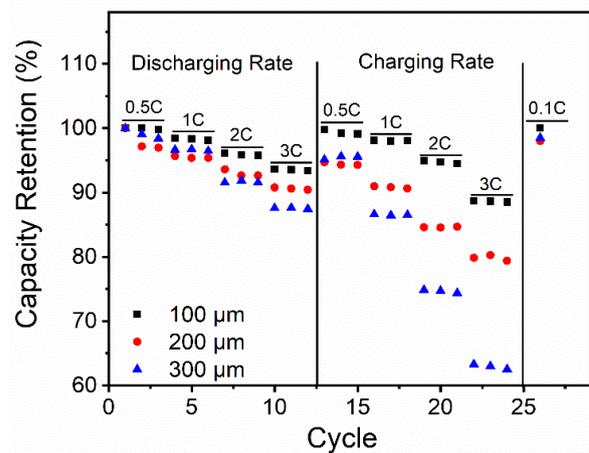
Figure 2. Test results of (a) Capacity (mAh) and (b) Specific capacity (mAh/g) with cathode coating thickness variations

The thickness variation used is the setting thickness variation when coating the cathode, 100 µm, 200 µm, and 300 µm thickness. After drying, the cathode thickness decreased by 47% for 100 µm thickness, 59% for 200 µm thickness, and 67% for 300 µm thickness. This decrease in thickness is predicted to be due to NMP evaporating from the cathode layer. The thickness drop increases in direct proportion to the setting thickness during coating. After drying, a calendering or pressing process is carried out to increase the density of the cathode. The level of pressing performed in this thickness variation step is the same, which is 45% of the initial dry thickness.

Figure 2(a) shows that the battery capacity has increased with increasing coating thickness. With the same dimensions, a thickness of 300 µm has the greatest capacity for both charge and discharge processes. The cathode which is coated on a thickness of 300 µm has a discharge capacity of 358.16 mAh which is higher than the thickness of 200 µm with a capacity of 206 mAh and 100 µm with a capacity of 171 mAh. Whereas in the specific capacity test shown in Figure 2(b). The specific capacity values of the 3 thickness levels show almost uniform values, with specific capacities of 180.75 mAh/gr for 300 µm thickness, 158 mAh/gr for 200 µm thickness, and 152.25 mAh/gr for 100 µm thickness. This is because the specific capacity test is obtained from the capacity value per active material contained in the cathode. As the thickness of the cathode increases, the amount of active material will increase, so that the lithium ions and electrons contained therein will produce a greater electrochemical reaction and produce greater electrical energy [43].



**Figure 3.** Cycling ability test results with cathode coating thickness variations



**Figure 4.** Rate ability test results with cathode coating thickness variations

Life cycle tests were conducted on NMC 811 batteries to determine the durability of the battery in long cycle usage. The tests were carried out by testing batteries with thickness variations of 100  $\mu\text{m}$ , 200  $\mu\text{m}$ , and 300  $\mu\text{m}$  for 50 cycles with a discharging current of 1C. Figure 3 shows the graph of life cycle test results on the battery based on specific capacity and retention capacity. The percentage decrease in capacity during the life cycle test for 50 cycles at a thickness of 100  $\mu\text{m}$  is 2.54%, a thickness of 200  $\mu\text{m}$  is 4.88%, and a thickness of 300  $\mu\text{m}$  is 8.99%. Therefore, after 50 cycles the battery still has a capacity of 97.46% at 100  $\mu\text{m}$  thickness, 95.12% at 200  $\mu\text{m}$  thickness, and 91.01% at 300  $\mu\text{m}$  thickness.

Based on the test results, the cathode with a thickness of 100  $\mu\text{m}$  has the lowest percentage decrease where the greater the coating thickness, the greater the percentage decrease in lifetime. Therefore, the greater the thickness of the coating on the cathode, the smaller the battery resistance to long-cycle usage. This can be caused by the greater error value that causes the battery to not last long and drop faster. The thick coating layer causes the lithium and electron transfer distance to be longer and decreases the conductivity value. So that the energy and power density produced will be smaller [44].

The rate ability or rate capacity test aims to determine the battery's resistance to charging and discharging against small and large currents. Rate capacity testing is done by varying the discharge current while the charge current is constant, then by varying the charge current while the discharge current is constant where the current variation used is 0.5C, 1C, 2C, and 3C for every three cycles and the constant current is 0.5C.

Based on the graph in Figure 4, there is a decrease in capacity both in the discharge current variation and the charge current variation. In the discharging rate test, there was a decrease in the specific capacity of the 100  $\mu\text{m}$  thickness cathode by 6.48% for the discharging current up to 3C. While the cathode of 200  $\mu\text{m}$  thickness and 300  $\mu\text{m}$  thickness experienced a decrease in specific capacity of 9.39% and 12.46% for discharging current up to 3C.

In the charging rate test, there was a decrease in the specific capacity of the 100  $\mu\text{m}$  thickness cathode by 11.38% for the charging current up to 3C. While the 200  $\mu\text{m}$  thickness and 300  $\mu\text{m}$  thickness cathodes experienced a decrease in specific capacity of 20.17% and 37.06% for charging current up to 3C.

Based on the results of the percentage of capacity reduction, it can be seen that the thickness of 300  $\mu\text{m}$  has the largest percentage of battery capacity reduction in both discharging and charging variations. Therefore, the greater the thickness of the coating, the greater the decrease in capacity. The existence of a large decrease in capacity from 0.5C to 3C can indicate that the battery does not have good resistance to large charging and discharging currents. However, at a thickness of 100  $\mu\text{m}$  and 200  $\mu\text{m}$ , the decrease in capacity is not too significant and can still maintain capacity stability in contrast to the thickness of 300  $\mu\text{m}$  which experienced a significant decrease. This is due to the internal resistance of the battery caused by high current variations. At a thickness of 100  $\mu\text{m}$ , the distance between ions is getting less so as to facilitate the interaction and intercalation process in the battery so as to produce better electrical conductance. The diffusion distance of lithium ions is also getting smaller so that it can reduce the internal resistance of the battery. Batteries with low internal resistance exhibit better rate capability under higher discharge currents. The capacity decreases as the internal resistance of the battery increases. In addition, batteries with lower internal resistance show higher capacity when discharged at the same discharge rate as batteries with higher internal resistance levels [23]. As the electrode thickness and current increase, ohmic limitation will become the limiting factor that dominates cell discharge. In addition, increasing electrode thickness leads to reduced active material usage and non-uniform usage across the positive electrode because during the discharging process, lithium intercalation at the surface concentration is always higher than the center concentration [45]. A cathode surface with a thick enough layer to facilitate improved performance would be essential to be ionically and electrically conductive but may increase the internal cell resistance thus adversely affecting normal battery operation. At high voltage operation, a significant drop in capacity is caused by NMC cathode polarization [46].

Electrode thickness has a significant impact on electrode energy density because the use of thicker electrodes can reduce the fraction of inactive materials such as current collectors and separators [33]. Thick cathode coatings are able to produce large capacities, but their performance stability at high currents is poor, and the battery life is shorter. On the other hand, with a thin cathode coating, the capacity is small, but the performance stability at high currents is very good, and the

battery life is longer. Considering the result of this research, the coating thickness of 200  $\mu\text{m}$  is the most ideal with the anode's type and dimension used in this research because it can produce a fairly high capacity and fairly good performance stability. It may result differently if using another type and dimension of the anode, considering the N/P ratio and theoretical capacity of the anode used [47].

### 3.2 Effect of Calendering Thickness of Cathode Material

Calendering or pressing is a compaction process that can reduce electrode porosity [26]. In batteries, the electrode compaction process is considered very important because volumetric energy density can be an important characteristic in energy storage systems. The energy density in lithium ion batteries can be increased by minimizing the space required per electrode mass [29]. Calendering is a simple process to determine the physical properties of the electrodes in order to increase the bond strength between the electrodes and the current collector [30]. Calendering on battery electrodes can increase capacity retention, reduce contact resistance, and improve cycling performance significantly [31]. In this study, there are three variations of calendering on lithium-ion battery cathodes with variations to be tested, batteries with a decrease in thickness after calendering by 30%, 45%, and 60%. The cathode used is a cathode with dimensions of 12 cm x 5.6 cm with a thickness setting of 200  $\mu\text{m}$  and a dry electrode thickness of 180  $\mu\text{m}$ .

The battery capacity test was conducted with an initial formation where the initial current given was 0.1C. The battery capacity test results are shown in Figure 5(a). With the same dimensions, the battery with a calendering level of 60% has the largest capacity in both the charge and discharge processes, with a discharge capacity of 258.34 mAh. The battery with a calendering level at the cathode of 30% has a discharge capacity of 182.77 mAh which is smaller than the battery with a calendering level at the cathode of 45% with a capacity of 206 mAh. The specific capacity test results are shown in Figure 5(b). The specific capacity values of the 3 calendering levels show almost uniform values, with specific capacities of 124.5 mAh/gr for 30% calendering level, 158 mAh/gr for 45% calendering level, and 174.9 mAh/gr for 60% calendering level. The graph shows that both the capacity (mAh) and the specific capacity (mAh/g) increase as the calendering percentage increases.

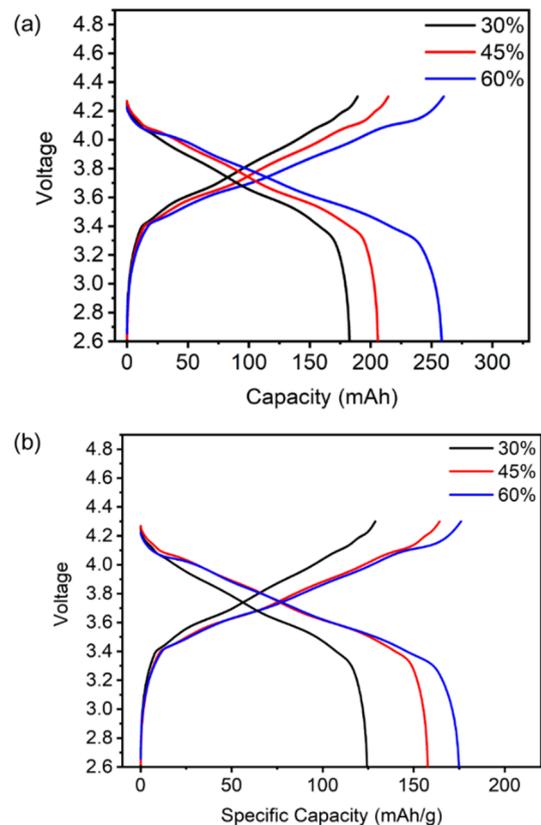
**Table 2.** Cathode dimensions based on calendering variations

Calendering adjustment	Calendered cathode thickness ( $\mu\text{m}$ )	Cathode mass (gr)	Active material mass (gr)	Mass loading ( $\text{gr}/\text{cm}^2$ )
30%	126	1.99	1.468	0.0218
45%	99	1.88	1.373	0.0204
60%	72	2.00	1.477	0.0220

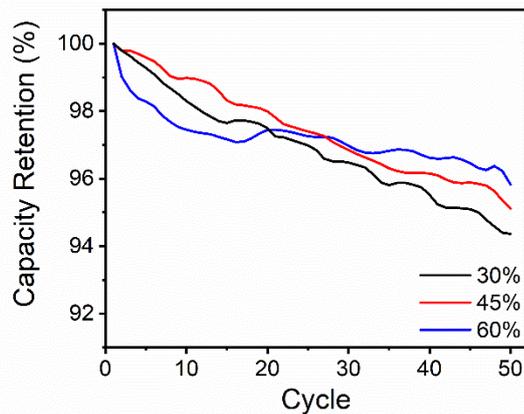
In the cathode calendering process, there is a reduction in cathode porosity and electrode resistivity, which results in a decrease in the overall cathode thickness [26]. Applying pressure to the cathode causes a decrease in porosity which results in increased compactness so that the contact between particles increases resulting in increased electronic conductivity [48]. During discharge, the electrical conductivity of the battery is low because ions flow from the anode to the cathode through the electrolyte while electrons are forced to flow from the anode to the cathode through the

load [49]. Electron transport in lithium-ion batteries is an important factor in determining whether or not the performance of a battery is good [31]. One of the influences on electron transfer in batteries is the thickness of the active material layer. Thicker electrode layers tend to have low conductivity values because the transfer of ions in them becomes more difficult. In lithium-ion batteries, the thicker the layer, the conductivity and energy density will decrease because the diffusion distance of electrons and  $\text{Li}^+$  ions is getting bigger [44]. The transfer of electrons and ions will affect the charge and discharge conditions of the battery.

The battery cycling ability test is carried out to determine the estimated length of battery usage time and see the amount of battery capacity drop during its use cycle. The life cycle test for the battery samples in this study was carried out in as many as 50 cycles with a discharging current of 1C. The data obtained is shown by the graph in Figure 6 below. The capacity retention rate is the ratio of the actual battery capacity to the initial battery capacity. This parameter is important to know how the performance by looking at the decrease in battery capacity [50]. Batteries with 30%, 45%, and 60% calendering each experienced a decrease in the percentage of capacity retention during the life cycle test. However, the results obtained show that each battery sample has a high-capacity retention after the 50-cycle test. This is consistent with the statement that calendering of battery electrodes can increase capacity retention, reduce contact resistance, and also significantly improve cycling performance [31].



**Figure 5.** Test results of (a) Capacity (mAh) and (b) Specific capacity (mAh/g) with cathode calendering variations

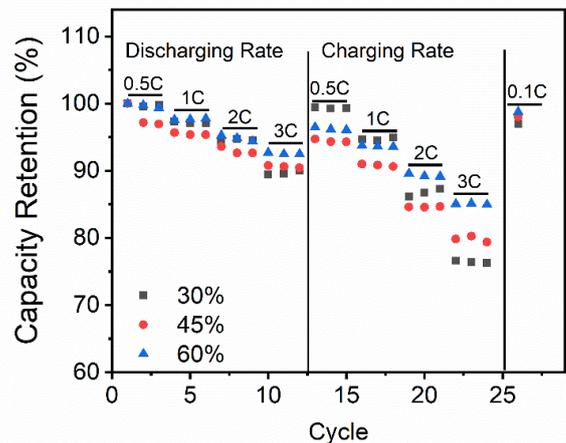


**Figure 6.** Cycling ability test results with cathode calendaring variations

At the 50th cycle, the battery with 60% calendaring percentage showed higher capacity retention compared to the battery with 45% calendaring percentage. Similarly, the battery with 45% calendaring percentage showed higher capacity retention than the battery with 30% calendaring percentage. The higher the capacity retention, it means that the battery has better stability and durability. In other words, the battery lifetime becomes longer or more durable. Lithium battery cathodes subjected to calendaring have better electrochemical performance, stability, and cycling performance [13]. In the test from cycle 1 to 50, each battery has a low-capacity drop, which is 5.63% for 30% calendared batteries, then 4.88% for 45% calendared batteries, and 4.18% for 60% calendared batteries. This means that batteries with cathodes with a larger percentage of calendaring have a smaller drop. The smaller the battery drop, the better the durability of the battery.

Rate tests on batteries are carried out to find out how the battery performs during charge - discharge (CC - DC) with high currents and to see the durability of the battery. Previous research states that electrodes with higher density show better rate capability than electrodes that are not calendared. Calendaring is important for higher charge and discharge [31]. For this study, a rate test was carried out with a CC - DC rate current of 0.5C to 3C and vice versa and then given a CC - DC current of 0.1C to see the ability of the battery to reach its initial capacity. The data obtained can be seen from the graph in Figure 7 below.

For batteries with 30% calendaring at the time of rate discharging with 3C current, the specific capacity decreased by 10.35% and at the time of rate charging with 3C current, the capacity decreased by 23.60%. For batteries with 45% calendaring at the time of rate discharging with 3C currents experiencing a decrease in specific capacity of 9.39% and at the time of rate charging with 3C currents experiencing a decrease in capacity of 20.17%. For batteries with 60% calendaring at the time of rate discharging with 3C currents experiencing a decrease in specific capacity of 7.46% and at the time of rate charging with 3C currents experiencing a decrease in capacity of 14.95%. After testing up to 3C current, the battery is returned to testing at 0.1C current as in the initial capacity test. Based on the test results, the battery with 60% calendaring level was able to maintain its capacity according to its first discharge capacity better than the battery with a calendaring level 30% and 45%.



**Figure 7.** Rate ability test results with cathode calendaring variations

This shows that batteries with a higher percentage of cathode calendaring have a lower drop. This means that the more the cathode is pressurized (calendaring), the less the drop so that the better the durability and stability of the battery. In addition, battery performance during charge-discharge for batteries with a higher percentage of calendaring is also better. This is due to the calendaring treatment on the battery electrodes which increases capacity retention, reduces contact resistance, and also improves cycling performance significantly [14].

The calendaring process in lithium-ion battery fabrication is proven to have a significant impact on battery performance. Based on the test results, the calendaring process up to 60% thickness reduction is proven to produce the highest capacity, the best cycle life, and better resistance to high currents when compared to the calendaring process of 30% and 45%. Compaction of cathode material is proven to be able to increase the effectiveness of ion and electron transfer in li-ion batteries during the charging and discharging process. The calendaring process on cathode materials with high nickel content is feared to cause the cathode particles to be destroyed [51]. However, in this study, it is proven that the calendaring process on NMC 811 cathode up to a decrease in thickness level of up to 60% still gives the best performance in the battery. Further research still needs to be done to determine the effect of calendaring with a decrease in thickness above 60% to determine the maximum ability of NMC 811-based cathodes with additional conductive materials AB and graphene when given high pressure. Further investigation related to changes in electrode characteristics after being given high pressure also still needs to be done for further research.

#### 4. CONCLUSIONS

In order to fulfill the energy needs in the world, lithium-ion batteries that are able to generate the best performance are increasingly needed. The performance of a lithium-ion battery is largely determined by the cathode component in the battery. The cathode fabrication process is proven to greatly affect the performance of the resulting battery. In this study, the cathode that has the highest thickness, which is 300  $\mu\text{m}$ , produces a capacity of 358.16 mAh (180.75 mAh/gr) higher than batteries with cathode thicknesses of 100  $\mu\text{m}$  and 200  $\mu\text{m}$ . However, in the life cycle test, the battery with a thickness of 300  $\mu\text{m}$  experienced a capacity decrease of 8.99% over 50 cycles,

much higher than the battery with a thickness of 100  $\mu\text{m}$  which experienced a decrease of 2.54% and a thickness of 200  $\mu\text{m}$  of 4.88%. The rate capability test also shows that the greater the cathode thickness, the greater the decrease in capacity experienced. The thinner the cathode, the less distance between ions so as to facilitate the interaction and intercalation process in the battery so as to produce better electrical conductance and the resulting battery will provide better performance. In the variation of calendering rate, the battery with 60% thickness reduction rate produced the highest capacity of 258 mAh (174.9 mAh/gr), higher than the battery with cathode with 30% and 45% thickness reduction rate. In the life cycle test, the battery with the 60% thickness reduction rate decreased in capacity by 4.18% over 50 cycles, the lowest compared to the battery with the 30% thickness reduction rate and the 45% thickness reduction rate. The rate capability test also showed that the cathode calendaring level of 60% produced the best performance compared to the calendering levels of 30% and 45%. Compaction of cathode material is proven to be able to increase the effectiveness of ion and electron transfer in li-ion batteries during the charging and discharging process. Further research still needs to be done to determine the effect of calendering with a decrease in thickness above 60% to determine the maximum ability of NMC 811-based cathodes with additional conductive materials AB and graphene when given high pressure. Further investigation related to changes in electrode characteristics after being given high pressure also still needs to be done next.

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