A New Perspective on the Advanced Microblade Cutting Method for Reliable Adhesion Measurement of Composite Electrodes

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1. Binder distribution analysis of the composite electrode

Fig. S1. A) LIBS measurement points on the composite electrode sample, B) fluorine element ratios according to the depth of the composite electrode measured by LIBS, and C) the sample photo after measurement; D) the magnified surface in the dotted area of C.

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2. Physical analysis of pristine and peeled composite electrodes

To confirm the reliability of the SAICAS measurements, the actual depth of cut was evaluated using a confocal optical microscope (HYBRID Color Laser Confocal Microscope, Laser Tec) and scanning electron microscopy (SEM, FE-SEM, SU8020, Hitachi, Japan). The depth as well as the surface and side uniformity were analyzed (Figure S2).

Checking whether a sample is neatly cut is important for accurate peel strength measurement because several particles may separate from the bottom and the side, which affects the measurement results after pretreatment (side-cutting of the sample) and precutting (cutting a top-layer). Therefore, the surface was analyzed after the peel strength measurement at a cutting depth of 80 µm. First, the real cut depth was analyzed using a confocal optical microscope (Figure S2A). At the bottom of the sample, the real cut depth was uniformly 80 µm; this almost equal to the set cut depth, implying that the bottom of the sample was tidily cut. On the other hand, on the side of the sample, the peeling of some particles was observed near the surface. For an in-depth analysis, a scanning electron microscope was used (Figure S2B). The length of the most damaged part was approximately 30 µm on the side of the sample. Thus, the effect of the damaged part is negligible because the blade width of 1 mm is much larger. Cut particles were observed at the bottom of the sample. These results demonstrate that the stress was concentrated at the bottom of the blade for cutting the bottom of the sample, and relatively widely distributed on the blade, as shown in Figure 2.

Fig. S2. Analysis of the real cut depth and the surface condition after measurement at a cutting depth 80 µm using A) confocal optical microscope and B) scanning electron microscope.
3. Process and principle of adhesion measurement using SAICAS

The measurement process and conditions are shown in Scheme 1. First, the composite electrode was cut vertically at a speed of 0.5 \( \mu \text{m s}^{-1} \) and horizontally at a speed of 1 \( \mu \text{m s}^{-1} \) until the target depth was reached (regions i and ii in Scheme 1a). As shown in Scheme 1b, the diamond microblade has a width of 1 mm, a front angle of 20\(^\circ\), and a bottom angle of 10\(^\circ\). Then, the peel strength was measured by cutting a sample horizontally at a speed of 2 \( \mu \text{m s}^{-1} \) (regions ii and iii in Scheme 1a). The total measurement period was set to 350 s. The average values between 250 s and 350 s were obtained after the start of the measurement. The measurements were repeated at depths of 20 \( \mu \text{m} \), 40 \( \mu \text{m} \), 60 \( \mu \text{m} \), and 80 \( \mu \text{m} \). Scheme 1b–d show the schematics of snapshots at measurement moments of i, ii and iii in Scheme 1a.

When the blade cuts the sample with a force \( R \), it encounters a repellent force \( R' \), which is divided into the friction \( F_{fr} \) and the normal force \( F_n \) at the blade surface (Figure S3). The force \( R \) can be divided into the horizontal force \( F_h \) and vertical force \( F_v \), which act in parallel and perpendicular to the cutting direction, respectively. Because the blade does not move in the vertical direction during the peeling mode, only the horizontal force \( F_h \) supplies the energy required for horizontal cutting. Thus, the horizontal force can be regarded as the cutting force, which includes the intrinsic peel force, the horizontal friction \( F_{frh} \), and additional forces for sample deformation (Fig. S3). The friction \( F_{fr} \) is not a negligible value, but the horizontal friction \( F_{frh} \) has little effect on the horizontal force \( F_h \) because the blade slope is 20\(^\circ\) and the surface of blade is smooth. Deformation rarely occurs in brittle samples, such as composite electrodes of LIBs. Thus, in general, the horizontal force \( F_h \) is translated into the peel force of the sample. The corresponding peel strength (\( \text{kN m}^{-1} \) or \( \text{N mm}^{-1} \)) can be easily obtained by dividing \( F_h \) by the blade width.

Fig. S3. Free body diagram of the blade and sample when measuring the peel strength using SAICAS, and derivation of an equation showing that horizontal force can be used as a peel force.
4. Weight of the cut parts during the peel strength measurement

The areal mass of the electrode used in this experiment was 35.69 mg cm\(^{-2}\), which can be converted into the area weight (N m\(^{-2}\)) by multiplying the areal mass by the acceleration of gravity. Assuming that the components of the composite electrode are uniformly distributed, the weight of the electrode with different thickness can be converted into force by multiplying the area weight, cutting length, width of the blade, and thickness / total thickness. The maximum weight is shown in Figure S4, assuming that the cut parts were never separated.

Fig. S4. The weight of the cut parts after the peel strength measurement.

5. Friction on the side of the blade

If the side of the sample is cut neatly, then a friction force will not be generated. However, cutting remains, such as a burr, may cause friction at the side of the blade.

Fig. S5. Peel strength generated by the friction force on the sides of the blade during the peel strength measurement.

6. Comparison between peel strengths measured by conventional and advanced method

<table>
<thead>
<tr>
<th>Depth ((\mu m))</th>
<th>Original (kN m(^{-2}))</th>
<th>Pretreated (kN m(^{-2}))</th>
<th>Difference (kN m(^{-2}))</th>
<th>Reduction Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.0681±0.0020</td>
<td>0.0643±0.0015</td>
<td>0.0038</td>
<td>5.6</td>
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<tr>
<td>40</td>
<td>0.1039±0.0030</td>
<td>0.0801±0.0034</td>
<td>0.0238</td>
<td>22.9</td>
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<tr>
<td>60</td>
<td>0.1482±0.0059</td>
<td>0.1192±0.0056</td>
<td>0.0290</td>
<td>19.6</td>
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<tr>
<td>80</td>
<td>0.2406±0.0106</td>
<td>0.1971±0.0076</td>
<td>0.0435</td>
<td>18.1</td>
</tr>
</tbody>
</table>

Table S1. Peel strengths of original and pretreated samples with cutting depth
Table S2. Peel strengths at 40 µm and 80 µm depth with different cutting thickness

<table>
<thead>
<tr>
<th>Depth (µm)</th>
<th>Cutting Thickness (µm)</th>
<th>Peel Strength (kN m⁻¹)</th>
<th>Difference (kN m⁻¹)</th>
<th>Reduction Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
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<td>0.0554±0.0018</td>
<td>0.0247</td>
<td>30.84</td>
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<tr>
<td></td>
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<td>0.0801±0.0034</td>
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<tr>
<td>80</td>
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<td></td>
<td>60</td>
<td>0.1971±0.0076</td>
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