Motion Analysis of the Pounding Technique Used for the Second Lining in the Fabrication of Traditional Japanese Hanging Scrolls

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Abstract. This study focuses on the technique used to adhere the second lining in the fabrication of traditional Japanese hanging scrolls, or *kakejiku*. We analyzed the motions of both expert and non-expert artisans during the adhesion process, using optical and infrared motion captures. We then conducted a peel test from both samples, and used the results of this test to correlate the motion of the artisan with the adhesive strength of the second lining.

Keywords: scrolls, secondary lining, pounding brush, motion analysis.

1 Introduction

Hanging scrolls are a traditional Japanese ornamental art, which can include paintings and calligraphy. Distinct from Western picture frames, scrolls have the unique ability to be unrolled and hung on a wall or in an alcove when displayed, and rolled up in a box for storage. Figure 1 shows an image of a hanging scroll on display in an alcove. This method has been recognized as a superior way to preserve paintings and calligraphy, because the works of art are better protected from light and air.

To allow each scroll to hang straight when displayed and roll smoothly for storage, four layers of paper, called “lining papers,” are adhered with starch paste to the back of the scroll. The lining papers are typically numbered with the first lining paper pasted closest to the artwork, followed by the second, third, and final lining papers. In production, each lining paper is adhered to the back of a hanging scroll in a process called "pounding," with each step named with the layer of paper being adhered. This study focuses on the pounding of second lining.

The adhesive used for each layer of lining paper is made by heating wheat starch. The paste used for the first lining paper has strong adhesive properties, and is made by cooling the paste right after heating. For the second and subsequent layers, a

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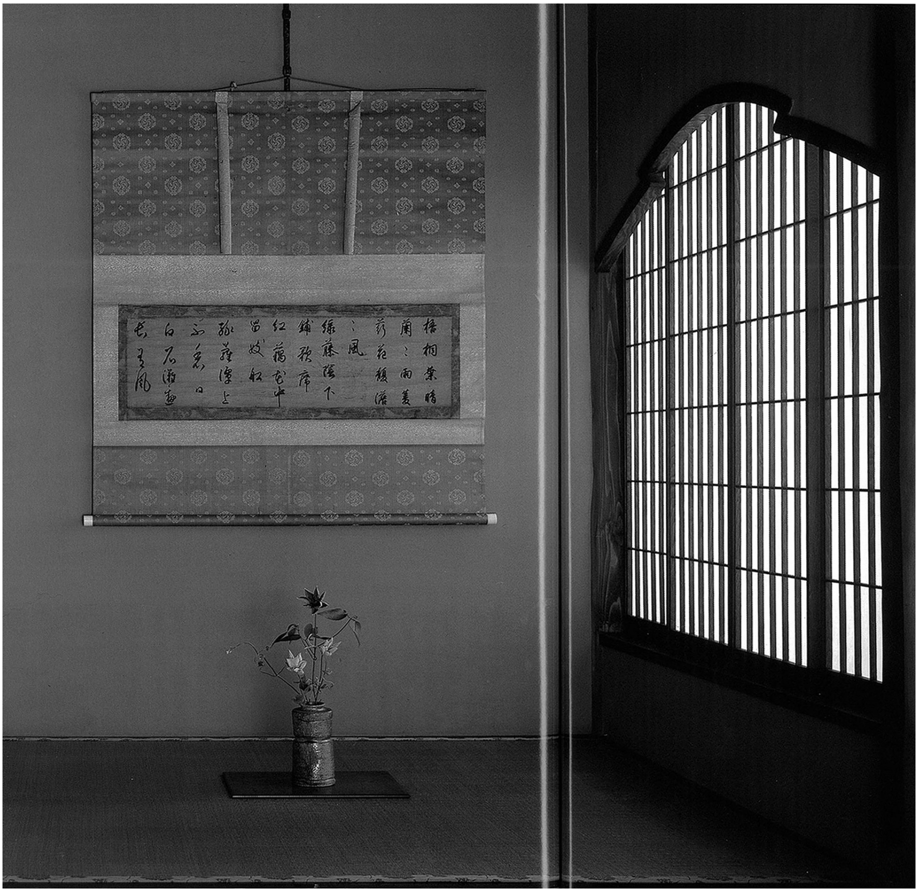

Fig. 1. Image of a hanging scroll on display in an alcove

special adhesive, known as aged paste is used. The aged paste is kept in a cool dark place, allowing the adhesive properties of the aged paste's to become weaker. Scroll makers then use a traditional technique of pounding the surface of each lining paper with a special "pounding brush" to provide better adhesion. The pounding brush has bristles made of hemp-palm fibers, and typically weighs about 460 grams. One such brush is shown in Figure 2.

After dilution, aged paste is applied to the second lining paper, which is then placed carefully on the back of the first lining paper. Care is taken to prevent any wrinkles from appearing. Once the second lining paper is in place, the surface of the paper is pounded with the bristles of the pounding brush.

During pounding, the bristles of hemp-palm make holes in the surface of the secondary lining paper, penetrating to the first lining paper layer. This process allows the mulberry paper fibers contained in the first lining paper to rise. These plant fibers tangle together with the fibers of the second lining paper, enhancing adhesion property of the aged paste. This adhesion mechanism is shown in the schematic diagram in Figure 3.

Fig. 2. Image and measurement of a pounding brush

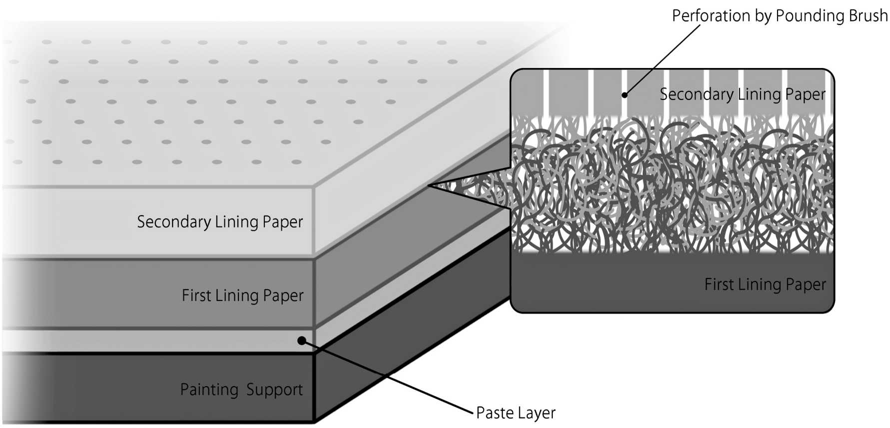

Fig. 3. Diagram of the adhesion mechanism between the first lining paper and secondary lining paper

If too much power is used during pounding, the bristles of the brush penetrate even the first lining paper and reach the art work beneath. In the worst case, it opens very small holes in the art work. However, using too little power out of caution, will not obtain the desired adhesive effect.

It is a simple operation to pound the surface of a lining paper with a brush, but to pass down the proper technique and control is a very difficult task. As with other traditional techniques, this technique has been passed down only through the observation of expert craftsmen.

Moreover, this pounding technique is considered indispensable for repairing valuable paintings or works declared to be cultural assets. A hanging scroll, which has been preserved and repaired through generations, must continue to remain a hanging scroll through many repairs. The pounding technique thus plays a pivotal role in protecting and restoring valuable cultural assets. As many Japanese and East Asian hanging scrolls are now in Europe and the United States, there has been a need to teach this technique in order to ensure that these works are preserved.

In this study, we analyzed the pounding technique of an expert and a non-expert and observed the correct traditional technique, passed down from craftsman to craftsman.

We also conducted a peel test on pounded samples of second lining paper from each craftsman and verified how proper pounding technique influences adhesiveness.

2 Method

2.1 Subjects

The subjects for this study are two craftsmen, who fabricate and repair hanging scrolls. The "expert" technician has 20 years working experience, (age 38 years, 171cm height, 72kg weight, male, right-handed), and the "non-expert" has four years working experience, (age 25 years old, 170cm height, 54kg weight, male, right-handed).

2.2 Procedure Under Analysis

In the place of a work of art, a piece of plain silk was used, on which the first lining was completed, (700mm in length x 400mm in width). We instructed the subjects to adhere the second lining paper using aged paste and complete the pounding of the second lining. If the weight or shape of a tool or the height of the workbench were diriated from normal, then comparison of the exact difference in technique would not be detected accurately. Therefore, we conducted the study in the workshop where the subjects work, using the same equipment and materials.

Each piece of secondary lining paper is about 150mm long and 700mm wide, so three pieces of paper were used to cover each sample. The subjects applied paste and placed each paper in the appropriate location, with no signs of wrinkles. They then pounded as described below with a pounding brush. The dimensions of the pounding brush used in this study are shown in Figure 2.

Both subjects started pounding from the right near side, gradually moving the brush away from their body until they reached the far side. They continued pounding evenly, progressing to the left side, and then slowly moving back to the right side. The track of the brush movement is shown in the schematic diagram in Figure 4.

To cover the entire surface shown in gray in Figure 4, the craftsmen pounded from the near right corner to the near left corner in the course indicated by the solid line ①, completing the first process. While pounding in the opposite direction, as indicated by the dotted line ②, each subject returned to the starting location. Finally, as represented by line ③, they pounded in the same direction as ①, finishing in the near left corner. Thus, they completed the pounding technique for the second lining in one and a half circuits of the paper.

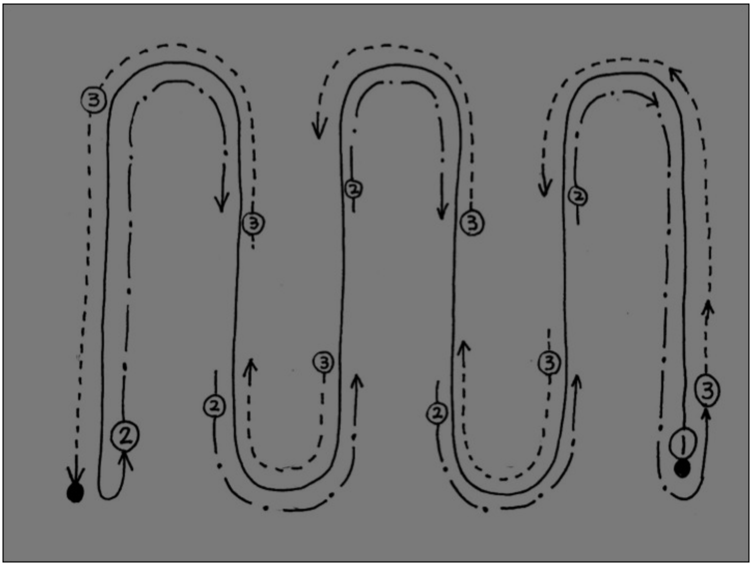

Fig. 4. Diagram of the progession of the pounding brush

2.3 Measuring Conditions for Motion Analysis

The poundings executed by the subjects were recorded by two digital cameras. One real-time optical motion capture system (MAC 3D SYSTEM, Motion Analysis Corporation) and six infrared cameras (Raptor-H, Motion Analysis Corporation) were used. For behavior analysis, infrared reflective markers were attached on both shoulders, elbows, and wrists of the subjects, and on the handle of the pounding brush. The sampling rate was set at 120Hz. The subjects applied aged paste to the second lining paper on the pasting board, placing it carefully on the samples prepared with the first lining paper. The samples were then pounded to enhance the adhesion of the paste. We measured the movements during pounding using the attached markers, as shown in Figure 5.

Fig. 5. Image for the measurement of the pounding process

2.4 Measuring Methods for Peel Test

We cut out three vertical pieces and three horizontal pieces from three parts of each sample, with each piece 20 mm wide and 200 mm long, as shown in Figure 6. 10mm at the end of each piece was then dipped in water and pinched in the chuck of an Instron universal testing machine, set to peel the second lining paper from the silk sample at a peeling speed of 300 mm/min.

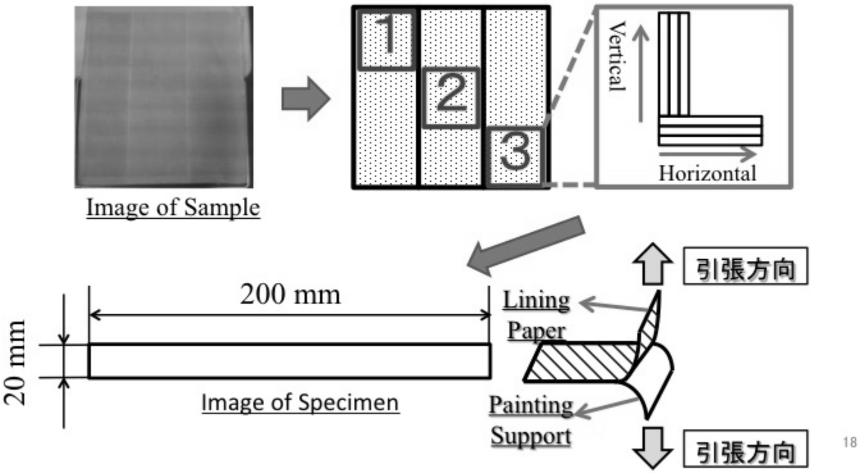

Fig. 6. Procedure of the peeling test

2.5 Results and Discussion

First, we focused on the track of the marker attached to the handle of the pounding brush. We extracted the track of the marker for one row of pounding for both craftsmen, as shown in Figure 7. While the non-expert seemed to proceed by simply moving the pounding brush up and down, the expert combined the vertical movement of the pounding brush with horizontal movement. Referring to Table 1 and Figure 7, the difference in the movement between the expert and the non-expert can be seen. The expert completed the second lining pounding more quickly and in fewer pounds. Measuring the distance between pounded spots by the movement of the markers, we verified that the expert had wider spacing. This result suggests that the expert conducted the work more efficiently than the non-expert.

We then looked at the track of the markers attached to the handle of the brush using an X-Y coordinate grid. This allows us to observe the track of the brush handle as seen from above. As in Figure 7, we extracted the track of one row of pounding, shown in Figure 8. We found that the expert was pounding while rotating the brush handle extensively, where the non-expert did not show such extensive movement.

We also extracted one row of movements done by the expert in the X-Z plane, shown in Figure 9. This corresponds to the track of the movement observed from the front during pounding. This data verifies that the expert applied a certain angle to the brush while pounding.

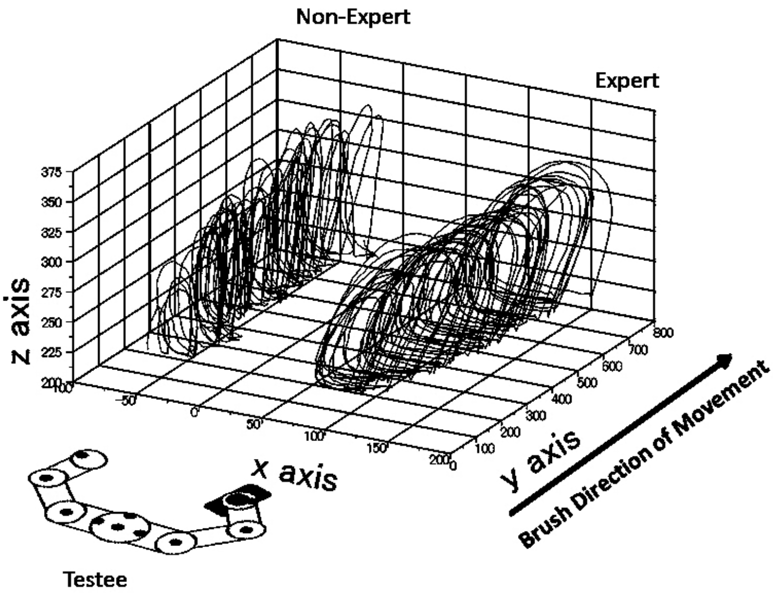

Fig. 7. Comparison of brush movement between the expert and non-expert

Table 1. Comparison of "working time", "pound number", and "interval of pound" between expert and non-expert

	Working Time (sec)	Pound Number	Interval of Pound (mm)
Expert	451	1120	25.1±9.9
Non-Expert	603	1358	18.0±9.0

The reason that the expert tilted the brush while pounding has to do with the shape of the trimmed bristles of the brush. In the manufacturing process, the bristles of the pounding brush are tied by a paper band a few centimeters from the tip of the brush and trimmed. When opening the paper band for regular work, the bristles are curved, as shown in the diagram in Figure 10. This curved shape makes it ideal to incline the brush and pound at an angle, instead of swinging the brush down perpendicular to the surface.

By using the brush at an angle, the craftsman is able to take advantage of the large surface area of the bristles, preventing the brush from hitting the paper's surface more strongly than necessary. This is one aspect of the traditional technique that is explicitly shared with non-experts. As the track in Figure 9 shows, the expert practiced this behavior to reduce the risk of bristles passing through the first lining paper to the silk beneath.

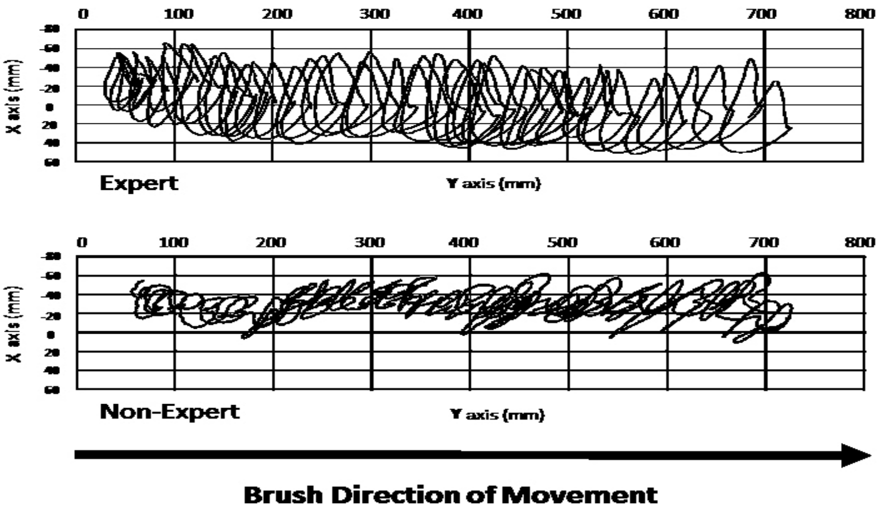

Fig. 8. Comparison of the locus of the pounding brush between and expert and non-expert

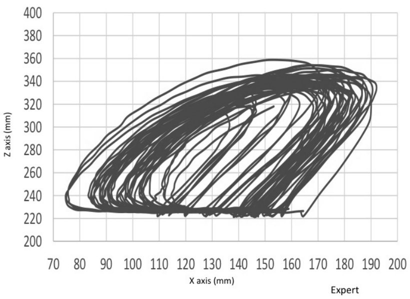

Fig. 9. Expert's locus of the pounding brush shape

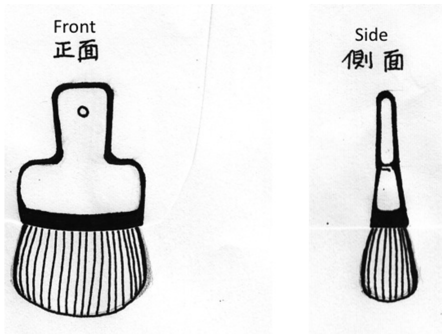

Fig. 10. Diagram of the pounding brush bristle

Figure 11 shows the movement of the markers attached to the brush handle in the non-expert's work. It suggests that the non-expert was also attempting to apply a certain angle to the brush at the time of pounding. However, the angle was so shallow that the brush was almost in the upright position. The data also suggests that the angle of pounding was not constant. In order for a scroll to hang straight, the adhesion must be even across the back of the scroll. This reveals a significant difference in the pounding techniques between the two craftsmen.

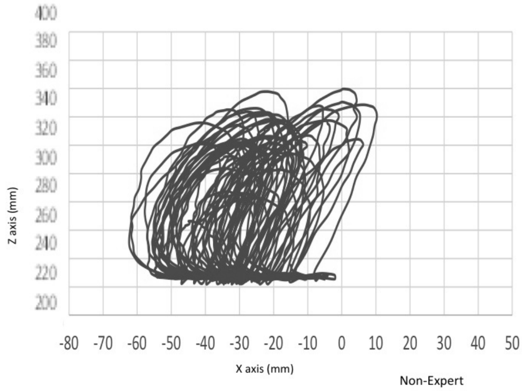

Fig. 11. Non-expert's locus of the pounding brush (X-Z)

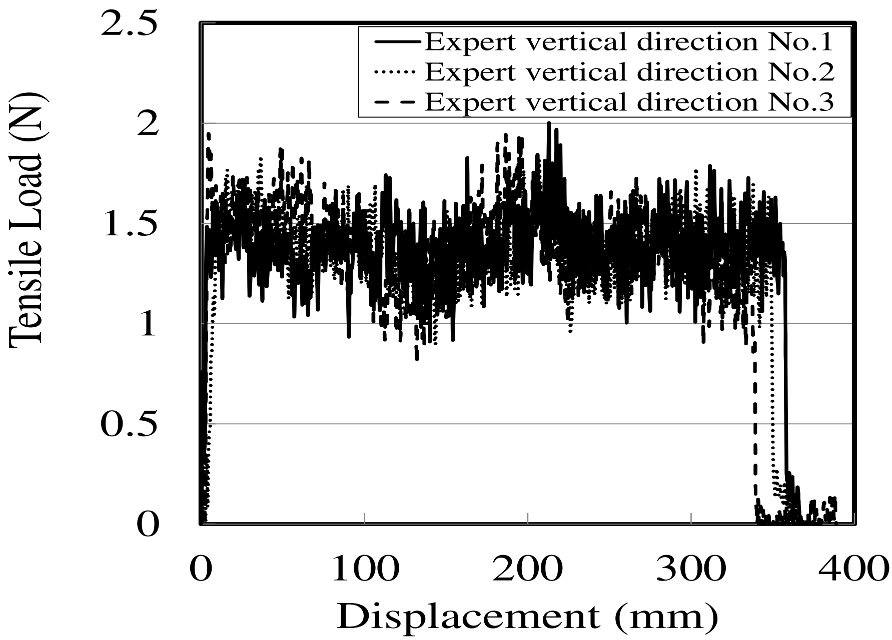

Fig. 12. Change in the load while vertically peeling the sample made by the expert

Comparing figures 9 and 11, it is obvious that there were differences in the angle of the brush during pounding. The expert tilted the brush to a greater degree, which enabled him to pound a larger area than the non-expert each pound.

As the results in Table 1 suggested, this increase in surface area leads the expert's shorter work time and fewer pounds. Similarly, the increased surface area of each pound caused by pounding at an angle would contribute to the expert's wider distance between pounding spots compared to the non-expert.

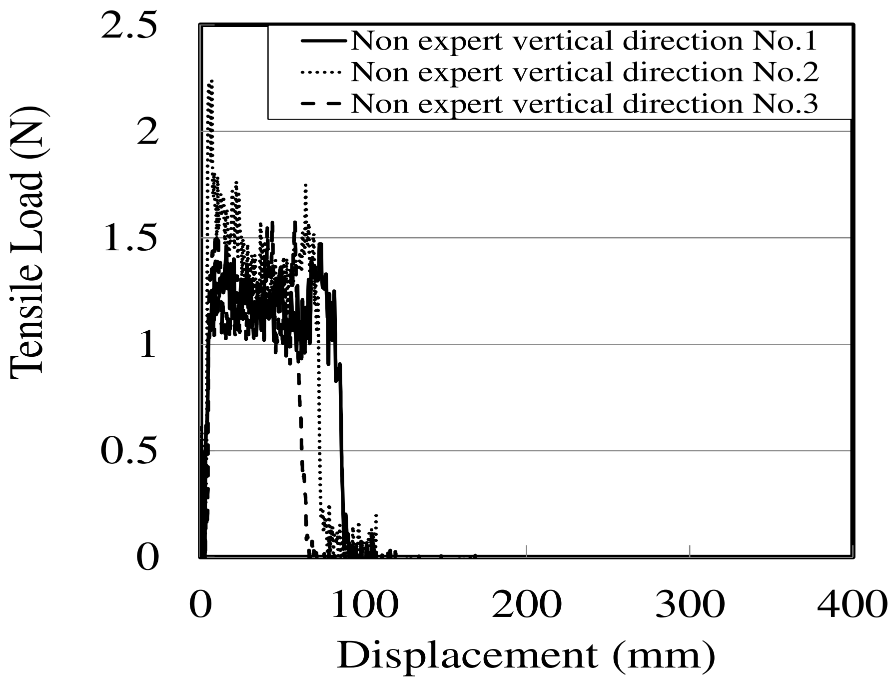

Fig. 13. Change in the load while vertically peeling the sample made by the non-expert

Lastly, we conducted a peel test on the specimens finished in this process, and evaluated the differences between the two samples. Figure 12 shows the change in the load while vertically peeling the sample made by the expert. Figure 13 shows the same for the samples made by the non-expert. We found that the specimen made by the expert could be peeled off stably with a constant force. In contrast, for the sample made by the non-expert, the load applied to the sample resulted in unstable peeling, and the specimen was torn in the middle of the test. This shows that the difference in pounding skills exerts significant influence on the adhesion between layers.

3 Conclusion

In this study, we focused on the pounding technique used for the second lining—an essential step in the fabrication of hanging scrolls. Specifically, we compared the pounding technique performed by an expert craftsman and a non-expert. As a result, we found that the expert was practicing the traditional method of pounding the brush at an angle, which has been passed down through the ages. This element was not clearly observed in the non-expert's technique. The peel test revealed an obvious difference in the adhesion status of the samples taken. The sample made by the expert could be peeled off with stable force, and adhesion was less uneven when compared to the sample made by the non-expert.

Our behavior analysis revealed that correct pounding technique is strongly correlated with stronger adhesion.

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