

An Investigation on Skillful Gel-Coat Techniques and its Application to Beginner's Application

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Abstract. Gel Coating has been used for forming composite structures since ancient times. On the other hand, gel coating work itself relies on human skills, which means that the finish differs according to the operator carrying out the work, the quality of the product differs among parts depending on the ease of forming. Hence highly specialized control technique and the tradition of skill are required to ensure the consistent stability of product quality. Therefore, in this study, motion analysis experiment of gel coating experts by MAC 3D System was conducted to obtain objective data on an expert applicer's skills (the default value) with compared to the non-expert one. Furthermore, dimensional stability measurements were made, and an investigation of the correlation to an expert's application techniques was conducted in order to pass the suitable training and communicating technical skills to advanced management engineering and inexperienced applicers.

Keywords: Dimension stability · Motion analysis · Explicit knowledge

1 Introduction

Gel Coating relies on the skill of the person doing the applying. Gel Coating is an important process which determines the appearance of product. This NG of operation is related to product NG straightly. Moreover, controlling the thickness of Gel Coating is very difficult because of it may become thin and the color may become transparent. However, when the thickness is thick, especially before the Gelling coat gel, it will drop at the vertical plane. The dropped vestige will make bad appearance on product surface. As a result of its difference from common Gel Coating, it isn't able to judge the quality of Gel Coating, the gel coat failure would generate a large loss. For this reason, motion analysis of the spray up method process was conducted to obtain objective data on an expert applicer's skills (the default value). Furthermore, dimensional stability measurements were made, and an investigation of the correlation to an expert's

application techniques was conducted. In this way, suitable training and communicating technical skills can be passed on to advanced management engineering and inexperienced appliers. Also, the degree of master craftsmanship (called *takumi* in Japanese) needs to be quantified, so that more advanced technology will become manageable.

2 Methodology

2.1 Subjects

In this study, two people were tested: an expert gel coating craftsman (male, 54 years old, 32-year work career) and a non-expert (male, 25 years old, 1-year work career). The biological data of the subjects is shown in Table 1. One was left handed, and another was right handed. They didn't have physical handicaps or a disease that restricted their work. The purpose and method of this study were explained in advance to the subjects. Their consent to participate was obtained.

Table 1. Biological data of subjects

Subject	Age	Years experience	Height (cm)	Weight (kg)	Dominant-hand
Expert	54	32	169	66	left
Non-expert	25	1	168	62	right

2.2 Analysis Objective

The object of the analysis was to evaluate the work done for making gel-coated plate. The size of the mold was 1820 mm high and 910 mm wide. A blue rectangle (1250 mm × 800 mm) was drawn on the 1 m² spray region (Fig. 1).

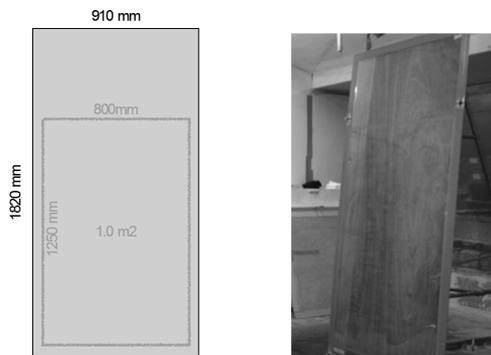


Fig. 1. Mold used in this study (1820 mm high, 910 mm wide)

2.3 Gel Coating

The gel coating machine that was used was made in Japan. As a base material, the vinyl ester resin was used.

2.4 Dimensional Stability

To compare the dimensional stability of the expert and non-expert, the surface coarseness of the plane of the acquired molded product was measured. A micrometer was used for measuring thickness.

All samples (1250 mm × 800 mm) obtained in the experiment were cut and divided into 16 sections. Moreover, the thickness of the cross section of each area was measured every 10 mm. About 1,110 data points were obtained per subject.

2.5 Measurement Techniques of Operator’s Skill Level

Motion analysis (Figs. 2, 3) and eye movement measuring (Fig. 4) were done from start to finish for the entire work process. The experiment was performed under the same circumstances as their usual workplace so that the subjects could work as normal. Moreover, instructions—except restrictions for measurement—were omitted so that the subjects could work at their own pace. In addition, three-dimensional motion and eye movements were measured separately.

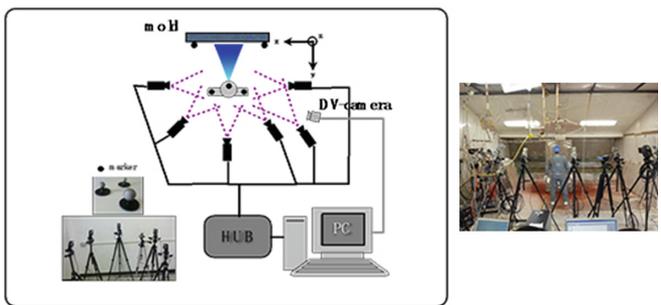


Fig. 2. Motion analysis system



Fig. 3. 19 markers were attached to the subject’s body (infrared reflective markers were reflected as white).



Fig. 4. Eye movement measurement system

3 Results and Considerations

3.1 Dimensional Stability

The dimensional stability (thickness distribution) of the expert and non-expert are shown in Fig. 5. The classification by color in the figure is every 0.2 mm.

The expert's average thickness was 0.27 mm and the coefficient of variation (C.V.) value was 13.2 %. On the other hand, the average thickness for the non-expert was 0.19 mm and the C.V. value was 29.4 %. As the theoretical thickness of this study was 0.3 mm, the non-expert's thickness distribution was thin and the C.V. value was also large (Fig. 6). In particular, there are very thick regions in the bottom of product done by non-expert. This dimensional stability shows that the expert had precise thickness control. In other words, the expert's loss of gel coating also decreased. Improving the gel coating technology would substantially contribute to dimensional stability and reduced waste.

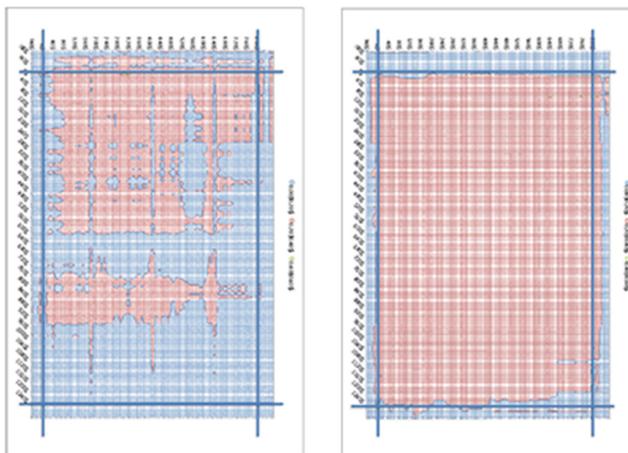


Fig. 5. Comparison of thickness distribution (left: non-expert, right: expert) (Color figure online)

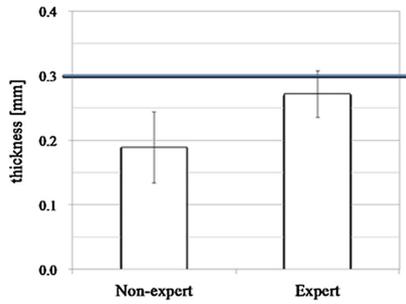


Fig. 6. Comparison of thickness distribution

3.2 Process Analysis

First, each motion under work was defined, and could be divided into two motions: first the “horizontal stroke” and second the “vertical stroke”. The “stroke” was defined as the one-way movement of the gel coating in the horizontal and vertical direction of the mold (Fig. 7).



Fig. 7. Definition of “horizontal stroke” and “vertical stroke”

There are great differences between experts and non-experts workers, especially in operation time (Fig. 8). The daub done by experts was even no matter the longitudinal direction and the constant direction. However, the non-experts don’t conduct in this way.

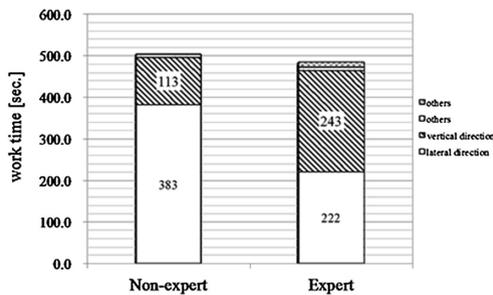


Fig. 8. Comparison of work time

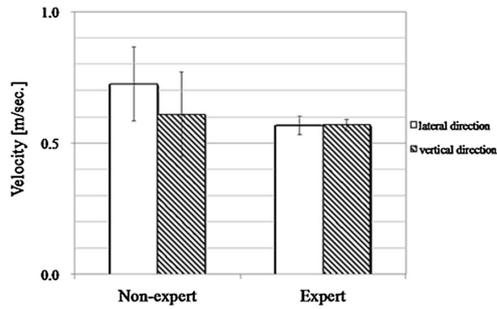


Fig. 9. The mean work time per stroke for each process

Next, the mean velocity of the stroke in each process was compared (Fig. 9). The experts daubed in same speed both in the longitudinal direction and in the content direction, thus less deviation can be concluded.

3.3 Motion Analysis

The operations at the time of the gel coating by the expert and non-expert were compared. Attention was paid to the motion of the gun of gel coating. The difference in motion was especially noted (Fig. 10). Here, the x axis is defined as the direction perpendicular to the spray. The y axis is defined as the spray direction. And the z axis is defined as the height direction.

To better understand the series of motions, the “crookedness expansion movements” of the expert and non-expert were compared. The angle variations between the knee, greater trochanter and shoulder (right side) are shown in Figs. 11 and 12. The expert had a wide angle variation (wide arc) and it turns out that this is the stable angle variation. Moreover, it is clear that the expert is further “crooked” by about 50 degrees, and it turns out that the “crookedness expansion movement” for each stroke by the expert was performed smoothly. That is, the expert is performing the “crookedness expansion movement” efficiently while on tiptoes.

The difference in the angle variation can be clearly seen from this figure. Moreover, because of the efficient body movement of experts, spray gun is always perpendicular

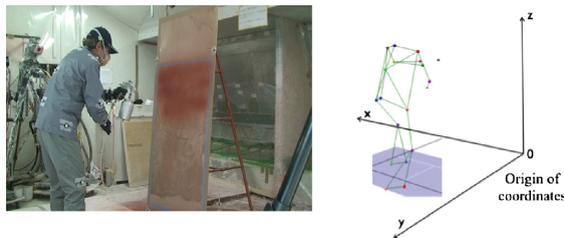


Fig. 10. Motion analysis

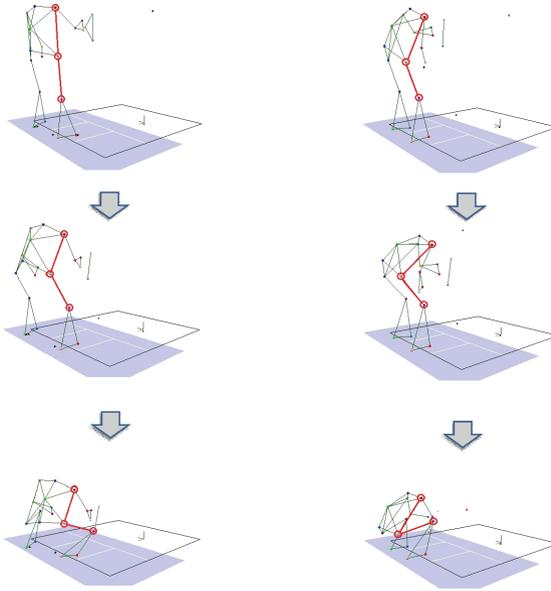


Fig. 11. The comparison of the angle variations (right side) between the knee, greater trochanter and shoulder (left: non-expert, right: expert).

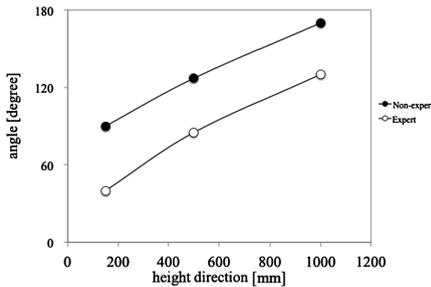


Fig. 12. Angle between the knee, greater trochanter and shoulder (right side)

to the lower part of daub area. Thus, daub loss declined and stable size of product can be gained. However, the angle of spray gun is not perpendicular, the loss may increase and then, there is a trend to be even thick for the bottom of daub area.

Next, the tracings of the gun top's x-z coordinates were measured (Fig. 13).

The expert focused on painting up and down first, but also paid attention to the alternate coating in the horizontal and vertical directions. On the other hand, the non-expert focused almost exclusively on painting with horizontal strokes (Fig. 14).

In addition, the horizontal direction coating is thicker than the vertical direction coating. Here are the trace comparisons in horizontal and vertical directions between the expert and the non-expert. The expert focused on painting in the vertical direction paint. On the other hand, the non-expert focused on painting in the horizontal direction.

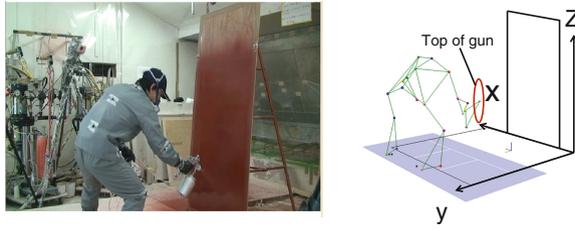


Fig. 13. Tracing of the gun top

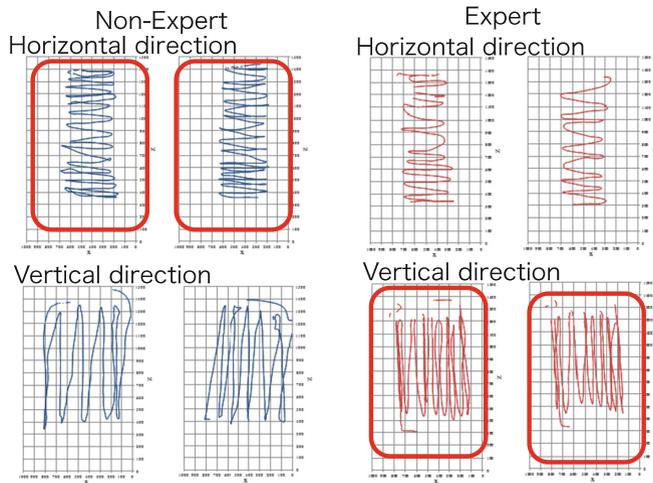


Fig. 14. The comparison of the tracings of the gun top's x-z coordinates (left: non-expert, right: expert).

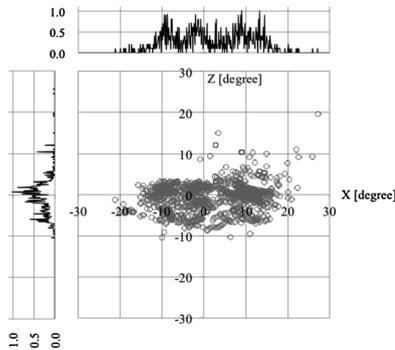


Fig. 15. Comparison of points of view for expert (in case of horizontal direction)

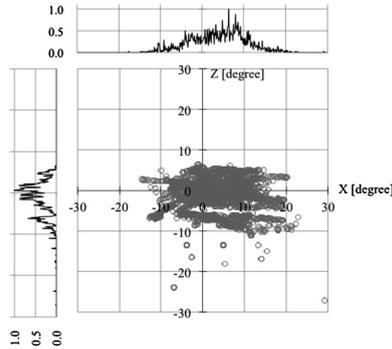


Fig. 16. Comparison of points of view for non-expert (in case of horizontal direction)

3.4 Eye Movement Analysis

By observing the point-of-regard track, Horizontal axis is x , longitudinal direction is z , learn that the movement in the transverse direction is very even and smooth, the vertical direction was always stable. That is, skilled workers were very intently watching the daub area, rather than the obviously unstable movement of non-experts in different directions and absent-minded sometimes when working (Figs. 15 and 16).

4 Conclusions

The results for the expert can be summarized as follows:

1. The thickness of coating by the expert is uniform.
2. The expert sprayed in both the vertical and horizontal sections at a similar pace.
3. The expert's main focus was on the vertical coating.
4. The expert's eyes covered a wider range than the specified area

Furthermore, it was found that the above four points can be incorporated into the educational tools of non-experts and intermediates, sharply reducing the skill acquirement time. Moreover, the expert's motion data was fed to a gel coating robot, resulting in minimal errors during fabrication of composite panels.

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