Research and Development of Robots with Advanced Skills in Hand Lay-Up

Tetsuo Kikuchi and Erika Suzuki

Abstract Hand lay-up fabrication is a form of craftsmanship and an implicit skill supported by individual sense, and subjective implicit values deep-rooted in expertise and judgment by touch and from appearance based on "instinct" and "know-how" skills inherited from past generations for the evaluation of thickness and impregnation, removal of voids, etc. Typically, more than 20 years of experience is required for a person to become a skilled craftsman in hand lay-up fabrication. Challenges the need to be addressed are how to pass their skills onto future generations, foster artisans, and construct a sustainable manufacturing process. In this study, the development of HLU molding robots input with the knowledge of skilled engineers as an achievement of this research will help overcome the lack of skilled workers during the stage of training young personnel to replace their predecessors as generations change.

Keywords Hand lay-up · Tacit knowledge · Compressive pressure · Dimensional stability · Robotization

1 Introduction

Expectations on robot technology have been growing as a means to solve the lack of manpower due to the ageing population and declining birthrate, improve the labor environment, and enhance productivity. Within this context, this study aims to develop robots with advanced skills in hand lay-up (HLU) molding of composite materials and utilize them in the production of composite materials, to build a system for continuous supply of high quality composite material products.

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The HLU method has been used since long to fabricate composite materials. A simple mold, the skills, and raw materials are all you need in hand lay-up molding. The molds used for hand lay-up process is inexpensive and this method requires little equipment investment, allowing the manufacturer to flexibly respond to wide-ranging requirements in terms of production volume, size, and changes in product shapes. Meanwhile, there are disadvantages: as the HLU method depends on human skills, product quality differs by the worker who fabricated the product and even between different parts of the same product. For these reason, highly sophisticated control techniques and the succession of molding skills are required to constantly provide products with stable quality. In other words, HLU molding requires craftsmanship. The skills for removing air bubbles and smoothening material surface are based on "instinct" and "knack" passed down from predecessors, which are all tacit knowledge rooted in subjective senses such as touch, vision and bodily feelings obtained from repeated motions, supported by experience and individual sensitivity. Typically, an HLU molding worker would need more than 20 years to become fully experienced. Process analysis results suggest that the work time in the deaeration process and the method of using a roller characterize the HLU method. We therefore themed this study on the comparative review of the skills applied in the deaeration process and investigation on methods for converting tacit human skills to explicit knowledge and incorporating such knowledge into robots as explicit values.

While growing demand for housing and hotels is expected with Tokyo hosting the 2020 Olympics and Paralympic Games, the serious lack of labor skills and front-line workers is increasingly standing out.

Considering such circumstances, the development of HLU molding robots input with the knowledge of skilled engineers as an achievement of this research will help overcome the lack of skilled workers during the stage of training young personnel to replace their predecessors as generations change. In addition, it will enable a flexible response to the need for small lot production of diverse products, the reduction of manufacturing costs, high productivity, and other advantages of the HLU molding technique leveraging the low facility and operation costs involved. While applying such strengths, it should also realize the continuous and stable supply of high precision, high quality products originally expected of robots. Consequently, this may promote the further evolution of composite materials design and rapidly increase the opportunities of fabricating composite materials using HLU robots.

2 Methodology

2.1 Subjects

The subjects were four craftsmen consisting of an expert in HLU with 27 years of experience, and craftsmen with experience of 13, 3, and 0.5 years, respectively. Table 1 shows the biological data of the subjects.

Table 1 Biological data of subjects

Subject person	Age	Years of experience (year)	Height (cm)	Weight (kg)	Dominant-hand
Expert	50	27	171	52	Right
Intermediate-1	35	13	179	66	Right
Intermediate-2	31	3	164	52	Right
Non-expert	31	0.5	182	77	Right

2.2 Experimental Protocol

The subjects carried out FRP forming by HLU on the measuring device (Fig. 1). The roller used in this study was that used in normal work. Attached with 3 mm hog bristles throughout the whole circumference, the roller measured 14 mm in diameter and 70 mm in width (Fig. 2). Video was taken using one video camera. Figure 1 shows the measurements using a reaction force measuring device. As for the coordinates, the front-back direction in respect to the subject was taken to be the x axis, the left-right direction the y axis, and the up-down direction the z axis. Without specifying the roller work time, the subjects were asked to carry out finishing work using the roller until they were satisfied.

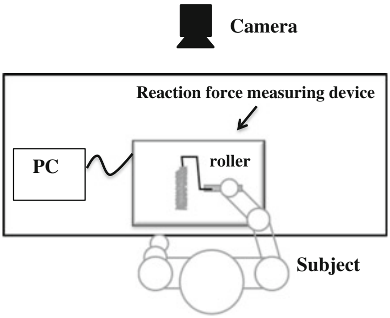


Fig. 1 Measurement environment of this study

Fig. 2 Defoaming roller

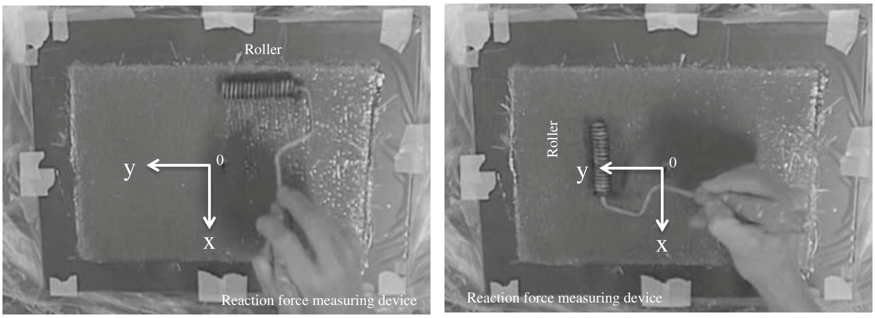


Fig. 3 Photo of reaction force measurement (*left* x-direction, *right* y-direction)

The requirements of the finishing roller work were the elimination of voids inside the FRP laminated layers and smoothness of the finished surface. Finishing is an important step in HLU fabrication and the step where difference in the level of experience appears most conspicuously. The unsaturated polyester resin used in this study changes to gel in 30 min because it is a photocurable resin, which means that the work time is restricted (Fig. 3).

2.3 Materials

Glass fiber chopped strand mat (450 g/m^2) was used as the reinforced substrate. For the matrix, unsaturated polyester resin made with isophthalic acid was used. A curing agent (MEKPO) was added to the resin at a ratio of 100:1.0. Three glass fiber chopped strand mats were laminated in the forming work. The size of the fabricated FRP sheet was horizontally 300 mm and vertically 200 mm (Fig. 4).

2.4 Measurement of Dimensional Stability

To compare the dimensional stability of the obtained samples, the thickness of the FRP sheets was measured every 20 mm using a micrometer (Fig. 4).

2.5 Measurement of Reaction Force

To measure the reaction force imposed by the finishing roller on the laminated layers using the HLU method, the reaction force measuring device was used

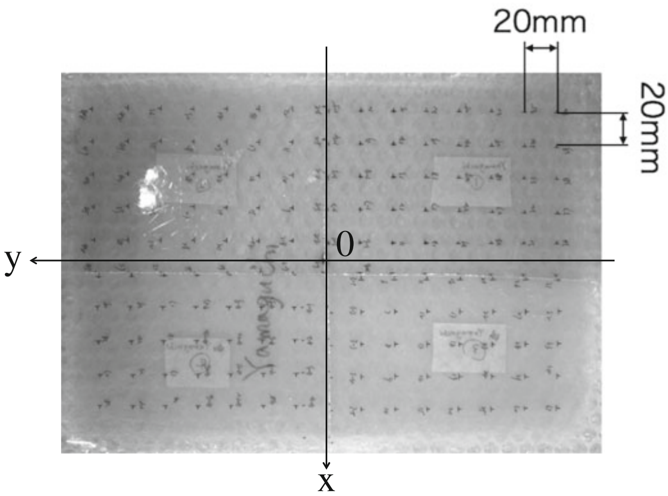


Fig. 4 Thickness measurement range

Fig. 5 Reaction force measuring device

(TF-3040-A, 400 mm × 300 mm, Tec-Gihan) (Fig. 5). At a sampling frequency of 100 Hz, the reaction force of all operations from start to end was measured. At the same time, the trajectory of the x-y plane was also measured. The center of gravity of the reaction force is shown for the trajectory. The origin means the center of the reaction force measuring device.

3 Results and Consideration

3.1 Dimensional Stability

Figure 6 shows the distribution of the thickness of the fabricated FRP sheet. The FRP sheet fabricated by the expert had stable thickness in both the X and Y directions, whereas it should be especially noted that the thickness of the FRP sheets fabricated by the non-experts was conspicuously inconsistent at the turning points of the stroke. (The edge of the flat FRP sheet is thin.) Figure 7 compares the average thickness of the FRP sheets fabricated by each subject. It can be clearly seen that the thickness of the sheet fabricated by the expert is stable around 2.1 mm in both the x and y directions. Inconsistency in the thickness was also small and the finished surface was smooth. On the other hand, the finished surface by the non-experts appears rough and undulated even to the naked eye, and the inconsistency of the thickness is large. The average thickness and number of years of experience were found to be closely correlated among the three subjects excluding the subject with experience of 0.5 years (simple correlation coefficient: 0.97).

These results suggest that how the roller is used clearly affects the thickness of the planar, elevation, and R convex sections, in other words the stability of the shape. In addition, it is evident that how the roller is used is closely related to operations that define “career,” as shown in Fig. 7.

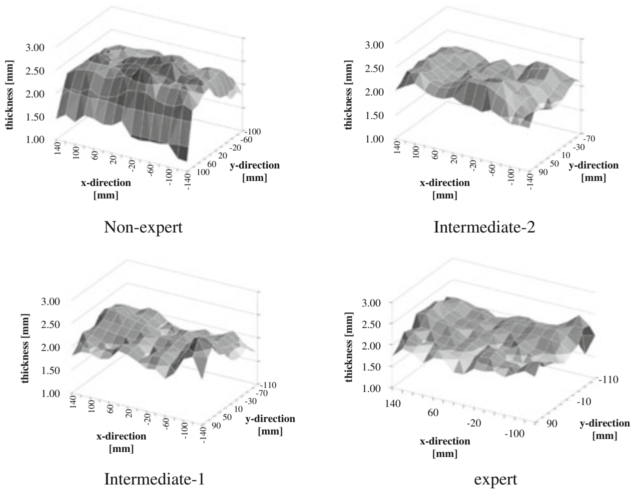


Fig. 6 Comparison of dimensional stability

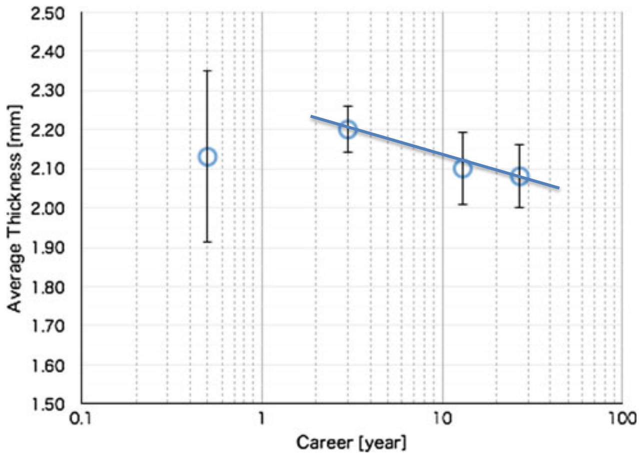


Fig. 7 Relation between average thickness and years of experience

3.2 Compressive Pressure of Roller

The effects of years of experience on compressive pressure of roller were investigated. Figures 8 and 9 show the trajectory of roller.

Next a relation between compressive pressure of a roller and working hours is indicated. Each chart indicates working hours in a transverse and indicates

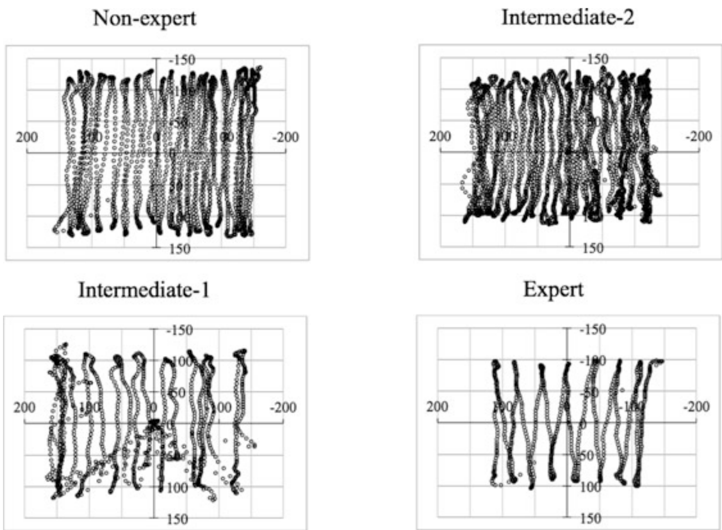


Fig. 8 Comparison of trajectory on x-y plane (x-direction)

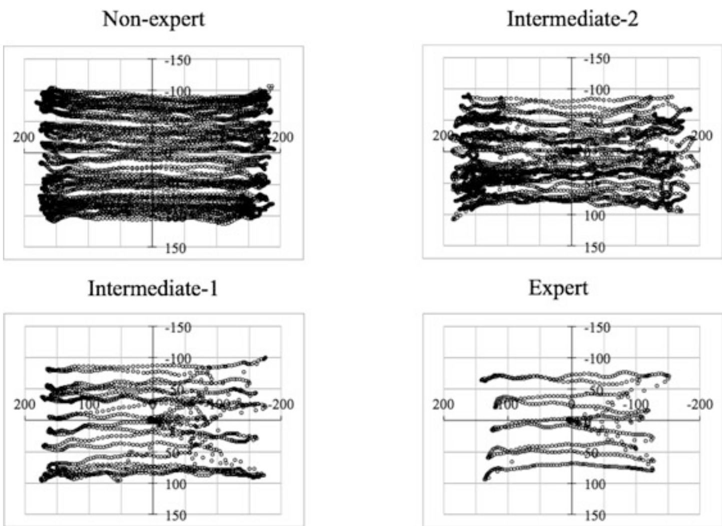


Fig. 9 Comparison of trajectory on x-y plane (y-direction)

compression pressure in vertical axis. There are no changes in compression pressure of a roller of intermediate 2 and an non-expert person (Fig. 10).

On the other hand, a change is big in compression pressure of a roller of expert and intermediate-1.

Figure 11 indicates the location of the x axis in a transverse, and vertical axis indicates compressive pressure of a roller. Roller compressive pressure of intermediate-2 and non-expert person doesn't depend on the location and is stable.

Fig. 10 A relation between compressive pressure of a roller and working hours

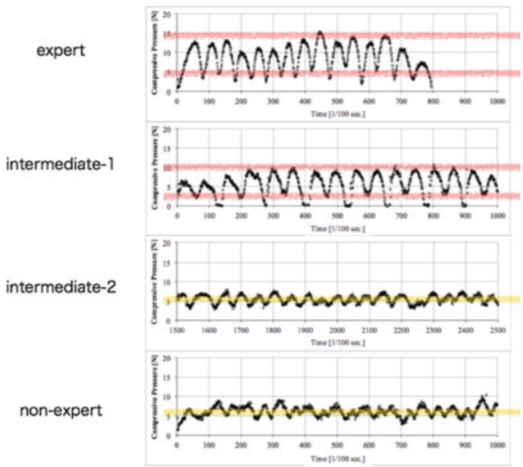
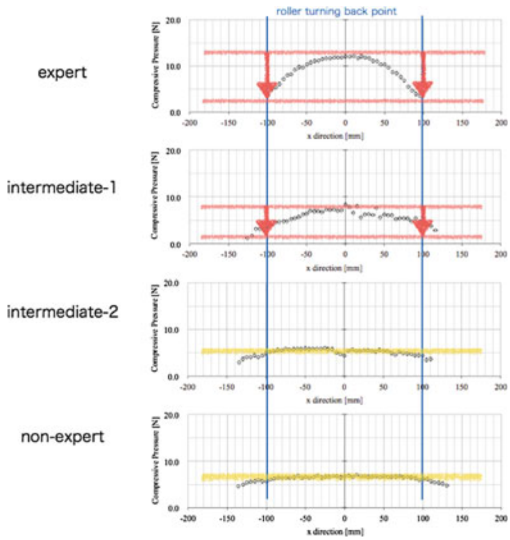


Fig. 11 A relation between x-axis and roller compressive pressure



On the other hand, expert and intermediate-1 are making compressive pressure fall at a roller turning back point. In particular, expert's compressive pressure falls to at most 1/3 at a roller turning back point.

3.3 *Robotization*

Aim of this research is to develop HLU molding robots input with the knowledge of skilled engineers. These quantified data is installed in a program of a robot. An efficient finishing process becomes possible by roller compressive pressure control. It can also be utilized as a tool of skill succession (Fig. 12).

Fig. 12 Robots with advanced skills in hand lay-up

4 Conclusions

The findings suggest a close relationship between how the roller is used (e.g., direction, frequency, and load), which is a measure of career, and mechanical property. Characteristics of the expert can be summarized as follows:

1. Compressive pressure of roller is evenly distributed. Then the coefficient of variation of the thickness and mechanical strength is estimated to be small.
2. Sample thickness that expert finished is uniform; this has been suggested to be responsible for the mechanical properties improved.
3. The defoaming work which is practician's tacit knowledge was quantified by compressive pressure of a roller.

Furthermore, it was found that the above three points can be incorporated into the educational tools of non-experts and intermediates, sharply reducing the skill acquirement time. And the national technical skills test is a national certification program to test and certify the skills of workers based on certain criteria. It is designed to motivate workers, including monodzukuri workers, to acquire skills, and it has contributed to improving the social status of workers. Robots with advanced skills in hand lay-up will be tested and certified by the national technical skills test in the near future.

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