Expert vs. Elementary Skill Comparison and Process Analysis in VaRTM-Manufactured Carbon Fiber Reinforced Composites

Yasunari Kuratani[1(✉)], Kentaro Hase[2], Takahiro Hosomi[2], Tomoe Kawazu[2], Tadashi Uozumi[3], Akihiko Goto[4], and Hiroyuki Hamada[1]

[1] Kyoto Institute of Technology, Kyoto, Japan
kuratani@kado-corporation.com, hhamada@kit.ac.jp
[2] KADO Corporation, Tatsuno, Japan
{hase,hosomi,kawazu}@kado-corporation.com
[3] Gifu University, Gifu, Japan
uozumi@gifu-u.ac.jp
[4] Osaka Sangyo University, Daito, Japan
gotoh@ise.osaka-sandai.ac.jp

Abstract. VaRTM requires a preform to be manufactured before molding. However, it is often said that the accuracy of the preform affects the mechanical properties of the mold. Despite the progression of investigations into the automization of this process in recent years, preforms manufactured by hand still make up the majority, and the accuracy of these preforms lies in the ability of the worker. In this study, we have instructed three subjects with varying amount of years of experience working with composite materials, and manufactured VaRTM moldings. By analyzing the time taken, attitude and posture, and use of tools within the work process when layering, and by conducting an interlaminar shear strength test, we have acquired good results within the product quality of the mold, working time, and interlaminar shear strength in order of the number of years of experience. In the future, we will continue to research this subject so that we can focus on the creating a setup that has the same, consistent accuracy, regardless of the worker manufacturing the preform.

Keywords: CFRP · Vartm · Process analysis · Year of experience · Working posture

1 Introduction

Within the carbon fiber reinforced plastic industry (CFRP), the VaRTM molding method (Vacuum assisted Resin Transfer Molding) and the high-cycle RTM method (Resin Transfer Molding) are used for large molds. Research for the next generation of molding manufacturing technology is being actively pursued and used widely. With the VaRTM method, because there is no need to install equipment which will apply high temperatures and pressure, and because it can be used for complex shapes, it is

V.G. Duffy (Ed.): DHM 2015, Part I, LNCS 9184, pp. 133–142, 2015.
DOI: 10.1007/978-3-319-21073-5_14

considered a cost efficient and high-quality molding method. However, it requires that a fiber base-material preform is manufactured before molding. Manufacturing the preform takes a lot of time, and the accuracy of the preform affects the mechanical properties of the mold. In recent years, research into the automatic manufacturing of this preform have continued to progress; however, the majority are manufactured by hand.

Research of CFRP molding focusing on the flow and hardening of resins is currently underway, but the effect of the worker's manual labor is also considered to be an important factor. For example, in conjunction with analyzing the movements and work process of workers in hand lay-up molding and spray-up molding [1–3], Kikuchi et al. have begun tests that aim to scientifically explain the manual labor of workers in molding, such as investigating the subtly different effects that each worker had on their molding [4].

This research focused on VaRTM molding. However, this form of molding also has manual labor involved in its process, which is considered to have a large effect on the finished molding. Thus, we investigated the difference in the time it took the subjects, all of whom have varying years of experience working with composite materials, to manufacture the preform, and the mechanical properties of the test panel produced by the VaRTM molding, and how these factors affect the accuracy of the mold.

2 Experimental Method

2.1 Experimental Materials

We used a fiber base-material produced by SAERTEX, a carbon fiber NCF (Non-Crimp Fabric). The fixing agent was powder. (see Table 1) And we used a matrix resin produced by Axon Inc., EPOLAM5015 (main agent) and EPLOAM5015 (curing agent).

2.2 Molding Method

In order to stack the layers in the shape shown in Fig. 1 we manufactured the preform by layering the carbon fiber NCF, setting the silicon mold to produce a hat-shaped mold in the center, and then layering the same fiber, based on the layer structure chart shown in Table 1. The preform manufacturing process is comprised of three sections.

Table 1. Stacking sequence

Skin section			Hat-shaped section		
ply #	Fiber orientation (angular degree)	Thickness (mm)	ply #	Fiber orientation (angular degree)	Thickness (mm)
1	[+/−45]	0.25	1	[+/−45]	0.25
2	[0 /90]	0.25	2	[0 /90]	0.25
3	[90 /0]	0.25	3	[90 /0]	0.25
4	[−/+45]	0.25	4	[−/+ 45]	0.25
Total		1.00	Total		1.00

Sections 1 and 3 are the stacking sequence of the skin section and the stacking sequence of the hat-shaped mold, and Sect. 2 is setting the mold in order to create the hat shape (Table 2 shows the preform manufacturing process). After manufacturing the preform, resin is infused into the preform using the VaRTM method. After infusion, the preform is hardened at 25°C for 12 h, 40°C for 2 h, and then 80°C for another 2 h.

We informed the three subjects of the work process order and how to conduct the work beforehand, and provided them all with exactly the same tools. We also made them use a fiber base-material that had been cut the same size as the mold as well as auxiliary materials for the molding, all of which had been cut the same sizes. However,

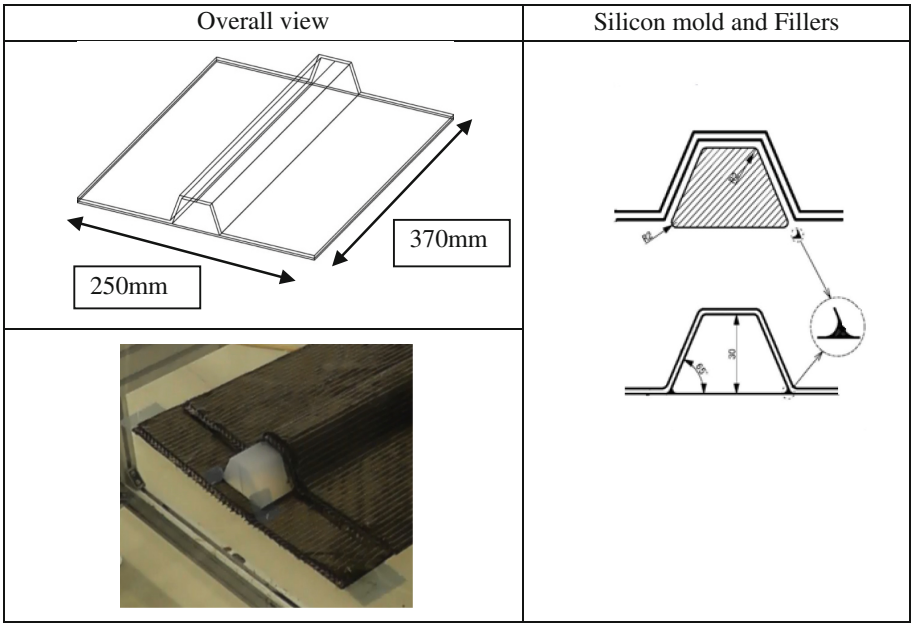


Fig. 1. CFRP perform

Table 2. Process flow of manufacturing preform

I	**the Skin Section (n=1～4)**
	n ply Fiber orientation confirmation
	n ply Stacking sequence
II	**Installation Section**
	setting the Silicon mold
	Fillers installation
III	**the Hat-Shaped Mold Section (n=1～4)**
	n ply Fiber orientation confirmation
	n ply Stacking sequence

despite specifying the tape used as an auxiliary material, we left the length to cut it and where to stick it up to the judgment of the subjects. The years of experience of the three subjects (how many years they have been working with composite materials) in order of most years of experience to least is Expert, Elementary and Beginner, with 8 years, 1.5 years, and 0 years of experience (first time) respectively.

2.3 Evaluation Method

For the subject's working posture and how they used the tools (iron), we divided up the time they spent on each of the processes and compared their actions based on the footage that captured each of the subjects creating the preform. For the physical properties, we investigated the length of each process based on the video recording of each of the subjects making preforms, cut out specimens from the skin section of the molds after the VaRTM, shown in Fig. 2, measured the interlaminar shear strength, and compared the results.

For the interlaminar shear strength test between layers, the molds were evaluated using the short beam method, based on the JIS standard (K7057) (Fibre-reinforced plastic composites – Determination of apparent interlaminar shear strength by short-beam method).

The measurements for each of the specimens were 20 mm in height, 18 mm in width, and 2.22 mm in depth. A three-point bending test was conducted with a test speed of 0.5 mm/min, support radius of 2 mm, indenter radius of 2.5 mm, and an 11 mm gap between the support points. From these tests, we have identified the effect that the difference in the subjects' number of years of experience had on the inter-laminar shear strength between layers.

3 Experimental Results

Figure 3 shows the time required for each respective worker-the expert, the elementary-level, and the beginner worker-to complete the molding process.

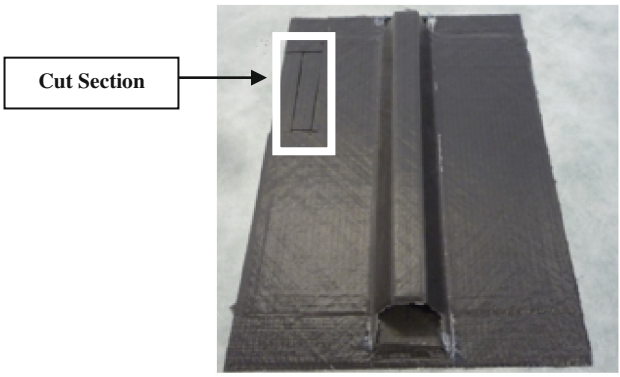


Fig. 2. Specimen cutoff

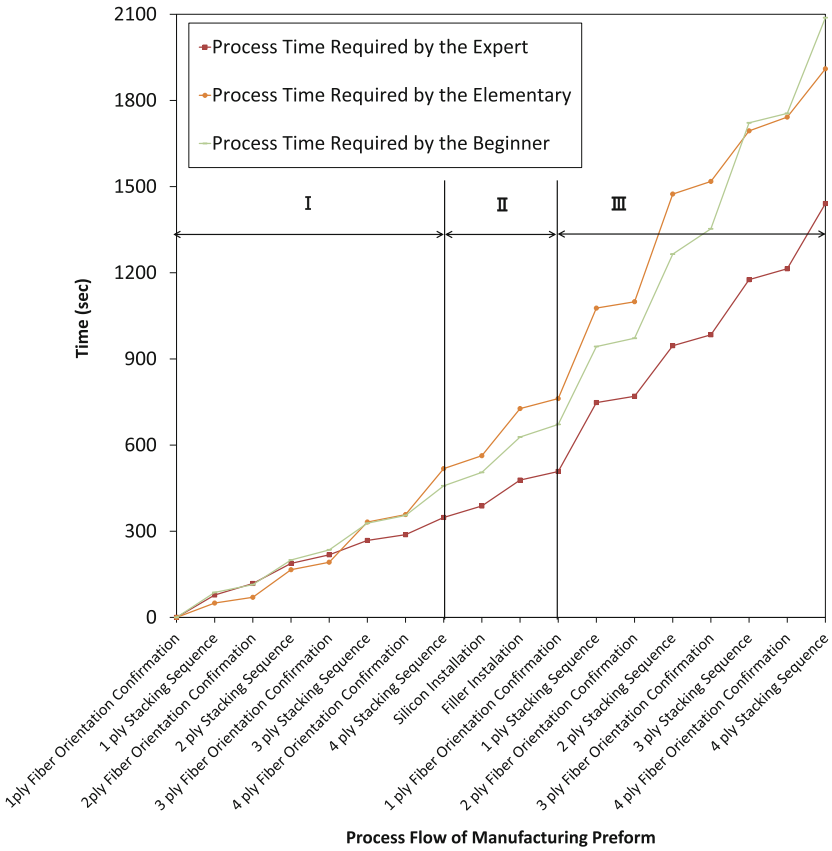


Fig. 3. Time required for each worker and process

The underside of the skin surface after the VaRTM showed the largest difference in the workers' level of experience (shown in Fig. 4). The experimental procedures for this research consisted of the subjects placing the silicon mold in order to create the hat shape, and then proceeding with the layering. However, if the worker does not make the fiber base-material fit and stack the layers while pressing an iron against the edges of the silicon mold, the edge line will rise up after the VaRTM, as is shown in Fig. 4, causing a difference in product accuracy. The preform's level of accuracy affects the mechanical properties of the mold. However, even in this experiment, the preform made by the subjects with little experience had visible edge lines in their specimens on the underside of the skin layer. Thus, this time, we analyzed the working posture and approach to applying the iron, which was used to join the fiber base-material.

3.1 Grip Used on the Iron

Expert: Held the iron in his hand with four fingers, gripping it tightly.

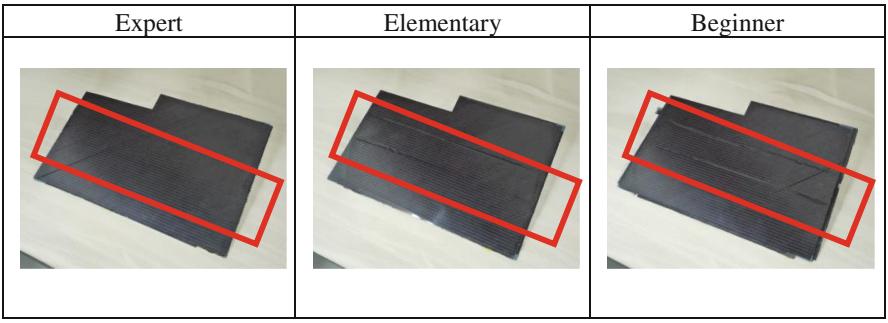


Fig. 4. The underside of the skin surface

Elementary and Beginner: Held the iron in their hands with three fingers, using their index fingers for support.

3.2 Posture Used to Apply the Iron

Expert: Changed the angle of his body based on where he was pressing the iron and put all of his strength into pressing the iron against the preform because his body was positioned in a way that it looked as though he might topple forwards.

Elementary and Beginner: Stood straight and rarely moved. They attempted to join the fiber base-material using their hands and the heat from the iron (Fig. 5).

3.3 Method Used to Apply the Iron

We informed the subjects of the work procedures beforehand. However, aside from using the iron, we left how the fiber base-material is fitted into the mold up to each of the subjects. The reason for this is because that the purpose of this research was to increase preform accuracy through the worker by establishing the Beginner's way of learning, so we did not delve into explaining the finer points of molding.

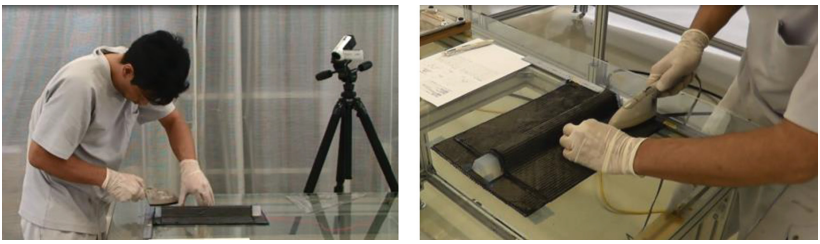
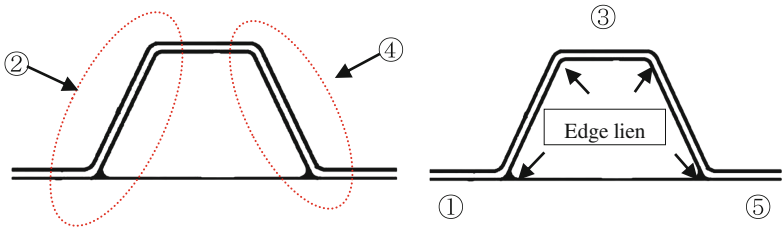


Fig. 5. Posture of expert



1	Left-side skin surface
2	Edge line including the left-side slope
3	Hat-shaped mold upper surface
4	Edge line including the right-side slope
5	Right-side skin surface

Fig. 6. Places the Iron was Pressed

Various differences arose in the order, places and angles in which each of the subjects applied the iron.

Thus, we divided the places on the molding that the iron was pressed against into five different places (see Fig. 6). We compared how long each of the subjects pressed the iron against the molding in the first ply layers and fourth ply layers for the hat-shaped mold (see Fig. 7).

Expert: Spent time on the edges and applied the iron while paying attention to the angle it was on because he understood the importance of fitting the fiber base-material into the edges of the silicon mold.

Elementary and Beginner: Spent a lot of time applying the iron to the skin surface rather than fitting it into the mold, attempting to secure the fiber base-material and quickly continue onto the next step.

Throughout the entire process, before applying the iron, the expert fitted the fiber base-material into the mold, pressed down the fiber base-material and mold with the hand that was not holding the iron so they would not move, and adjusted the iron's angle and the strength he was holding it down with, causing the fiber base-material to fill in excellently. For his posture when applying the iron, he stacked the layers while applying the iron, with his entire body pressing against the fiber base-material, preventing looseness between the layers. After the VaRTM, the resin flowed evenly into the fiber base-material, achieving a finish so clean that it is unclear where the mold is positioned just by inspecting it. However, the Elementary and Beginner subjects with little experience did not pay attention to the edges of the silicon mold (Fig. 6) when stacking the layers, but instead focused on securing the skin surface with the iron so that the fiber base material would not move. Thus, the fiber base-material was not properly stacked onto the edge line, resulting in the mold fitting being loose for the entire layering process, and sharp edge lines forming on the silicon mold on the underside of the skin surface after the VaRTM.

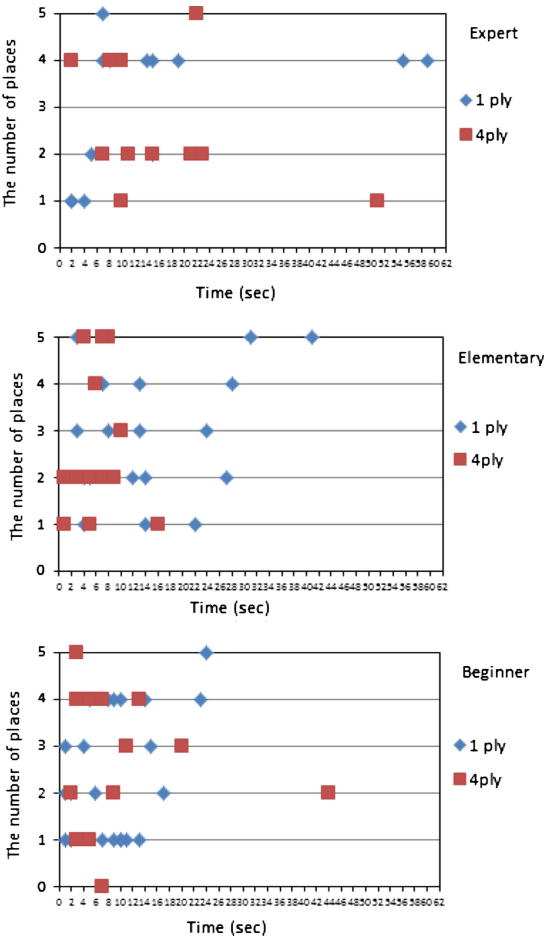


Fig. 7. Length of time and places each of the subjects pressed the iron

It was clear that because the last step in the process is vacuuming that, while that no major problems occur in the skin surface if the angle and other aspects of the fiber orientation have been properly layered, if you do not apply strength and use the iron evenly on when layering, the mold edge lines show on the underside of the product. Because we were able to check the differences in product quality just by looking at them, this time, we cut specimens out from skin sections which did not have edge lines showing and were also predicted to have few dispersions and twists in the fiber orientation (at the very least, they appeared exactly the same just by looking at them), and measured the interlaminar shear strength. However, as is shown in Fig. 8, differences were observed in the interlaminar shear strength among specimens in order of how many years' experience they had (Expert, Elementary and Beginner).

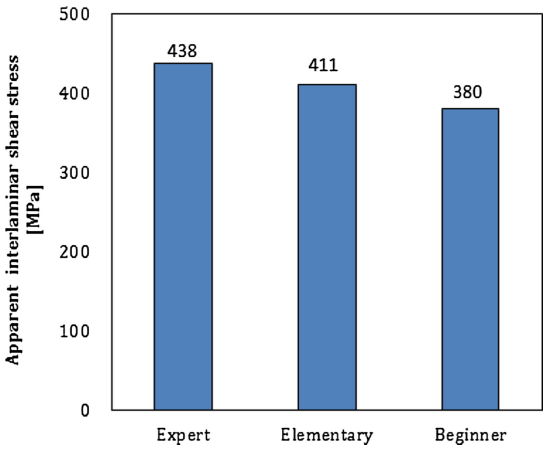


Fig. 8. Differences in the apparent interlaminar shear strength in each of the subjects

4 Discussion

From the testing the interlaminar shear strength, it was clear that even on the skin surface, which was believed to be unaffected by the number of years' experience that each of the subjects possessed, there was a difference in shearing strength due to the number of years' experience the subjects had, making it clear that the strength is proportionate to how many years' experience the worker has. Thus, we predict that, by taking cutoffs from various places on the hat-shaped layering surfaces and slanted sections, conducting an interlaminar shear strength test, pull test, and compression test, there will be a difference in strength, making further investigation necessary. In this research, we informed the subjects of the work procedure. However, because we did not inform them of the angle, posture, how to fit the fiber base-material, and the key places to apply the iron's heat on the fiber base-material when applying the iron, we predict that instructing the Elementary and Beginner subjects would cause a difference not just in their hand movements, but also in their posture and in their eye movements. We predict that there will be differences in the accuracy of future moldings.

5 Conclusion

In the future, we will need to research the effect that manufacturing preforms has on the mechanical properties of molds by investigating what the differences are in the strength, caused by the dispersion that the subjects create, through means such as recording the fiber orientation of each of the plies etc., subdividing the differences in strength caused by fiber orientation and dispersion in the fiber orientation, and clarifying the effects, such as strength caused by differences in the resin content. Therefore, because there was a lot of dispersion in the fiber density of the NCF we used this time, in the future, we will use a UD fiber base-material, which has a stable fiber density,

focus on identifying the molding conditions and techniques of the workers, and continue to analyze. We would also like to cut out specimens from places besides the skin section, and as well as testing interlaminar shear strength, we would also like to use pull tests and industrial CT scans, measure fiber orientation angle and resin rate of impregnation, inspect the inside of specimens, measure the actual pressure that the workers apply onto the fiber base-material, and use the results for analysis.

We were unable to measure how much strength each of the workers applied this time because we only focused on the time it took the workers to complete the task for the work analysis. First, we will make the workers aware of how to appropriately setup the fiber base-material properly, and then we will conduct research that takes into consideration the aim of creating a molding instruction manual that includes vital points and an education system, enabling products with consistent preform accuracy to be created, regardless of who is making them.

References

1. Kikuchi, T., Koyanagi, T., Hamada, H., Nakai, A., Takai, Y., Goto, A., Fujii, Y., Narita, C., Endo, A., Koshino, T.: Biomechanics investigation of skillful technician in hand lay up fabrication method. In: Proceedings of the ASME 2012 International Mechanical Engineering Congress & Exposition, IMECE2012-86270, pp. 533–539 (2012)
2. Kikuchi, T., Hamada, H., Nakai, A., Ohtani, A., Goto, A., Takai, Y., Endo, A., Narita, C., Koshino, T., Fudauchi, A.: Relationships between degree of skill, dimension stability and mechanical properties of composites structure in hand lay-up method. In: Proceedings of the 19th International Conference on Composite Materials, pp. 8034–8042 (2013)
3. Kikuchi, T., Tani, Y., Takai, Y., Goto, A., Hamada, H.: Biomechanics investigation of skillful technician in spray-up fabrication method converting tacit knowledge to explicit knowledge in the fiber reinforced plastics molding. In: Duffy, V.G. (ed.) DHM 2014. LNCS, vol. 8529, pp. 24–34. Springer, Heidelberg (2014)
4. Kikuchi, T., Hamada, H., Nakai, A., Ohtani, A., Goto, A., Takai, Y., Endo, A., Narita, C., Koshino, T., Fudauchi, A.: Process analysis of hand lay up method by various experience persons. In: Proceedings of the 19th International Conference on Composite Materials, pp. 8113–8120 (2012)