DEVELOPMENT OF BENDING PROCESS FOR FRTP PIPE

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ABSTRACT

Well known FRP pipe with curvature (referred to as bent pipe) could be made from using thermosetting resin by winding prepreg sheat on the bent mandrel. To improve the productivity, a method to bend a straight molded composite pipe by bending machine should be established. Though, thermosetting resin requires a lot of molding time for its chemical reaction, to enhance the productivity, thermoplastic resin has been requested to be used for matrix resin [1]. Molding process for thermoplastic resin can simply be explained by starting with heating, and finishing only by cooling down the item. As it could be processed quickly, the heating temperature and heating time will largely effect to the products by making voids and delamination. Also, unlike the metal materials bending, fiber reinforced thermoplastic materials can easily make creases at the compressed area from its thermosoftening by heating. From this reason, composite pipe must be tensioned during bending to reduce its creases. From this study, the displacement added during bending process was searched to be effective for preventing creases at the inner circumferences side .And the deflection temperature underload was the most appropriate temperature to bend the pipe.

1 INTRODUCTION

Recently, composite materials are used in various areas such as automobiles and aircrafts for its high rigidity and strength with light weight [2]. Though it has these kind of advantages, still has difficulties in applying on complex shapes. In the field of engineering, it's widely known that continuous fiber composite pipe which could be freely processed in every dimensional way are demanded. Thereupon, bent pipes are required for its usefulness for making these kind of complex shapes. To produce continuous fiber reinforced thermoplastic bent pipe in secondary process, the mechanism of fiber orientation change, cross-sectional shape, and creases occurrence has to be examined and prevented. These factors are well known to affect their mechanical properties. In this study, the appropriate bending temperature and displacement for pipe bending were investigated

2 BENDING DEVICE AND EXPERIMENT METHOD

In this study, carbon fiber(400tex, TR50s, MITSUBISHI RAYON CO., LTD) and resin fiber of poly-amid(170tex, melting point:215℃, LEXTER8500, MITSUBISHI GAS CHEMICAL CO, INC) have been used by mingling in a partially impregnated condition of which called PCY(Partially impregnated Commingled Yarn). As the thermoplastic resin has disadvantages to impregnation, PCY can make the molding items condition close to fully impregnated. Filament Winding (FW) method was chosen for making 45 degree helical winded carbon fiber pipe. The fibers were winded on a diameter of 27.2mm mandrel. The total amount of lamination was set up to 6ply. To complete the impregnation, tape wrapping method with reheating was added. Figure 1 shows the schematic drawing of tape wrapping device.

This tape wrapping method is a method that uses metal tape, wrapping over the molded item by a certain tension with reheating. By this process, voids will be cleared out. After every process, the completed pipe was made in diameter of approximately 30mm with thickness of 1.4mm.

Figure 2 shows the picture of the bending machine. Bending machine has a rotary axis to bend the pipe at the 150mm position from the head of left chuck device. Bending process can be done by rotating this chuck device on the rotary axis. In addition, this machine can add displacement to the chucked item. By adding tensioned displacement, the creases that occurs at the inner circumferences side of bending pipe can be eased. The displacement amount can be changed by the length of screw that sticks out from the left chuck device. As the pipe needed to be heated equally over the surface, band heater was used for heating system to cover all over the pipe. And also, chucked pipe can be rotated in a circumferential direction to prevent temperature irregularity. At the end, after removing the heater, by pushing pipe into the die made with curvature of R500, bent pipe will be made with natural cooling. To not to deform the cross-sectional shape, an inner core was inserted inside the pipe.

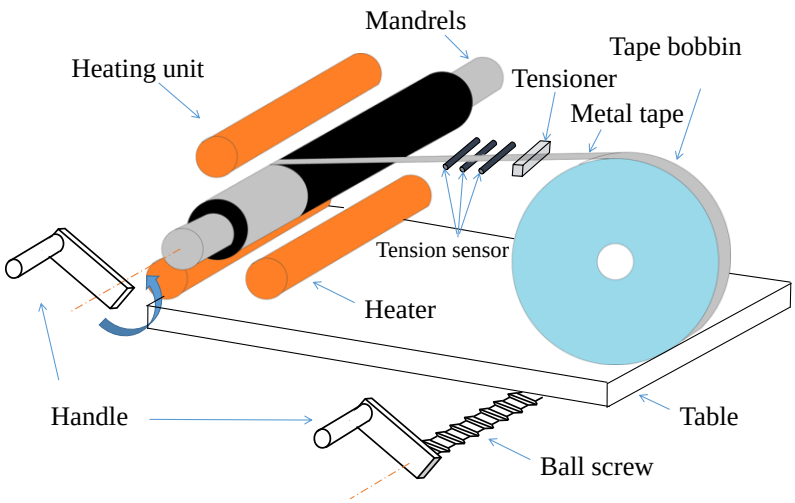


Figure 1: Schematic drawing of tape wrapping device with reheating.

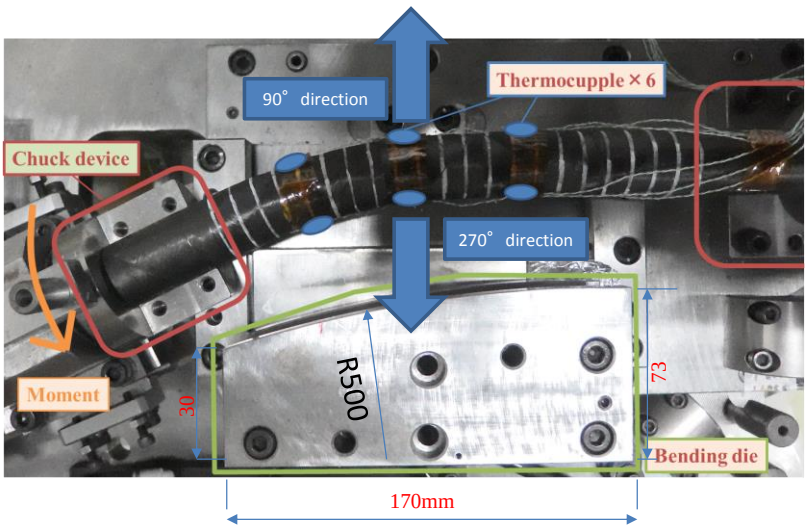


Figure 2: Picture of bending machine.

3 TEMPERATURE CONDITION DETECTION

3.1 Experiment method

As the thermoplastic resin has a characteristic that becomes soften by heating, appropriate heating condition for bending process must be specified. To search the appropriate temperature, three types of temperature target was compared. The base temperature for the different three temperature was set from the deflection temperature underload. The deflection temperature underload was measured by thermocouple from the temperature when the deflection reached the calculated amount. To measure the deflection, bending load was added on the test pipe with heating. The calculated amount we needed for deflection was 1mm and the deflection temperature underload was 184℃.

For the structure that band heater covers all over the pipe surface, the heater must be removed after finishing heating process. After the heater has removed, temperature decreased naturally until the bending process began. To search the temperature decreasing during this process, temperature history from the heat start to the end of bending process was recorded. Temperature was recorded by thermocouples attached to 138mm, 182mm, 227mm left from the head of the right chuck device. Both inner and outer circumference side on each position which totals 6 area was recorded. 182mm position is the position where the item touches the centre of the die. Other positions are 70 mm distance to the left or right from the centre. At the bending process, temperature decreased to deflection temperature underload in a condition of 244℃ temperature target. From this result, 214℃ and 274℃ which were 30℃ lower and higher were also recorded.

As a factor to search the influence on temperature target difference, deformation was searched by two kinds of measuring method. One is by measuring the contact angle difference shown in Figure 3. By this method, the bent angle will be evaluated from the each tangent line of pipe surface and the die. The other method is by measuring the cross-sectional shape. Each direction of the pipe was defined as 90° direction, 270° direction shown in Figure 2 while the vertical direction to both direction was defined as 0° direction, 180° direction. To evaluate the difference of each cross-sectional shape, diameter before bending of each 90°-270° direction and 0°-180° direction was measured. After finishing the bending process, the thickness of each 0°, 90°, 180°, 270° direction was also measured.

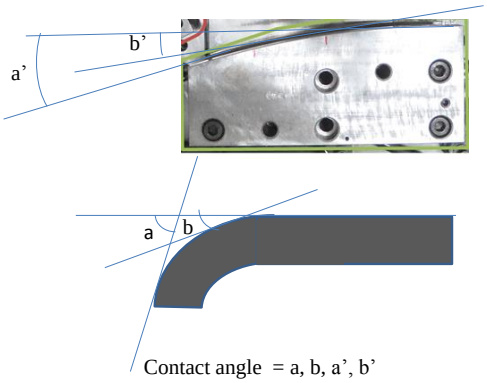


Figure 3: Schematic of Contact angle difference.

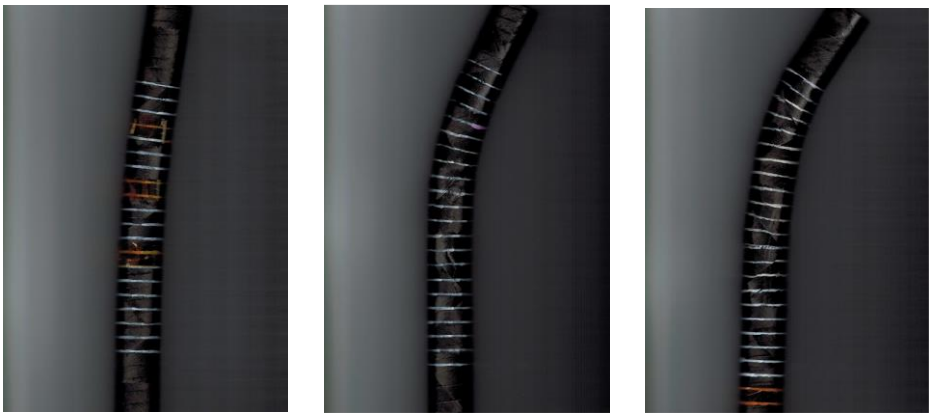
3.2 Result and consideration

Figures 4 (a), (b), (c) show the picture of bent pipe for each temperature target. As the temperature target increases, the curvature radius became small. Figure 5 shows the temperature history of each temperature target. Of the inserted 6 thermocouple, only 4 thermocouples could record temperature through all process. In the temperature history, after the temperature reached to the target, it naturally decreased by removing the heater. And the time from when the heater removed to bending start was recorded to detect the temperature when the bending started. From the recorded time, it was confirmed that bending started at the 595sec, 1080sec and 1090sec point in each temperature history. The temperature recorded at the time bending started was named as process temperature, and is shown in a dot line. Process temperature of each temperature target conditions are shown in Table 1.

From the thickness measured before and after bending, the cross-sectional shape of each temperature target condition was compared. The rate calculated from dividing its thickness after bending by thickness before bending was defined as cross-sectional retaining ratio. Roundness of each tested pipe were evaluated by this rate. Table 2 shows cross-sectional retaining ratio of each direction from 0° to 270°. Although the thickness of 244℃ test pipe increased equally in all direction, either of the cross-sectional shape kept their roundness.

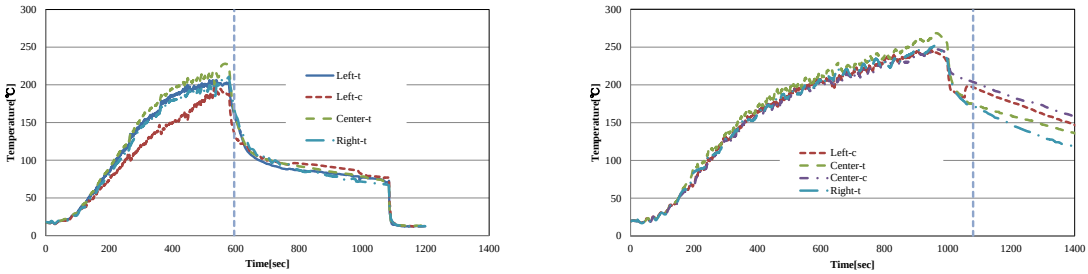
Figures 6(a), (b), (c) show cross-sectional observation of each temperature target. From this picture, the temperature target which is higher than resin fiber melting point made voids between their fiber bundles. By these voids, the thickness of 244℃ test pipe increased. As the 274℃ test pipe was heated in a condition far higher than the melting point, voids and delamination at the outermost layer were observed. To avoid these disadvantages, heater that could maintain their temperature steady at the deflection temperature underload was needed.

Table 3 shows the measured data of contact angle and contact angle difference. Contact angle difference was measured from the center and left end of the bending pipe compared with same position of bending die. Contact angle difference was measured as it was shown in figure 3. The measured contact angle of bending die was in order of 7.59° and 17.58° from left. In this study, contact angle that reaches near to the bending die contact angle was concluded that curvature radius reached the target value. This means that the smaller contact angle difference makes a curvature radius near to the target value. From these results, contact angle difference at the center of the die became larger as the temperature target got lower. Contact angle difference at the left end showed a large value in each temperature condition compared to center. The temperature condition of which showed the contact angle difference to positive number means that an angle is not enough, while negative number means that an angle is large enough. That means, the low temperature condition of 214℃ had not enough contact angle, while 244℃ and 274℃ had enough contact angle for making curvature radius of R500. From these results, most well shaped bending pipe was made by the temperature target of 244℃ which processing temperature is near to the deflection temperature underload.

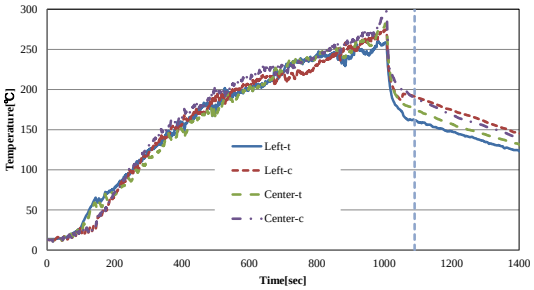


(a)214 ℃ (b) 244 ℃ (c)274℃

Figure 4: Picture of bending pipe.



(a) (b)



(c)

Figure 5: Temperature history
(a)214℃ , (b)244℃, (c)274℃

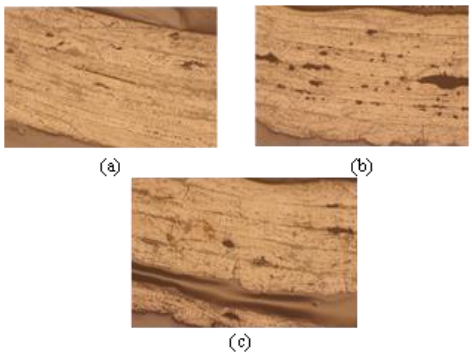


Figure 6: Cross-sectional observation of
(a)214℃, (b)244℃, (c)274℃.

Table 1: Processing temperature.

Temperature target(℃)	Processing temperature(℃)
214	151.8
244	182.1
274	185.5

Table 2: Cross-sectional retaining ratio.

	Average		
	214℃	244℃	274℃
0	0.86	1.17	0.90
90	0.81	1.29	0.93
180	0.84	1.21	0.91
270	0.88	1.28	0.89

Table 3: Contact angle and contact angle difference.

	angle of bending die	214℃		244℃		274℃	
		angle	angle difference	angle	angle difference	angle	angle difference
center(deg)	7.59	4.89	**2.7**	5.71	**1.88**	7.51	**0.08**
left(deg)	17.58	8.41	**9.17**	26.4	**-8.78**	33.0	**-15.46**

4 EFFECT OF TENSIONED DISPLACEMENT.

4.1 Experiment method

In this section, about the effect of tensioned displacement on bending pipe was examined. In metal material bending, tensioned displacement is normally added. But for composite material bending, from the difficult internal structure with anisotropy it has, the added displacement greatly affect their bending workability. Reinforced fibers are strong in the use of tensile direction, though are weak in use of compressed direction. From this reason, bending method that could prevent creases at the inner circumference side must be established. In this study, the displacement which added from the left chuck device is called tensioned displacement.

To examine the effect of tensioned displacement difference on each side of displacement area, three displacement condition of 2mm, 4mm, 6mm were tested. To measure the displacement on both side, white slit was printed on the pipe surface before bending. The way to give tensile load is shown in Figure 7. The displacement amount can be changed by the length of screw that sticks out from the left chuck device. And by measuring the distance between each slit before and after bending, the displacement of each side was compared. To figure out the difference which can be seen from the changed displacement, best condition of 244℃ temperature target was selected for each condition. Contact angle and contact angle difference were also measured to search whether it achieved the target curvature or not. To notice whether the process temperatures were near deflection temperature underload, temperature histories were also recorded at the same position of 138mm, 182mm, and 227mm far from the right chuck device by 6 thermocouples.

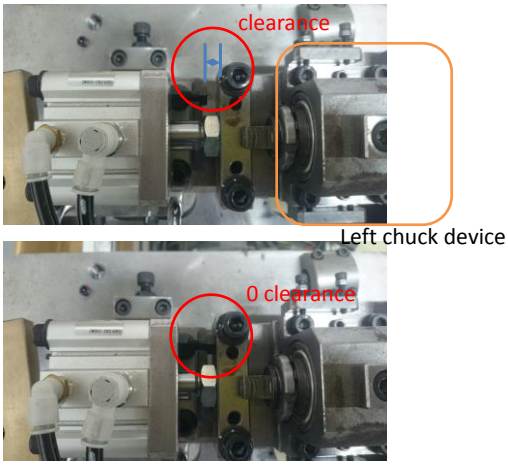


Figure 7: Clearance for adding displacement.

4.2 Result and consideration

The process temperature on each displacement is shown in Table 4. Process temperature was nearly the same between 180℃ to 190℃, which differed only for about 5℃ from deflection temperature underload. The bending pipe by adding each displacement are shown in Figure 8. Three pipe looked nearly the same in bent angle from the visual review. To search the displacement condition of both inner and outer circumference side, the distance between each slit were measured from 180mm far from the head of right chuck device. Figure 9 shows the displacement rate calculated on each slit position of bending area. Displacement rate can be calculated easily by dividing the measured distance after and before. Horizontal axis shows the each slit position and the graph were made from area where the slit distance changed significantly. Also the average were calculated from the position where the pipe began to curve. Table 5 shows the each average rate calculated from the bending position. From the average at compressed area in the Table 5, a tendency to decrease displacement rate as the displacement increased was found out. This means that displacement added during bending process was effective for preventing creases at the inner circumferences side.

Table 4: Processing temperature.

Clearance	Processing temperature(℃)
2mm	189.5
4mm	182.1
6mm	188.8

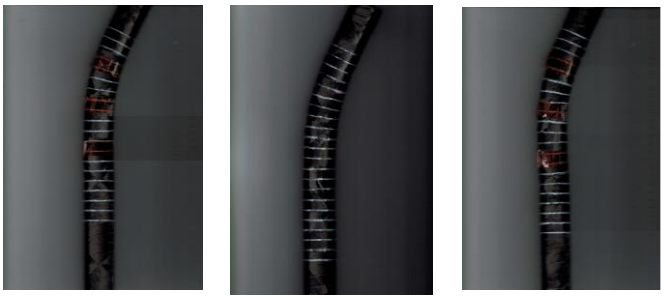
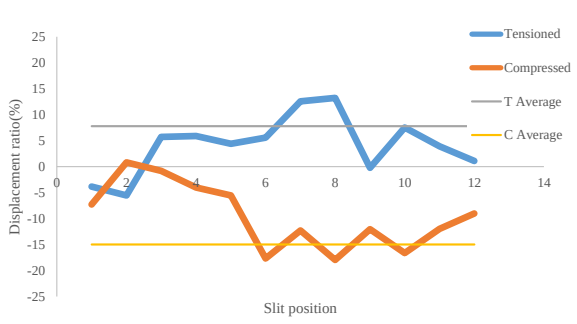
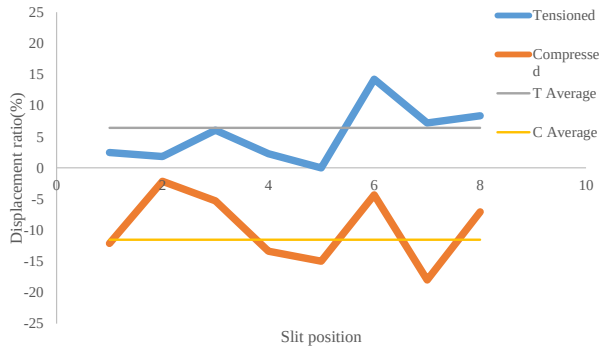


Figure 8: Photograph of each bent pipe



(a) 2mm



(b) 4mm

(c) 6mm

Figure 9: Relationship between displacement ratio and slit position of each displacement.

Table 5: Average rate of each area.

Clearance	Tensioned area average	Compressed area average
2mm	7.79	-15
4mm	6.42	-11.6
6mm	8.07	-11.1

5 CONCLUSION

From the experiment, the appropriate bending temperature was near to deflection temperature underload. And by heating in a condition far higher than the melting point, voids and delamination at the outermost layer were observed. To avoid these disadvantages, heater that could maintain their temperature steady at the deflection temperature underload was needed. Also the displacement added during bending process was searched to be effective for preventing creases at the inner circumferences side. In summary, FRTP straight molded pipe should be bent in a processing temperature of deflection temperature underload by adding certain amount of displacement. And from now on, the appropriate displacement amount will be searched for this study.

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