Effect of Winding Formats on Impact Resistance of Fiberglass Tank

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Abstract
The aim of this research is to study the relationship between winding format and impact resistance of fiberglass tank. The design of experiment was made and then manufactured 750-litre fiberglass tank for six different types. These fiberglass tanks were made of 'chopped strand mat fiber' (a sheet of fiber glass) on the first level and then winding over with glass fiber to reinforce the strength in close format or in cross format. Consequently, samples from these tanks were cut into two different formats: along the winding direction and in diagonal or cross winding format for testing by ASTM standard to study the effect of these winding methods on the impact resistance. The result of this study showed that the winding format in each type yielded distinctive perspective of impact resistance value which suitable for different applications.

Keywords*: Fiberglass, Winding Format, Impact Resistance, ASTM standard*

1 Introduction

The special attention focused on reinforced materials containing various synthesis and natural fibers, including glass fiber, is due to their excellent physical-mechanical properties and promising corrosion resistance [1]. Nowadays, fiber glass tank has been widely used for many purposes such as liquid container, chemical tank, automobile accessories. The main reason of the popular usage is because the fiber glass has advantages of higher toughness, lower manufacturing cost, and longer life span when comparing with parts or structures made of other materials [2]. Many of Small and Medium Enterprises (SMEs) in thailand still rely on skilled labor for fiber winding process that results in slow production rate and inconsistent properties. An automatic fiberglass winding machine was then developed to improve the capacity and manufacturing process of fiberglass tank for waste water treatment to meet customer's demand [3]. In addition, it has been reported that winding angle and number of winding level affect the mechanical properties, specifically tensile, notched and impact resistance and flexural properties of epoxy composite pipe [4,5]. Moreover, the investigation of relationship between fiber winding formats and impact resistance of fiberglass tank would give the valuable information of impact resistance value for each winding format that has not been reported yet. This information will be useful for the manufacturer in order to improve the fiber glass's production process to satisfy customer's need and meet standard better. The present work addresses the reinforcement of fiber glass tank via the winding techniques and to study their impact properties.

2 Experimental Procedure

2.1 *Design of Experiment*

For these trails, fiberglass tank which made of 'chopped strand mat', shown in Figure 1, was used. This so called 'chopped strand mat' or woven was composed of fiber glass sheets by plying fiberglass yarn, shown in Figure 2, in random orientation on another level, consequently getting the fiberglass that is similar to a mat. After the preliminary study of the fiber glass tank industry, it was found that there were two main manufacturing methods: spraying and hand lay-up by using two types of fiber. In this research,

the automatic fiberglass winding machine developed earlier to improve the capacity for fiberglass tank for waste water treatment [3], shown in Figure 3, was utilized to manufacture samples. In addition, the coil winding technique of hot plate in rice cooker to improve its efficiency [6] was applied in this experiment. The samples from automatic fiberglass winding machine can be seen in Figure 4.

Figure 1: 'Mat fiber' manufacturing process

Figure 2: Fiberglass yarn

Figure 3: Automatic fiberglass winding machine [3]

The variables in this study were winding formats and number of winding level (1-3). Therefore, design of experiment was ended up with six different formats which illustrated in Table 1 and Table 2. The first three formats were made of 'Mat fiber' as the base level and then followed by glass fiber in close direction as shown in Figure 5a and Figure 5b. The next three formats were made of 'Mat fiber' as the base level and then followed by fiber in diagonal or cross direction as shown in Figure 6a and Figure 6b. These samples were labeled with roman number (I-III) which represented the number of winding level and letter 'A' represented the close winding, letter 'B' represent cross winding and number of level of glass fiber.

Figure 4: Sample of fiberglass tank from automatic fiberglass winding machine

Table 1: Glass fiber winding format used in this study

Format #	Code	Mat Fiber (level)	Close Winding (level)
1	I - A1	1	1
2	I - A2	1	2
3	I - A3	1	3

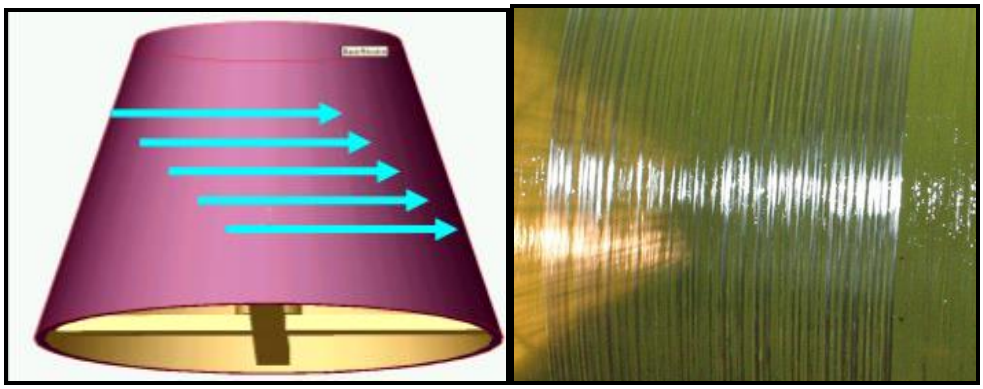


Figure 5a: Schematic of close winding format and **Figure 5b:** Physical close winding format

Table 2: Glass fiber winding format used in this study

Format #	Code	Mat Fiber (level)	Cross Winding (level)
4	I - B1	1	1
5	I - B2	1	2
6	I - B3	1	3

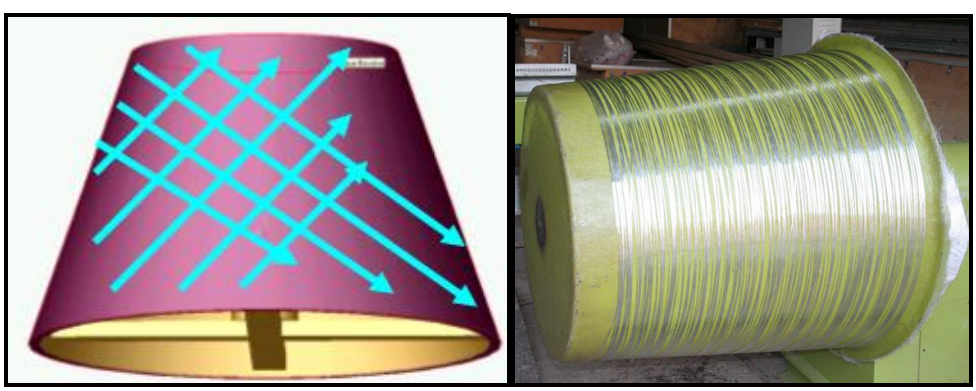
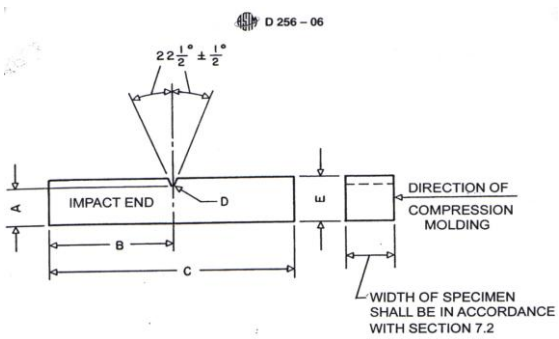


Figure 6a: Schematic of cross winding format and **Figure 6b:** Physical cross winding format

2.2 *Sample Preparation*

Samples were prepared according to ASTM D 256 – 06 standard [7] by cutting into small pieces with dimension of 12.7 x 63.5 mm^2 and average thickness in the range of 2.12-3.77 mm using band saw along winding direction and across winding direction. These samples then were made the v-shape with 45 degree as shown in Figure 7.



	mm	in.
A	10.16 ± 0.05	0.400 ± 0.002
B	31.8 ± 1.0	1.25 ± 0.04
C	63.5 ± 2.0	2.50 ± 0.08
D	0.25R ± 0.05	0.010R ± 0.002
E	12.70 ± 0.20	0.500 ± 0.008

Figure 7: Sample preparation [7]

2.3 *Testing Set-up*

The experiment was performed according to the ASTM D 256-06 standard which is the RESIL IMPACTOR Izod Impact testing machine, shown in Figure 8, and repeated 5 times for each winding format and cutting direction.

Figure 8: Izod impact test set-up

The hammer used for the impact test has energy of 15 J. The experimental set-up can be seen in Figure 9.

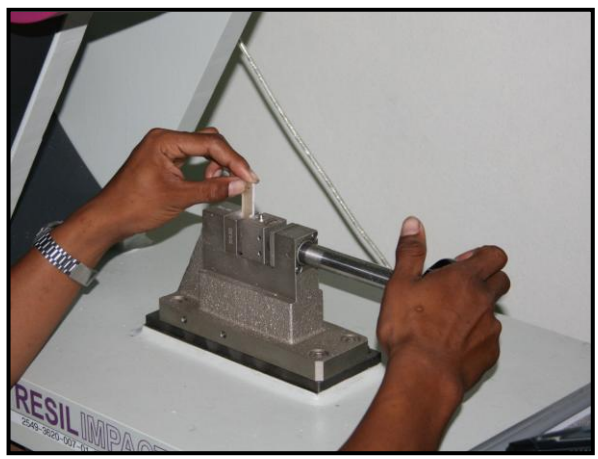


Figure 9: Sample set-up

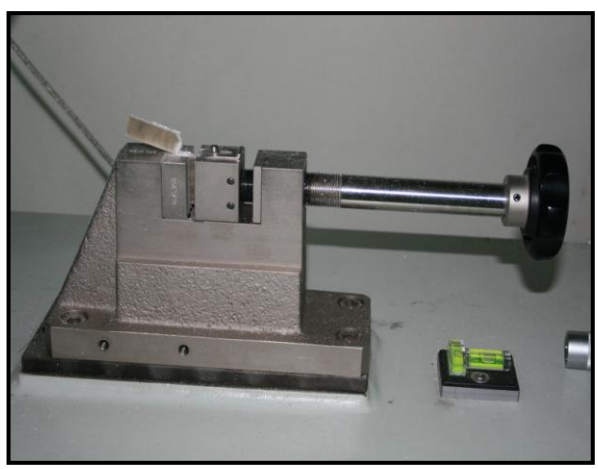


Figure 10: Sample after impact test performed

3 Results and Discussion

Izod Impact test is important method to study the toughness of reinforcing materials [8, 9]. The result of the impact test performed can be seen in Figure 10. It should be noted from the experiment that, impact resistance values of samples cut along winding direction format were in range of 18.42 – 56.57 KJ/m^2 which exhibited huge change when adding more layers for both close and cross winding format. Moreover, it was also found that the sample I-B3 had the highest impact resistance according to results shown in Figure 11.

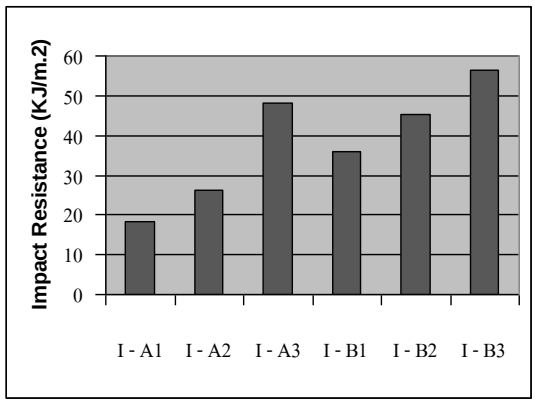


Figure 11: Impact resistance of sample cut along the fiber winding direction

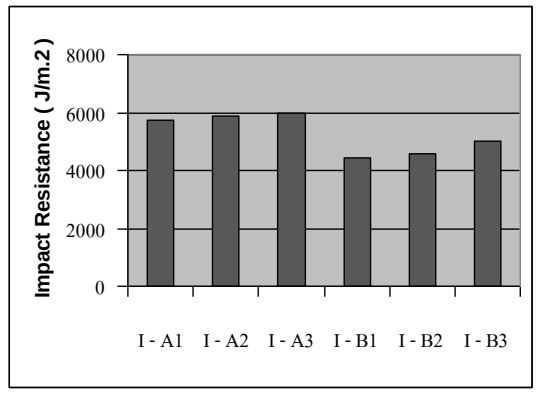


Figure 12: Impact resistance of samples cut across the fiber winding directon

It has been reported that by adding inorganic fiber, such glass fiber, affect the strength and stiffness behavior [10,11]. This is in accordance with the impact observation as shown in Figure 11 and 12. Additionally, the impact resistance values of specimens when cut across fiber winding direction format were in smaller range of 4.45-5.98 KJ/m^2. Besides, it was also found that the sample A3 yielded the highest of impact resistance which illustrated in Figure 12.

From the results shown, one can notice that the more number of level used in glass fiber winding resulted in the higher impact resistance values of fiberglass sample. This can be explianed by the fact that more layers yield more thickness and therefore give the more strength and resistance to the impact. The sensitivity analysis was also conducted to further investigate the percentage increase in impact resistance when number of winding level changes as follows.

Table 3: Comparison of percentage increase in impact resistance values on samples cut along fiber winding direction using close winding format versus using cross winding format

# of Level	Impact Resistance of Close Winding Format (J/m^2)	% Increase in Impact Resistance	Impact Resistance of Cross Winding Format (J/m^2)	% Increase in Impact Resistance
1	18,416	42.95%	36,050	25.24%
2	26,326	82.50%	45,150	25.28%
3	48,045		56,565	

Table 4: Comparison of percentage increase in impact resistance values on samples cut across fiber winding direction using close winding format versus using cross winding format.

# of Level	Impact Resistance of Close Winding Format (J/m^2)	% Increase in Impact Resistance	Impact Resistance of Cross winding Format (J/m^2)	% Increase in Impact Resistance
1	5,724	2.48 %	4,446	-3.46 %
2	5,866	1.94 %	4,600	9.20 %
3	5,980		5,023	

From Table 3 and 4, by using 'chopped strand mat fiber' as base level and winding over with glass fiber in close winding format from one level to two levels and then to three levels yielded considerably increase in impact resistance to 42.95% and 82.50% respectively. This can be explianed by the fact that when cutting the fiber along the fiber winding direction, the fiber lay over one another in the close direction help strengthen the sample. Since the effect of long and continuous fibers with 0^0 orienation gives the samples high force transfer along the composite bundles. The results found here is in accordance to what has been observed by [5]. On the other hand, the values of impact resistance of samples cut across winding direction gave no significant difference in impact resistance values. It was observed just only 2.48 % when adding one layer to two layers and found the impact resistance value of 1.94 % when adding the third layer. However, when using another method by winding over the base level with cross winding format and increased the number of winding level from one to two and three levels and cut specimens in this fiber winding direction resulted in evenly increase in impact resistance of 25.24% and 25.28% respectively. Similarly, for the samples cut across the fiber winding direction provided the increase in impact resistance value to 3.47% to 9.20 % respectively. Again the percentage increase in for the cross winding is similar to the samples from the close winding format. One can notice for above results that, in general, the toughness of the fiberglass tank system is strongly enhanced by increasing winding levels. The preparation techniques, yielding close and cross winding format, have also a great impact on the toughness.

4 Conclusions

The experimental testing was conducted to investigate the effect of winding format to the impact resistance value of fiberglass tank. The results can be concluded as follows:

1. Increasing the number of glass fiber winding level will result in higher impact resistance
2. Each winding format yields different values of impact resistance which suitable for different purposes. For samples cut along fiber winding direction, the cross winding format give the better impact resistance value than using close winding format. On the other hand, samples cut across fiber winding direction, the close winding format give the better impact resistance value than using cross or diagonal winding format. This information will be useful for the manufacturer in order to improve the fiber glass's production process to satisfy customer's need and standard better.
3. The winding formats used in this experiment had only six different formats due to the budget and time constraints. However, future investigation on the samples cut making the angle 45-60 degree with the winding direction would be interesting.

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