EVALUATION OF MECHANICAL PROPERTIES AND FORMABILITY OF GFRP FOR WIND TURBINE BLADE

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Abstract

GFRP with a higher specific strength is generally used for wind turbine blades. For blade molding, the RTM method is commonly employed. This method requires sufficient resin fluidity to ensure stable molding quality. Insufficient resin fluidity can cause problems, such as the inability to achieve the expected material strength. Regarding the effect of fiber specifications on the mechanical strength of molded parts and the effect of using the RTM method on resin fluidity, the following conclusions have been reached. (1) GFRP made by adding a short fiber mat to the material has a higher mechanical strength than that of material without the mat. (2) When the material with the mat is used, the RTM method results in lower resin fluidity. (3) With the molding of larger parts on the horizon, material selection that takes into consideration mechanical strength and formability will be increasingly important.

1 Introduction

Wind power generation has attracted attention as a means of sustainable and clean power generation using natural energy, and it has rapidly become widespread. The global wind power generation capacity reached approximately 47.45 million kW by the end of 2004, ten times as much as 10 years ago. A decade ago, the output power per wind turbine was generally between 300 and 600 kW. Today, large-scale wind turbines generating 1500 to 5000 kW are common. Larger wind turbines require longer blades; blades of about 35 m in length are used for 1500 kW class wind turbines, which are the present common size.

GFRP (Glass Fiber Reinforced Plastic) with a higher specific strength is generally used for wind turbine blades. For blade molding, the Resin Transfer Molding (RTM) method is commonly employed (Fig. 1). This method requires sufficient resin fluidity to ensure stable molding quality. Insufficient resin fluidity can cause problems, such as the inability to achieve the expected material strength because of uneven distribution of resin. Larger blades have higher risk of inferior material strength; eliminating this risk is a critical issue for developing larger blades in the future. The resin properties have conventionally been improved by lowering the resin viscosity and adjusting the cure time, but the impact of different types of glass fiber on resin fluidity has not been discussed in detail.

This study aims to determine the impact of fibers on resin fluidity in molding by examining the mechanical strength (tensile/fatigue strength) and resin fluidity of several types of GFRPs using different fibers. The test results show that GFRP with a non-directional short fiber mat added to the glass substrate provides an improved mechanical strength to molded parts while it has lower resin fluidity upon molding.

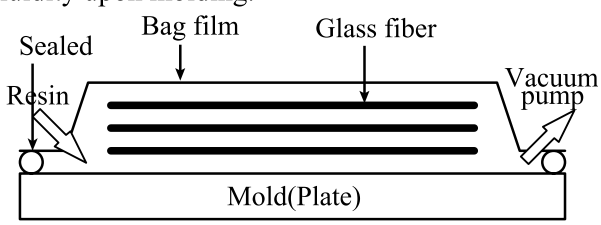


Fig. 1. Configuration of RTM

2 Test method

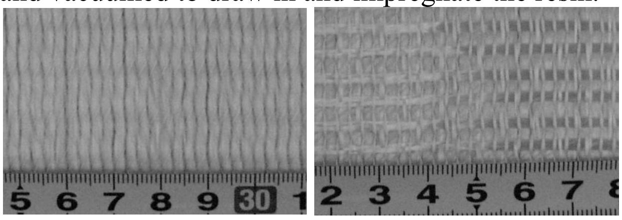
2.1 Material

"Knit fabric" (Fig. 2 and Fig. 3) was used as glass fiber for the GFRP. It is a fabric-like material made from glass roving and polyester yarns. It is widely used for blade molding because it has the advantage of being able to improve the mechanical strength of molded parts without ruffling. The following two types of knit fabric were tested to evaluate the mechanical properties of molded parts and resin fluidity in molding.

- Knit fabric without short fiber mat (Fig. 2)
- Knit fabric with short fiber mat (Fig. 3)

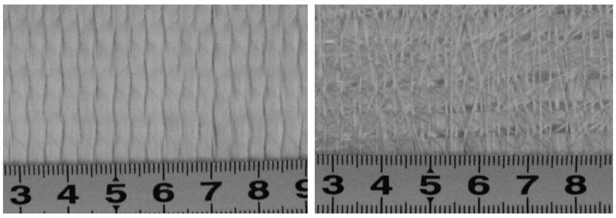
* The fiber direction was uniform (uni-direction).

The matrix composite and molding method were identical for all materials. An epoxy resin of low viscosity, which is actually used for wind turbines, was selected as a matrix composite. The RTM method, frequently used for molding wind turbine blades in recent years, was employed for molding. Two layers of knit fabric were put on each aluminum plate; the plate was sealed with bag film and vacuumed to draw in and impregnate the resin.



(a) Upper side (b) Under side

Fig. 2. Aspect of the fabric without short fiber mat



(a) Upper side (b) Under side

Fig. 3. Aspect of the fabric with short fiber mat

2.2 Strength test

Tensile tests were performed in accordance with JIS K 7054. We used B-II type (strip-shaped with tab) specimens. The crosshead rate was set at 3 mm/min. For each material, ten tests were performed to obtain the average tensile strength in the fiber direction and the coefficients of variation.

Then, tension fatigue tests in the fiber direction were performed in accordance with ASTM D 3479. The stress ratio was set at R = 0.1. To draw S-N curves, 12 specimens were prepared for each material and tested in different stress ranges so that the number of cycles to failure was distributed in a range between 10^3 and 10^6 (max. 10^6 times). The coefficients a and b of each material were calculated by applying the test results in the approximation formula (Formula 1) based on [1].

$$\sigma_R = a - b\log N \qquad (1)$$

where σ_R: stress range, N: number of cycles to failure, and a, b: material-specific coefficients.

2.3 Resin fluidity test

The relationship between "the time elapsed from the start of resin injection" and "the distance from the resin injection point to the resin front" was recorded during the process of molding the specimens (laminated plates) with the RTM method. Assuming that a longer distance with a shorter time indicated higher resin fluidity, we evaluated the resin fluidity of each material. The resin was injected in the direction perpendicular to the fiber direction to prevent easy flow of the resin.

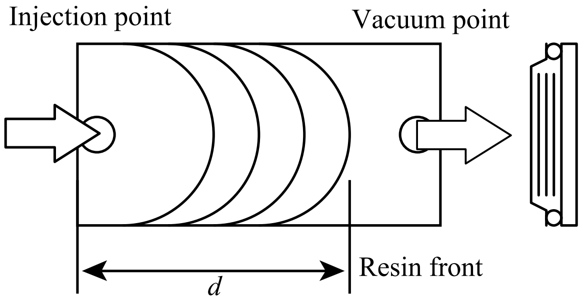


Fig. 4. Resin fluidity test

3 Results

3.1 Mechanical strength

Table 1 shows the results of the tensile and fatigue tests. For the fatigue test, b represents the slope of S-N curves; a lower value of b provides a smaller reduction in strength with repeated stressing, indicating a higher fatigue strength. These results show that, although the fiber volume fractions of the materials with and without the mat are almost the same, the tensile strength and fatigue property (value of b) of the one with the mat are superior to those of the other. The tests have determined that the mechanical properties can be improved by adding the mat, as expected.

3.2 Resin fluidity

Figure 5 shows the results of the resin fluidity test. The resin fluidity was quantitatively evaluated using d (= the distance between the resin injection point and the resin front as measured after two hours). In addition to the results of the mechanical property tests, Table 1 also gives the measured value of this distance. The time period of two hours was chosen taking into consideration the time required for the resin to harden. This result has proven that the resin fluidity of the material without the mat is higher than that of the other.

Table 1. Tensile/fatigue strength and fluidity

	Without short fiber mat	With short fiber mat
Vf (%)	50.1	50.6
Tensile strength (MPa)	783.7	887.7
Fatigue property (value of *b*)	0.143	0.114
Distance to resin front after 2 h (mm)	581	412

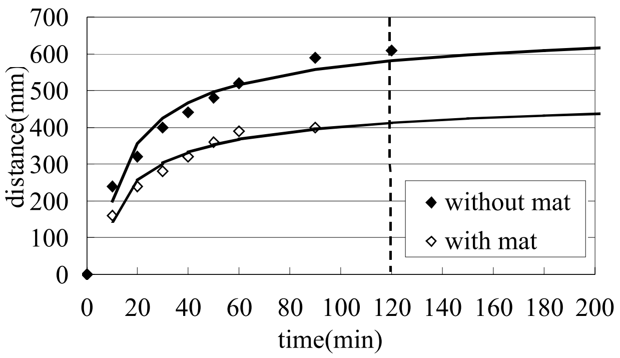


Fig. 5. Resin fluidity

4 Discussion

4.1 Effect of adding the mat on mechanical strength

The mechanical properties (tensile strength and fatigue property) of the material with the mat are superior to those of the other, despite the fact that both materials have almost the same fiber volume fraction. This suggests that there may be a factor or factors that cannot be explained by failure due to fiber breakage, which is predictable based on the rule of mixture. The mechanical properties of the material are improved because the addition of a randomly oriented mat to the crack-susceptible, resin-rich area between the layers on the glass substrate prevents the growth of interlayer cracks, which could cause the layers to peel away. Thus, the mat, when added, provides a higher interlayer strength.

4.2 Effect of adding the mat on resin fluidity

The resin fluidity of the material with the mat decreased 30 %, suggesting that the mat had an effect on resin fluidity. The material with the mat has short fiber glass in the resin flow path (interlayer area); the glass may increase the resistance to and disturb the flow of the resin. This phenomenon causes no significant problem in molding small- and middle-size blades, but it will have a critical impact on the molding of large-size blades that require higher formability.

Figure 6 shows the tensile strength and resin fluidity of the materials with and without the mat, as well as those of GFRPs (refs. 1 to 3) made by different manufacturers. There is a trade-off relationship between the tensile strength and resin fluidity with the former increasing as the latter decreasing. This result also demonstrates that the balance between strength and resin fluidity must be taken into consideration in material selection.

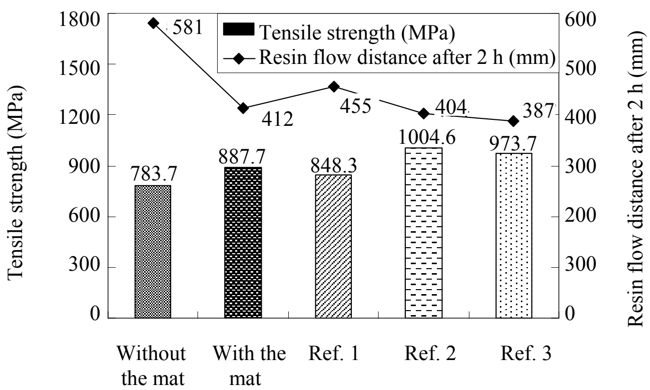


Fig. 6. Relationship between tensile strength and resin fluidity

5 Conclusion

This study focused on the significant effect of resin characteristics and fiber specifications on resin fluidity. Regarding the effect of fiber specifications on the mechanical strength of molded parts and the effect of using the RTM method on resin fluidity, the following conclusions have been reached.

(1) GFRP made by adding a short fiber mat to the material has a higher mechanical strength than that of material without the mat.
(2) When the material with the mat is used, the RTM method results in lower resin fluidity.
(3) With the molding of larger parts on the horizon, material selection that takes into consideration mechanical strength and formability (resin fluidity upon molding) will be increasingly important.

References

[1] Christoph W. Kensche. "*Fatigue of composites for wind turbine*". *Third International Conference on Fatigue of Composites*, 2006.