Adhesive Failure Analysis for Spar-Web Debonding of 5MW Class Wind Turbine Composite Blade using FE Model based on CZM

H. G. Kim[1], Y. J. Jang[1] and K. W. Kang[1*]

[1]Department, Kunsan National University, Kunsan, Republic of korea

[*]Corresponding author: kwkang68@kunsan.ac.kr

1. Introduction

The weight savings of wind turbine blades is recognized as an essential factor in the design phase for performance improvements. Researches on composite blades have been carried out to improve the weight reduction effect and physical properties. In particular, to prevent the increase in weight due to mechanical fastening, the composite blade is made of shear web and skin, and then fastened with adhesive. The advantage of the adhesive is that the loads can be distributed over a wider area than the mechanical fastening method without increasing the weight of the structure. On the other hand, such a fastening method is affected by the environment. In particular, in a blade for a wind turbines, there is a disadvantage that the adhesive section is evaluated as a weak part of the structure, and there is no clear breakage criterion for the adhesive [1-2]. Particularly, in order to evaluate by the analysis, modeling of the bonding condition is required, and a method capable of evaluating the flaw and stress of the bonding model is also required. There is already validated analytical model, Cohesive Zone Modeling (CZM) [3]. In this way, it is necessary to analyze the breakage tendency for the bonding condition at the weakening section.

In this paper, we used the CZM method in ABAQUS[4] to model the bonding part of the spar-web fastening structure of a composite blade structure for a 5 MW wind turbine, and to evaluate the safety of the structure under ultimate load conditions, The progressive failure analysis was also analyzed for 5MW wind turbine. .

2. Analysis method

2.1 Cohesive zone model

The 5MW composite blades in SANDIA report [5], were evaluated for structural integrity under the integrated load conditions according to IEC 61400-3 [6]. These loads were applied to the FE model shown in Fig. 1.

The CZM method, which is a technique to simulate the defect growth of adhesive, was applied to describe the adhesive at the spar - web structure of the model evaluated for structural integrity. In order to apply the CZM method, the interlaminar fracture toughness is required to simulate the directional behavior under the ultimate loading condition in the composite blade, and the properties were selected through the experiments and references. Progressive fracture analysis was performed to analyze the fracture behavior of the blade spear - web adhesive joint in accordance with the loads at the initial failure position.

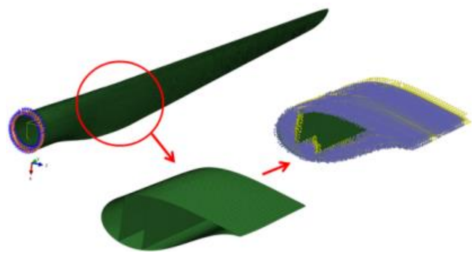

Fig.1 Finite element model of wind turbine blade

2.2 Failure evaluation

Since the loads applied to the composite blade exits in a mixed mode load rather than a single load, the interaction between the loads should be considered. To account for these interactions, two conditions were used for the analytical method of the adhesive in this study. First, the quadratic nominal stress criterion (QNS criterion) proposed by Gui et al. [7] was applied to identify the flaw or defect initiation. Second, the defect growth was occurred after the initial failure and the progressive failure evaluation was performed by applying the Benzeggagh-Kenane (B-K criterion) criterion which is the riterion of the defect growth failure. This is an evaluation method which is one of the energy bases widely used in the evaluation of interlaminar damage progress under the mixed mode loading conditions is applied, and the interlaminar fracture toughnesses of Mode 1, Mode 2, and Mixed Mode are required. The above-mentioned QNS and B-K reference equations are shown in Table 1.

Therefore, the method of this study is as follows: First, the load is calculated by the combined load analysis on the wind turbine. Second, structural safety evaluation was carried out using the calculated load. Third, the CZM technique was applied through the interfacial fracture toughness test and the analytical verification. Fourth, the debonding phenomenon and the structural integrity of the blades were evaluated. This is shown in Fig. 1.

Table 1 Table caption must be centered

Criterion	Failure condition
QNS criterion	$\left(\frac{\sigma_n}{N_{Max}}\right)^2 + \left(\frac{\sigma_s}{T_{Max}}\right)^2 + \left(\frac{\sigma_t}{S_{Max}}\right)^2 = 1$
B-K criterion	$G_{IC} + (G_{IIC} - G_{IC})\left(\frac{G_{shear}}{G_T}\right)^{\eta} = G_C$
N_{Max}: Interlaminar fracture nominal strength T_{Max}: Interlaminar fracture Tensile strength S_{Max}: Interlaminar fracture Shear strength $* \, G_C = G_I + G_{shear}, G_{shear} = C_{II} + G_{III}$	

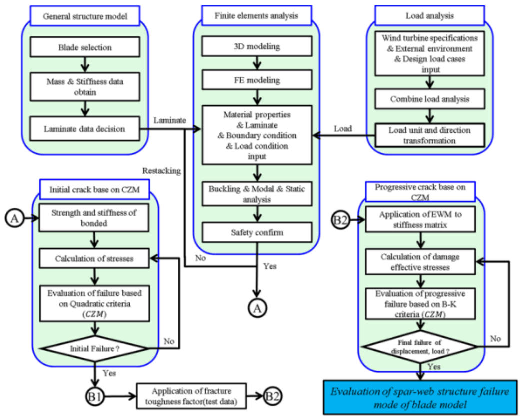

Fig.3 Analysis of wind blade based on CZM method

3. Results and Discussion

3.1 Composite blade safety analysis

We evaluated the structural integrity of 5WM composite blades was carried out using the FE analysis. Figs. 3 and 4 exhibit the modal analysis and static analysis results, respectively.

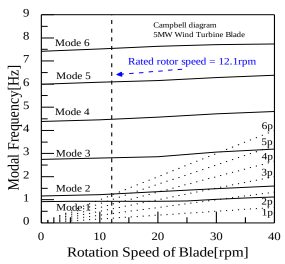

Fig.3 Campbell diagram of wind turbine blade

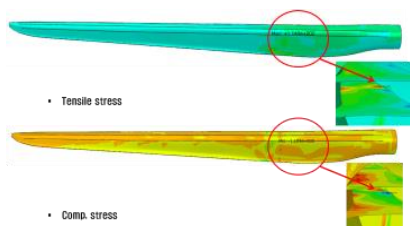

Fig.4 Stress shape of wind turbine blade

3.2 Adhesive Failure analysis

The bonding at the spar - web joint of the composite blade was modeled using the CZM, and the progressive failure analysis was performed under the combined mode loading conditions

4. Conclusion

In this paper, the progressive failure behavior of 5MW wind turbine composite blade was analyzed using the cohesive zone model and relevant interlaminar fracture toughness obtained from the experiments

Acknowledgment

This research was supported by the Korea Institute of Energy Technology Evaluation and Planning (No. 20173010024950, 20173010024870) and Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education (NRF-2016R1D1A1A09918310).

References

[1] D. G. Schesser, Unified Cohesive Zone Model for Damage Modeling Due to Cyclic Loading, *Open Access Dissertations*, (2015) 1404.

[2] May, M., Harper, P. W. and Hallett, S. R., 2018, "A Study on the influence of fatigue damage initiation laws for cohesive zone models in propagation-driven load cases," AIAA SciTech Forum.

[3] Kim, J. W., Shin, K. B. and Hwang, T. K., 2013, "Study on the Progressive Failure for Joint Part of Composite Pressure Vessel using CZM," The Korean Society of Propulsion Engineers, pp. 356~360.

[4] ABAQUS Ver. 2018, Dassault Systems Simulia, Inc.

[5] Brian, R. R., 2013, "Definition of a 5MW/61.5MW Wind Turbine Blade Reference Model. ", Sandia report SAND., 2013-2569.

[6] International Standard, IEC 61400-3, 2005, "Wind turbines – Part 1 : Design requirements," third edition.

[7] Cui, W. C., Wisnom, M. R. and Jones, M., 1992, "A Comparison of Failure Criteria to Predict Delamination of Unidirectional Glass/Epoxy Specimens Waisted Through the Thickness", Composites, Vol. 23, No. 3, pp. 158-166.