Evaluation of Residual Strength of Hole-Notched Plain Woven CFRP Composite under Fatigue Load

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Introduction

Unlike metallic materials, it has been known that FRP(fiber reinforced plastic) has various types of fracture mechanism~~s~~ such as delamination, debonding, and fiber breakage, etc. Because of such fracture characteristic~~s~~, it is impossible to analyze the notch effect~~s~~ in FRP by only considering the stress concentration factor.
In test results of the residual strength of composite material with a notch under fatigue load, it is worth paying attention to the fact that the residual strength after fatigue loading increases, compared to static failure strength. This phenomenon in the FRP material was explained by the assumption that at the initiation of ~~a~~ crack generation, fracture does not occur immediately and after the material stores cracks, they cause the stress-redistribution under repeated fatigue load[2, 3].
The purpose of this study is to experimentally estimate the residual strength of CFRP composite materials with a hole under fatigue loading, and to suggest the prediction-formula for the residual strength using the stress-redistribution function and the residual strength decrease model for un-notched specimen.

Residual Strength decrease model

Broutman and Sahu[(1)] suggested a linear-decrease model on the assumption that the residual strength of a un-notched specimen decreases linearly under fatigue load.
But, many researchers have subsequently verified the fact that the residual strength under fatigue decreases non-linearly. So, Reifsnider suggested non-linear decrease model by applying a non-linear variable, k, to the model of Broutman's [(2)].
Yip explained that the increase of residual strength is caused by the reduction of stress concentration and the stress-redistribution by stored fatigue cracks [(3)].
In this paper, we modified the residual strength decrease model and the stress-redistribution function for un-notched specimen into a proper function for notched material, and using this function, we suggested the residual strength decrease model for hole-notched specimen as Equation(1).

$$\frac{\sigma_{HR}}{\sigma_u} = \frac{\dfrac{\sigma_N}{\sigma_u} - \left(\dfrac{\sigma_N}{\sigma_u} - \dfrac{\sigma_{app,\max}}{\sigma_u}\right)\left(\dfrac{n}{N_f}\right)^k}{1 - \left(\dfrac{n}{N_f}\right)^q \times \left(\dfrac{\sigma_{app,\max}}{\sigma_u}\right)^p} \qquad (1)$$

Experimental

Materials
In this study, laminate was produced with a thickness of 3.52 mm (16plies) from WSN3K (thickness=0.27 mm). WSN3K is a fabric (plain woven) CFRP prepreg by the SK Chemicals Company. According to ASTM D 3039-07[(4)], specimens were cut in the fiber direction of 0°/90° and the width of 25 mm by NC machine. A center hole in the specimen was bored with an ultra hard metal drill of diameter 1 mm to prevent damage, such as delamination.

Apparatus and Procedures
The fatigue tests were performed during 10,000, 100,000, 200,000, 300,000 and 500,000 cycle under 93% of the failure load with a universal testing machine (model 8802) of a 250 kN capacity by the Instron Company. In the fatigue test, stress ratio (Min. stress/Max. stress) was 0.1 and test speed was 5Hz. And then, we obtained the residual strength data of the damaged hole-notched specimen by static fracture tests.

Results and Discussion

From a result of the experiment, it is found that the residual strength of hole-notched specimen under fatigue load slowly increases at the beginning of the fatigue test, dramatically increases after slow increasing, and decreases. By applying the test results to the residual strength decrease model equation (1), we determined the variables to k=7, p=4.8, and q=0.6 by the least square method. Test results and curve by equation (1) are shown in Fig.1.
This result agrees with the reports that residual strength increases due to the fatigue load in the case of notched specimen of FRP[(3)]. It is thought that this phenomenon is caused by the decrease of stress concentration in the tip of the notch due to the extension of the load-directional

crack as shown in Fig. 2. Fig. 3 shows the load-directional crack having taken place on specimen in this study.

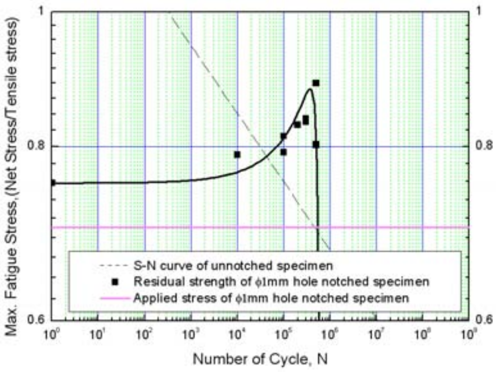
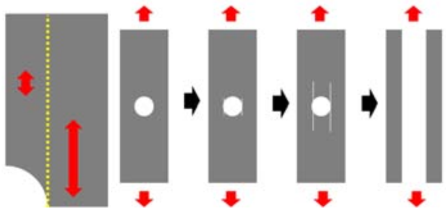


Fig. 1 Test results and degradation curve of residual strength for hole notched specimen



(a) (b)

Fig. 2 Schematic of fatigue behavior for hole-notched specimen

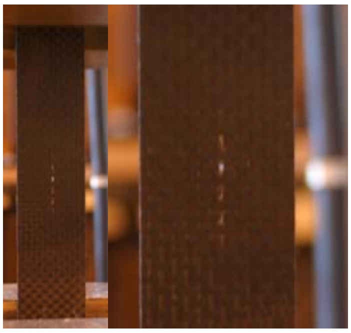


Fig. 3 Picture of vertical crack on hole notched specimen

Conclusion

In this study, we measured the residual strength of hole-notched specimen under fatigue loading by using plain woven CFRP composite materials. And we suggested a residual strength estimation model for hole-notched specimen. From this study, we can get the conclusions such as followings.

(1) In the case of hole-notched specimen of CFRP, it is found that after the residual strength increases up to a certain level, it dramatically drops according to the increase of fatigue cycle.

(2) It is thought that this phenomenon is caused by the decrease of stress concentration in the tip of the notch due to the extension of the load-directional crack

(3) In this study, we suggested a residual strength decrease model for hole-notched specimen and can see that the suggested prediction-formula agrees with test results.

Acknowledgments

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Reference

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