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【論文の内容の要旨】

Carbon fiber reinforced plastics (CFRP) possesses a superb strength and stiffness to weight ratio, and the use of CFRP for light weight structures is increasing tremendously, such as in airplane and car structures. However, conventional CFRP laminate are prone to delamination due to the weakness in the thickness direction. To overcome this problem, stitching process has been attracting a lot of attention. This thesis aims to evaluates experimentally and numerically the capability of stitching to increase mode II delamination behavior of CFRP.

Introduction to stitched composite, as well as literature review, objectives and layout of the thesis are presented in Chapter 1. Unlike opening mode testing, shear mode delamination testing of stitched composites is facing many problems. During end notched flexure (ENF) test that is widely used for mode II interlaminar toughness, the specimens are failed before crack propagation. Furthermore, the crack bridging mechanism by the stitch threads are not clearly evaluated due to its difficult testing condition. Objectives of this thesis are to overcome the current situations, by developing a suitable delamination test for stitched laminate, evaluating effect of stitching parameters on the delamination behavior, investigating the crack bridging mechanism, finally demonstrating delamination behavior of end notched flexure (ENF),

four point end notched flexure (4ENF), and quasi static indentation test.

Effects of stitching parameters (stitch density and stitch thread thickness) are described in Chapter 2. A modified method called tabbed end notched flexure (TENF) test is proposed by embedding high strength aluminum plates on top and bottom side of specimens. The results showed that for the specimens with low stitch density, the crack propagates suddenly to the center of loading, but for high stitch density, the crack propagates step by step. Therefore, there is almost no increment of energy release rate at lower stitch density. The effect of stitch thread thickness is revealed only in high stitch density. The energy release rates of specimen with high stitch density and thicker stitch threads are 2.4 times higher than those of unstitched one. Additionally, local fiber volume fractions are also investigated using burn-off test. The results exhibit that increased local fiber volume fraction due to stitching process explain the reason of decreasing critical energy release rate (up to ten percent) at initial crack length (25 mm).

Finite element (FE) simulation of tabbed end notch flexural (TENF) test is demonstrated in Chapter 3. In this FE model, the interaction between stitch threads and composite laminate become most important. Therefore, a novel interlaminar shear test (IST) of single stitched laminate is performed. The load displacement curve that obtained by IST is then applied to FE model using spring connector element and cohesive zone elements are used to simulate crack propagation. A parametric study is also conducted to find suitable cohesive zone parameters. The predicted load-displacement and crack length vs. displacement curve obtained by finite element analysis show excellent agreement with the experimental results.

A numerical investigation of using four point end notch flexural (4ENF) test is reported in Chapter 4. Compared to ENF test, 4ENF test provides stable crack propagation. The feasibility studies of using 4ENF test with and without tabs are conducted and similar modeling techniques with ENF model are adopted. The results show that the general 4ENF test (without tabs) is quite enough to evaluate critical energy release rate at initial crack length, but it has limited capability to be used for obtaining R-curves (crack propagation length vs. displacement). Based on stress distribution along the thickness direction, it seems that 4ENF specimen without tabs prone to be damaged before the crack reaches the center of loading span. Therefore tabs are needed in 4ENF test.

In the case of low velocity impact loading, mode II delamination is the dominant type of delamination in composite laminate. Therefore finite element simulation of quasi static indentation which is widely used to represent low velocity impact

response is demonstrated in Chapter 5. In this FE model, matrix crack is simulated following Hashin`s criteria. The FE result indicates good agreement with the experiments in term of delamination shape, but gives smaller delamination area. Thus it is need to modify the parameter for damage propagation criteria of the matrix crack.

The thesis is summarized in Chapter 6. It could be concluded that stitching has capabilities in enhancing mode II delamination toughness. For particular stitching parameter used in this thesis, the increment could reach 2.4 times of unstitched one. It is also concluded that tabbed end notch flexural test (TENF) has to be used for stitched laminate application. Tabbed 4ENF test is also recommended because it creates stable crack propagation, and provide the possibility to get more data in one test specimen. Furthermore the FE modeling techniques proposed in this thesis show the capabilities to simulate various cases of delamination.