DAMAGE EVALUATION OF COMPOSITE LAMINATES WITH VARIOUS FIBER PREFORM

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1 Introduction

The essential difficulty to evaluate the strength properties of composite materials lies in the fact that they are fabricated by composition of much different phases and configurations of constituent materials. It is generally difficult to make a precise prediction on the resulting strength of composite materials even if constituent materials are completely characterized. It is more difficult to predict the durability and the reliability since the failure process of composite materials is a very complicated damage growth process even for basic unidirectional and cross-ply laminates. It is one of the eternal problems in composite materials engineering.

As rather complex fiber preform such as multi-axial knitted fabric laminates has recently been applied, a three-dimensional characterization has been required on the internal damage morphology as well as basic plain woven fabric and quasi-isotropic laminates. The recent achievements in application of integrated experimental damage evaluation methodology to composite laminates are illustrated and discussed with special reference to impact damage and its growth behavior of multi-axial knitted fabric CFRP in comparison to plain woven fabric and quasi-isotropic CFRP laminates.

2 Three-Dimensional Observation of Damage

The applicability of existing non-destructive evaluation (NDE) methods has not yet been made clear on the unified comparative basis. For example, as the ultrasonic C-scan produces a good image showing the shape, size, location and depth of delamination-like damage, it is generally difficult to detect crack-like damage in composite laminates. On the other hand, a cross-sectional observation is a destructive method to give a fine microscopic view of damage. This method is usually performed selectively only on one or two sections since the procedure is laborious. If the systematic multiple cross-sectional observation is performed and synthesized, it can give a fine view of damage or defect distribution in composite laminates.

The both images observed by ultrasonic C-scan device and multiple cross-sectional observation give different plane information each other about the internal damage, and the information obtained is evaluated synthetically as schematically shown in Fig.1. This methodology can also be applied directly to visualize how the damage grows under fatigue loading as schematically shown in Fig.2.

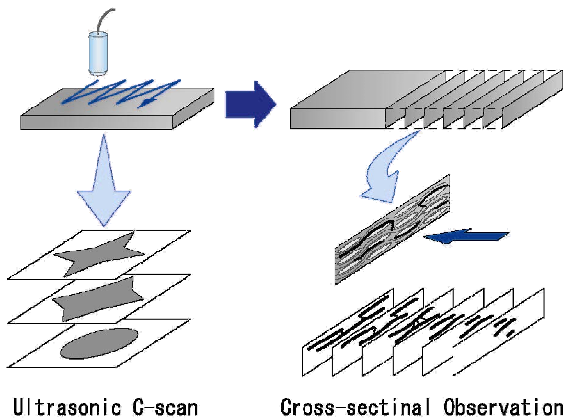

Fig. 1 Three-dimensional damage observation methodology.

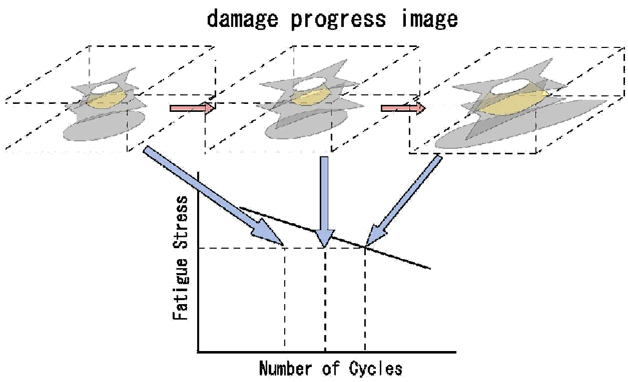

Fig. 2 Three-dimensional damage progress image.

These approaches were shown to be effective in constructing a three-dimensional damage distribution image in terms of complicated combinations of delamination and transverse cracks and successfully applied to characterize the internal impact damage and its growth behavior of multi-axial knitted CFRP laminates manufactured by vacuum assisted resin transfer molding (VARTM) method in comparison to basic plain woven fabric CFRP laminates for marine use [2, 3].

3 Characterization of Post-Impact Fatigue

A better understanding of post-impact fatigue behavior is very essential for structural reliability of CFRP laminates applied for primary structures, especially under variable amplitude fatigue loading.

Damage growth behavior is observed from the opposite side of impact side of coupon specimens by thermo-elastic stress analyzer (TESA) and ultrasonic scanning device. The former device can give in-situ damage growth images, and the latter can give internal damage information by sampling together with multiple cross-sectional observation. These two approaches are integrated and synthesized as shown schematically in Fig.3.

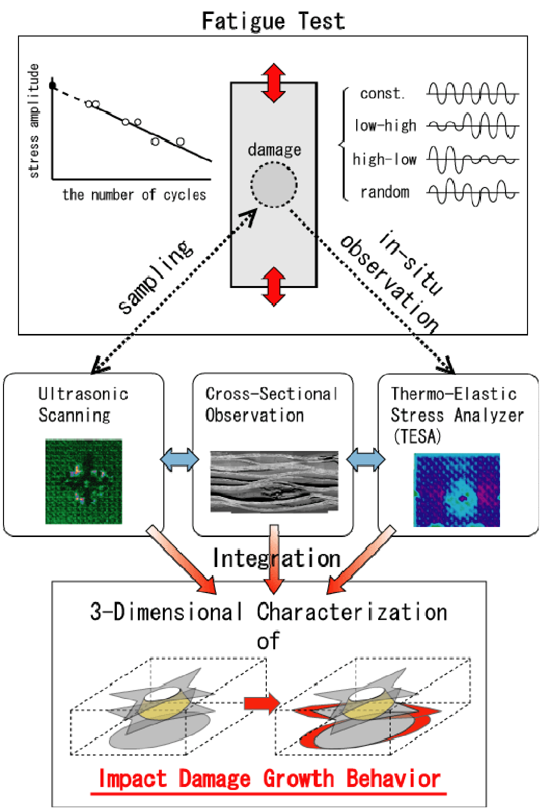

Fig. 3 Integrated damage evaluation methodology.

Under such variable fatigue condition, it is reported that fatigue life is significantly affected by the sequence of variation of stress amplitude. For example, it is well known that fatigue test under ‘low-high’ load sequence shows shorter life than that under constant amplitude and under ‘high-low’ load sequence, that is, the Linear Cumulative Damage law can not be applied to the variable amplitude fatigue. The proposed methodology was applied to characterize the three-dimensional configuration of impact damage and its growth behavior under variable amplitude fatigue loading for CFRP quasi-isotropic laminates. The invalidity of Miner’s law was discussed in terms of different damage growth mechanisms under different amplitude sequences [1].

4 Towards Damage Tolerance Design

There has still been a big gap between characterization of damage behavior of composite laminates with various fiber perform and laminated composite structures. It is expected to give a detailed visual data-base on various damage configurations in order to construct a more realistic damage modeling. A realistic numerical simulation should be useful together with some innovative design methodology to fill the gap towards the real damage tolerance design.

Acknowledgement

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References

[1] Saito, H., Takeuchi, H. and Kimpara, I. “Evaluation of damage growth of impacted CFRP laminate under variable amplitude fatigue”, *Proc. 9th Japan International SAMPE Symposium & Exhibition (JISSE-9)*, Tokyo, pp S4-15, 2005.

[2] Saito, H. and Kimpara, I. “Evaluation of Impact Damage Mechanism of Multi-axial Stitched CFRP Laminate”, *Composites Part A*, Vol.37, pp 2226-2235, 2006.

[3] Kimpara, I. and Saito, H., “Long-Term Durability and Damage Tolerance of Innovative Marine Composites (NICOP); Part II: Post-Impact Fatigue Behavior of Woven and Knitted Fabric CFRP Laminates for Marine Use”, *Materials System*, Vol.25 , 2007 (in press).