Available online at www.sciencedirect.com
ScienceDirect
Comput. Methods Appl. Mech. Engrg. 326 (2017) 1–19
Computer methods in applied mechanics and engineering
www.elsevier.com/locate/cma

Composite laminate oriented reliability analysis for fatigue life under non-probabilistic time-dependent method

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Received 8 March 2017; received in revised form 22 May 2017; accepted 26 July 2017
Available online 6 August 2017

Highlights

- The measurement of composite structural reliability under the non-probabilistic time-variant uncertainties is defined mathematically.
- By virtue of the first-passage theory, a new technique of time-dependent reliability model for composite structure is conducted.
- For structural fatigue reliability issue, the time-dependent model and the time-independent model is discussed.

Abstract

The problem of composite laminate fatigue assessment under small samples and less probability information is always concentrated, and the mechanical properties of composite structure are deteriorated due to damage accumulation effect of fatigue issue. On the basis of analyzing the current reliability modeling method, this paper developed the reliability evaluation strategy based on the non-probability theory, and considering composite structure response to the external cycle load influence, time-varying reliability analysis model is established, which is different from the quasi-static analysis method, and finally the application for composite structure fatigue problem based on the non-probability of the time-varying reliability analysis is put forward. In the proposed method, every single layer reliability is analyzed combining the non-probabilistic theory with Tsai–Wu failure criterion model, comparing with the traditional probabilistic reliability theory, the method of non-probability is not constrained by probability distribution information, in view of that, the approach has stronger practicability; Introducing for the first-passage conceptions, the crossing rate is evaluated through the non-probabilistic reliability method, finally the time-varying reliability index of composite material structure is established. After analysis steps are given in detail, laminated plate structure is presented to demonstrate the validity and reasonability of the developed methodology.

Keywords: Non-probabilistic; Time-dependent reliability; The first-passage theory; Composite laminate; Tsai–Wu failure criterion

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http://dx.doi.org/10.1016/j.cma.2017.07.029
0045-7825/

1. Introduction

Composites have been widely applied to engineering by virtue of its superior performance. Therefore, the safety estimation of mechanical property and reliability for composites have been hot topics that researcher focus on. Current composite structure reliability analysis not only needs to meet the static strength but also fatigue strength, even the damage tolerance strength, composite structure fatigue issue exists widely in engineering application, for instance the composite wing under external cycle load generated fatigue damage with increase of cycling times, thus the composite fatigue subject becomes also an obstacle to reliability assessment. Therefore, composites fatigue reliability analysis method is put forward aimed at the above difficulties. Kam [1] presented modified β-method to study the laminate fatigue reliability under spectrum stress combining the different damage models and fatigue experiment data, which demonstrated the method is applicable. Talreja [2] developed a two-stage reliability model considering composite laminate fatigue damage, the fatigue damage is described by residual strength which obeys Weibull distribution based on experiment data. Post [3], Cheng [4] and Xiong [5] introduced a residual strength degradation model for predicting the fatigue life of composites and determined the accumulation of damage, furthermore developed the fatigue reliability analysis method based on residual strength theory The above literatures show that composite structure fatigue reliability analysis method based on residual strength model has been matured theoretically and made great progress.

However, due to the complex manufacturing process, the material properties of composites tend to be more scattered than metallic, besides, the load variation, and the measurement error, these uncertainty factors are also necessary to consider for evaluating composite reliability issues in engineering problems. the above researches treating composites uncertainty parameters is to utilize random variables probability distribution function (PDF), but it is emphasized that composite high testing cost, furthermore, experiment data acquired is limited, then PDF is difficult to acquire with limited information in many complex structures where traditional probabilistic reliability solution method is not applicable any more. Therefore, some new methods are proposed to overcome the difficulty of insufficient probabilistic information. Ben-Haim [6] firstly proposed the concept of structural reliability based on the convexity theory. Almost simultaneously, Elishakoff [7] gave the definition of a non-probabilistic safety measure deduced from interval analysis. They provided a new method to solve the reliability assessment issue which is lack of probabilistic information. Luo [8,9] et al. proposed one method to deal with composite beams reliability under cyclic loading issue with probabilistic and non-probabilistic uncertainties and further carried out design optimization. Qiu et al. [10–12] established the fatigue reliability solution methodology based on interval reliability analysis method and residual strength theory, and have taken the lead in application of aerospace composite structures. Considering the uncertainty parameters variety, An [13] et al. built a hybrid fatigue reliability model for composite plate under probability and non-probability variables and complete reliability analysis by adopting the "stress–strength" theory. Similarly, the complexity of composite structures is taken into account, Jiang et al. [14,15] developed a new composite structural reliability analysis method for complex engineering problems by integrating the response surface (RS) technique with the convex model approach. In addition, some exploratory works had been carried out by Du et al. [16], Yang et al. [17] and Wang et al. [18]. It is observed that the non-probabilistic reliability measure is provided to overcome the lack of probability distribution information.

Although non-probabilistic reliability analysis theory has become one efficient approach to deal with the issue of limit probabilistic information, it is necessary to emphasize for composite structure fatigue reliability assessment, the most work were concentrated on time-independent reliability. However, response of composites structure in the life span is a dynamic process, which means the property of structure varying with time calculated, structural strength and stiffness present degradation state with external load cycle continuing, the previous cyclic loading time impact on next time should be considered. Thus traditional static reliability assessment is not reasonable, which can only provide us the instantaneous information at a specific instant time rather than take into account the time-dependent of structure performance. In view of this, significant researches have been carried out to deal with the time-varying subject. Kameda explained the definition of time-dependent reliability. A new attempt had been made by Kuschel [19,20], in which structural reliability was determined by the first passage theory. Stewart [21–23] presents a spatial time-dependent reliability analysis to predict the failure likelihood for reinforced concrete structures exposed to changing climate environment. Wirsching [24] established time-dependent reliability model for the metallic structure under fatigue load, utilizing the first passage theory and fatigue growth model. Du [25] et al. developed a time-dependent reliability analysis methodology based on up-crossing rate theory for river-based composite hydrokinetic turbine blades. Two efficient methods for time-dependent fatigue reliability are proposed by Mahadevan [26] on a