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A study of various indicators to determine the fatigue limit for woven carbon/epoxy composites under self heating methodology

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Abstract

The main objective of this paper is to present three indicators to determine the fatigue limit of woven carbon-fiber epoxy-matrix laminates using the Self-Heating test method. The approach adopted in the self-heating methodology consists usually in plotting the heat transfer indicator values versus the maximum stress values. This plot is named the self-heating curve and from the profile of the self-heating curve, one can identify the fatigue limit. During the self-heating experiments, the temperature of the specimen increases with the number of applied cycles and then stabilizes after a certain number of cycles. In this study a novel "peak-temperature point" approach was identified as the most suitable methodology to determine the fatigue limit for a class of composite materials. The paper also sheds some light on how a suitable approach can be chosen to uphold the economic aspect of the self-heating methodology. The purpose of the present paper is to validate this approach for an impacted laminate.

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Keywords: endurance limit ; self-heating ; heat transfer behavior ; carbon/epoxy, woven, composite

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1. Introduction

CFRP structures have mostly replaced aluminium and steel, primarily due to their high strength and high stiffness to weight ratios, which are more than five times greater than conventional structural materials. Therefore, it is of utmost important for the scientific society to clearly understand the mechanical properties of these fibre reinforced composite materials, and especially the fatigue properties. CFRP composites are highly anisotropic and hence have complex failure mechanisms. Wöhler curves have been used to estimate the fatigue life of metals as well as composite materials [1-4]. The determination of the fatigue limit of materials is mostly time consuming and expensive. To have a quick determination of fatigue limit of materials, a quite new methodology named the Self-Heating methodology was adopted by several researchers for metals [5-9] and composites [10-11]. This methodology has been proven successful in evaluating the fatigue limit of unidirectional and woven CFRP materials without any inherent flaws. The fatigue experiments based on the self-heating methodology take only a couple of hours (maximum of one day) in comparison to the conventional fatigue tests which takes months to produce results. This paper presents the different approaches that can be adopted in the self-heating methodology, such as the stabilisation approach, temperature slope approach and a novel "peak-point approach", to determine the fatigue limit of woven carbon fibre epoxy matrix composites which has inherent flaws due to its manufacturing processes. The new approaches described in this paper have the potential to widen the scope of the self-heating methodology for evaluating the fatigue limit of CFRP materials with prior damage or flaws. The approaches proposed have been validated by comparing the results with the conventional fatigue tests (Wöhler curves) results.

2. Self-Heating Methodology

This methodology is based on the link between heating effects and damage mechanisms during fatigue loading. It consists of applying a loading sequence of cyclic blocks. These several blocks consist of fatigue loads cycled at a low frequency in order to prevent the influence of temperature on the dynamic response of the material. Similar to a conventional fatigue tests, here we can also force either the mean stress (σ_m) parameter as a constant or the stress ratio (R) as a constant during the fatigue loading. After each block of cyclic loading, adequate resting time is provided so that the surface temperature of the specimen reaches the room temperature. This cancels the possibility of any carry over of temperature from the previous loading blocks on the successive blocks. An example of this methodology is represented on figure Fig. 1, where the mean stress is kept as constant during the entire duration of the test. During the fatigue cycling, the average surface temperature of the specimen increases with the number of applied cycles and is found to stabilize (attains thermal equilibrium) after a few cycles. The usual approach in self-heating methodology is to record this mean stabilisation temperature or the stable-state temperature ($\theta_{stabilised}$) per block as shown in figure Fig. 1, such as $\theta_{stabilised\ 4}$ and $\theta_{stabilised\ 5}$ corresponding to the loading blocks 4 and 5. These stabilised temperatures are then plotted versus the maximum stress amplitude in their corresponding loading blocks to obtain the self-heating curves. An analysis of this self-heating curve based on the dissipation mechanisms gives one the knowledge about the damage mechanisms which is used to determine the fatigue limit.