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Experimental monitoring of the self-heating properties of thermoplastic composite materials

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Abstract

The full estimation of the fatigue lifetime of a given material is needed for the industrial structures sizing. However, it requires time-consuming, expensive fatigue testing campaigns and a huge number of samples. An alternative experimental procedure is based on the monitoring of the "self-heating" properties. The aim here is to correlate the fatigue limit with a change of thermal behavior. The main advantage of such tests is that they only require few samples and are constituted of a limited number of mechanical cycles. Thus, self-heating tests lead to an accelerated estimation of the endurance limit. The purpose of the present paper is to validate this approach for carbon/thermoplastic composite materials.

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Keywords: endurance limit ; self-heating ; thermal behavior ; carbon/thermoplastic composite

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Nomenclature

σ or S	stress (MPa)
σ_{maxi}	maximal stress of a given block of mechanical cycles (MPa)
σ_D	stress value corresponding to the end of the linear domain during tensile test (MPa)
R_M	fracture stress value in tensile test (MPa)
N	number of mechanical cycles to failure (-)
ε_l	longitudinal strain (-)
ε_t	transversal strain (-)
R	load ratio (-)
T	temperature (°C)
θ	temperature rise or heating (°C)
θ_{exp}	experimental temperature rise reached at the end of a block of mechanical cycles (°C)
θ_F	stabilized temperature rise (°C)
τ	characteristic time of the thermal drift during mechanical cycles (s)
A_1	amplitude of the first harmonic of the thermal signal (°C)
ϕ_1	phase of the first harmonic of the thermal signal (rad)

1. Introduction

1.1. Composite materials

Composite materials are made of at least two components, usually fibers and matrix, which confer to the new material better mechanical properties than those of individual components [1], [2]. The fibers, either glass-fibers or carbon-fibers, confer the mechanical properties to the whole material, while the matrix is used as a resin to link the fibers to each other, and to distribute the loads applied on the material [3], [4]. Composite materials offer a strength/weight ratio better than the one of other homogeneous materials, like steel: this is why they are more and more used in aerospace industry [5]. The structure of composite materials depends on the orientation, the architecture and the size of the fibers, which can be short or continuous. Continuous fibers might be aligned in one preferential direction (unidirectional) or might be woven according to two or three directions.

1.2. Fatigue of composite materials

The fatigue phenomenon appears during the lifetime of a structure under cyclic loading. Indeed, during cyclic loading, the material might break even if the maximal load is lower than the damage threshold (thus lower than the failure load). A common way to represent fatigue behavior is to use the Wöhler or S/N curves which provide the number of cycles to failure for each load level [6], [7].

In order to build the Wöhler curve of a given material, a large number of mechanical tests are required. A cyclic load can be defined by its frequency, mean and maximal (or minimal) loads and the load ratio (ratio between maximal and minimal load). For a given cyclic load, the sample is tested until it breaks, and the number of cycles to failure N is reported on the curve. The process is repeated for each load S, from the lowest ones to the failure one (fracture load R_M). For the lowest loads, the sample can be tested for weeks before failure, or never break at all. (Fig. 1).

For many materials, an asymptote can be detected on the curve, for the lowest load values. Under this asymptote, the risk of a premature failure is almost non-existent: it seems that the sample would never break in fatigue. Such a limit, which is called the "fatigue limit", is used for structure designing purposes in the industry. However, the main drawback of this strategy, based on the use of Wöhler curves, is that they are built after several months of mechanical tests, and require a large number of samples (at least 5 by load level to reduce the data scattering).

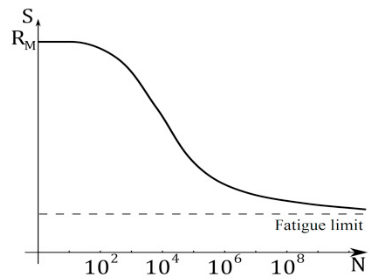

Fig. 1 : Wöhler curve