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Fatigue behaviour of carbon fibre reinforced plastic under spectrum loading

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ABSTRACT

In the present investigation the fatigue behaviour of carbon fibre reinforced plastic laminates under realistic service loading conditions has been examined. Laminates with different lay-up sequences have been tested for fatigue under spectrum loading with three different peak load levels. The damage in the laminates was characterized by using ultrasonic C-Scan as well as dynamic mechanical analysis and the damage mechanism was analyzed using scanning electron microscope. A similar investigation was also conducted on laminates with a hole. The results indicate that the spectrum loading did affect the modulus and fibre/matrix interfacial properties of all type of laminates investigated and also caused delamination in the laminate with a hole due to stress concentration around the hole.

1. Introduction

Fibre reinforced polymer (FRP) composites are extensively used in aircraft structures because of its high specific stiffness, high specific strength and tailorability. Though FRPs offer many advantages, they exhibit a form of degradation in service under cyclic loading conditions similar to metals. The mechanisms by which this deterioration occurs in composites are quite different from, and much more complicated than, those which are responsible for fatigue phenomena in metals. The complex nature of composite failure, involving different failure modes and their interactions, makes it necessary to characterize/identify their behaviour under cyclic loading conditions.

Fatigue has a major bearing on the design of any dynamically loaded structure. Traditionally, design against fatigue has been based on the performance of a material under constant amplitude fatigue conditions. However, it insufficiently represents the interaction effects that occur in service loading, which is variable or stochastic in nature. Consequently, the best design against fatigue is unlikely to be produced, since the available materials' fatigue data are not truly representative of the loading in service.

There are numerous methods of predicting the behaviour of composite materials under cyclic loading. They include modulus degradation [1,2,3], the derivation of fatigue modulus [4], residual strength [5], the strength-life-equal-rank-assumption [6,7], cumulative damage [8] and energy criteria [9]. All have their advantages and disadvantages, but are generally applicable to specific composite systems or to constant amplitude loading.

Variable amplitude fatigue behaviour of FRPs has been studied by Rotem [10], Bond [11] and Philippidis and Vassilopoulos [12]. The effects of load sequences and block loading on the fatigue response of fibre reinforced composites were studied by Vanpaepegan and Degrieck [13] and Gamstedt and Sjogren [14]. Schon and Blom [15] and Choi et al. [16] investigated the spectrum fatigue of laminates with a hole. They used delamination growth and longitudinal split length as a damage measure to predict the fatigue behaviour. The fatigue behaviour can also be studied by characterizing fibre/matrix interface using dynamic mechanical analysis [17]. The fatigue behaviour of carbon fibre reinforced plastic (CFRP) under block loading conditions was studied by Chen and Harris [18], who observed that the combination of tension and compression loading causes more damage than purely tensile or purely compressive stress cycling regimes.

In the present investigation, the fatigue behaviour of CFRP under variable amplitude load sequence has been examined. The delamination growth is used as a damage measure and the modulus and interfacial degradation due to fatigue loading is studied using dynamic mechanical analysis (DMA). Scanning electron microscope (SEM) examination is carried out to understand the damage mechanism.

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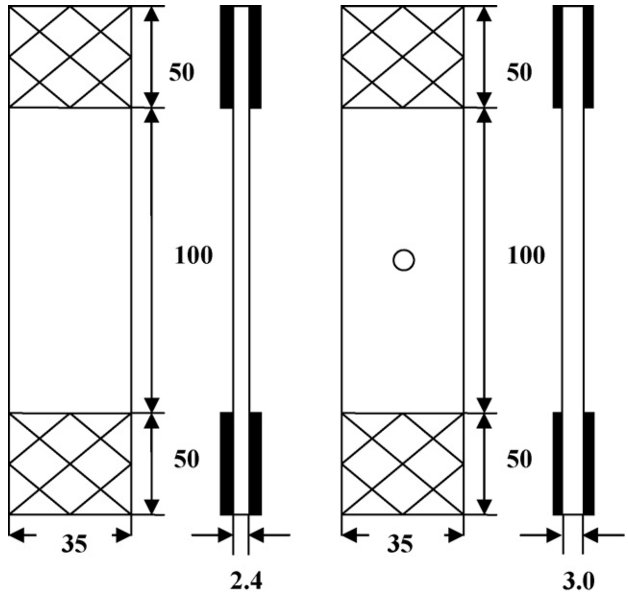

Fig. 1. Specimen geometry (all the dimensions are in mm) (a) QI laminate (b) 0° FD laminate with a hole.

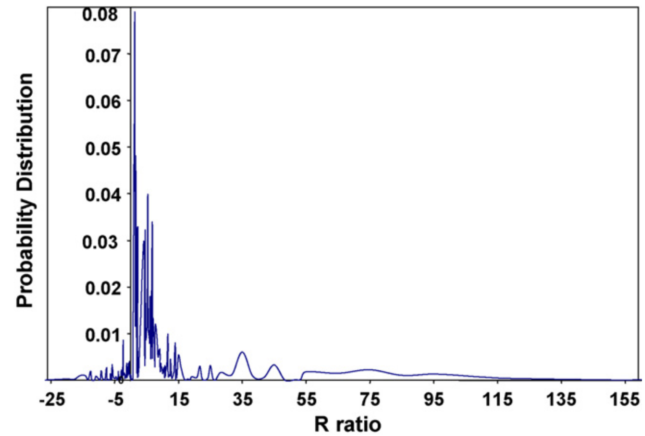

Fig. 3. Probability distribution of *R* ratio of the load spectrum employed in the study.

2. Experimental procedure

CFRP laminates fabricated with standard modulus carbon fibres as reinforcement and toughened epoxy resin as the matrix are studied in this work. The prepreg materials have a nominal cured thickness of 0.15 mm and are designed for high strength retention between −60 and 120 °C. The laminates selected for this study are $[\pm45/0/90]_{2s}$: quasi-isotropic (QI) laminates, and $[\pm45/0/45/0_2/-45/0/90/0]_s$: 0° fibre dominated (0° FD) laminates – both plain and with a central hole of 6 mm diameter. The nominal thickness is 2.4 mm for the QI laminate and 3.0 mm for the 0° FD laminate. These realistic lay-up sequences are typical of laminates used in aircraft construction. Test laminates of specified thickness and lay-up sequence were fabricated by hand laying, to a size of 350 mm × 650 mm, using flat Al plates and cured in an autoclave. From the cured laminates 20 mm of material was trimmed-off from the edges all around to remove wavy and non-uniform material. The laminates were subjected to ultrasonic C-Scan (Model: ULTRON-7000) to inspect any internal manufacturing defects. Specimens of required size were cut from the test panels using a water cooled diamond tip wheel cutter. Plywood loading tabs were bonded onto both ends of specimens using a high strength Araldite® epoxy adhesive. The specimen geometry is shown in Fig. 1.

Fatigue tests were conducted in a ±100 kN servo-hydraulic load controlled Instron 8032 machine. The realistic flight spectrum of a typical fighter aircraft is considered in this study. It is a variable amplitude random spectrum containing 21,025 load reversals or 10,513 cycles per block defined in peak and trough levels corresponding to +8 g and −3 g, respectively. This corresponds to one block of spectrum loading. Time series of this realistic spectrum, for a peak load of 31.573 kN is presented in Fig. 2.

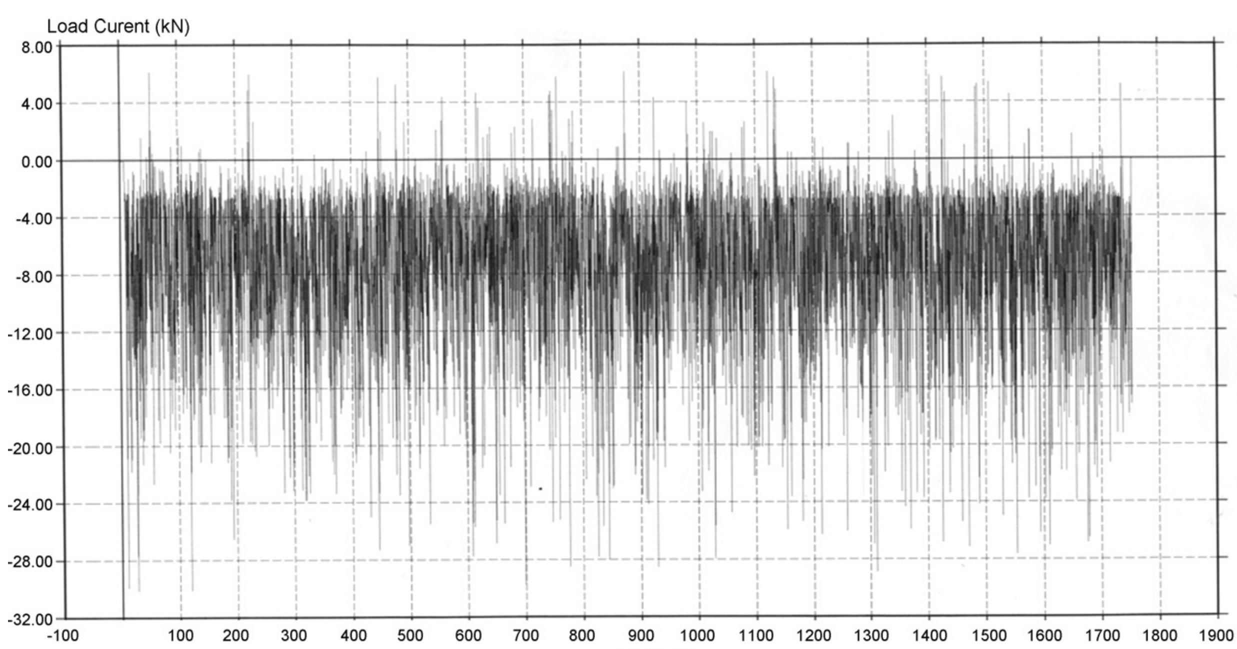

Fig. 2. Typical fighter aircraft spectrum time series.