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EVALUATION OF THE EFFECT OF IMPACT DAMAGE ON THE FATIGUE LIFE OF CARBON FIBRE COMPOSITES

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Abstract: *Carbon fibre in polyphenylene sulfide composites became popular material in aircraft industry but its fragility to impact loading limits the application of these composites in aircraft primary structures. The article deals with experimental investigation of the response of damaged composite. Material degradation of intact and damaged specimens during fatigue tests was investigated. As damage parameters the changes in natural frequencies, ultrasound wave propagation and bending stiffness were chosen. In the article the entire fatigue life of intact and damaged specimens was studied by all the presented methods and the accuracy and reliability of assessment of damage parameters were compared.*

Key words: *impact damage, carbon fibre composites, material degradation*

1.Introduction

The material research in field of aircraft construction was focused on strong lightweight materials from the beginning of aviation. The era of composites was interrupted for several decades by the dominance of light alloy mainly based od aluminum. In these days composites play in the aerospace industry a significant role when the wooden parts were replaced by mainly composites with carbon fibres. The reason the composite materials are preferred to metals lies in their strength to density and stiffness to density ratios given by synergic effect of their micro-structure. Although behavior of the applied materials is sufficiently known to be operated safely in civil aircraft, a complete understanding of these materials behaviour is yet to be gained.

A special class of fibre reinforced material - carbon fibre in polyphenylene sulfide (C/PPS) composites became popular material in aircraft industry but its fragility to impact loading limits the application of C/PPS composites in aircraft primary structures. The knowledge of the process of damage accumulation and identification of parameters connected to material degradation plays an important role in the safe operation of structures and equipment. Changes of mechanical properties, namely of bending stiffness coupled with microstructural changes and acoustic properties were investigated to obtain

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complex information about whole fatigue live of fibre composite.

2. Specimen description

C/PPS composite is an advanced material used mainly in aerospace industry or other hi-tech applications. The material consists of quasi-isotropic 8-ply of carbon fabric bonded by thermoplastic matrix. The matrix is the main difference from more common composites based on epoxy resin, i.e. thermosets.

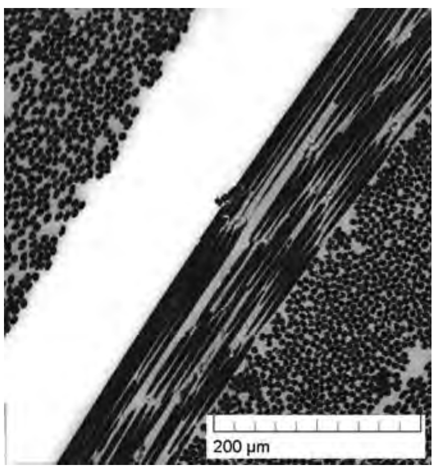

Fig. 1. *Detail of fibers in various plies and orientation obtained by scanning electron microscope micrograph taken in cathode luminescence regime*

Modulus of elasticity of carbon fibers reinforcement prepared from high-stiffness poly-acrylonitrile is in range from 40 to 400 GPa [1]. The differences are given by various manufacturing methods. Other mechanical properties of C/PPS composite are in detail described in manufacturer's datasheet [2]. The set of specimens with rectangular shape with dimension of 250x25 mm were cutted from plate with thickness of 2.5 mm. The sample surface is protected by a thin layer of glass fibers in epoxy matrix. The specimens were prepared using computer controlled water cutting machine.

3. Experimental procedure

The experimental procedure was a curried out on set samples with four different levels of initial impact damage. The samples set consists of i) intacted samples ii) impacted by impactor with diameter 10 mm and energy 10 J iii) impacted by impactor with diameter 20mm and energy 10 J iv) impacted by impactor with diameter 20mm and energy 20 J. Before fatigue testing the tension strength was measured by standard test. Strength of the samples was around 31 kN independent on initial impact. Sinusoidal run with mean level 8 kN with amplitude 7 kN with frequency 4 Hz was chosen. Higher frequency would caused heating of the sample with influence on the response of the material to the loading.

3.1. Fatigue testing

For the fatigue testing servo-hydraulic Instron 1603 loading machine was used. The control frequency 1000 Hz of the force and displacement transducers were chosen to guarantee the precise run of the experiment. Fatigue experiment was times interrupted at predefined intervals and number of cycles. The damage indicators were investigated after 0, 1000, 5000 and 10000 cycles.

3.1. Ultrasonic measurement

As a first degradation parameter the velocity of the longitudinal ultrasonic waves' propagation was taken. The experiment was carried out using testing device USG 20 used with a 250 kHz transducer (USG-T) and receiver (USE-T). From physical nature of the ultrasound [3], the wave propagate mainly through environment with the greatest density, therefore the velocity only in the fibres was measured.

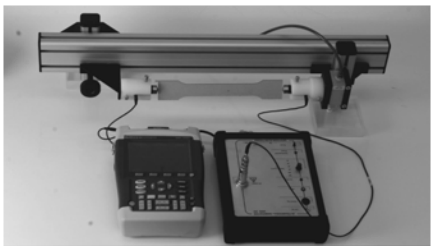

Fig. 2. *Ultrasonic measuring device with pneumatic fastening of the specimen*

The velocity change was not significant therefore it can be assumed that the fibres are strenuous in the elastic region and the degradation occurs mainly in the matrix and by pulling fibres from the matrix.

3.2. Three-point bending

The decrement of elasticity modulus was measured using three-point bending test [4]. Custom based loading device was employed for the test. Stepper motor with harmonic drive allowed displacement controlled experiments with accuracy 1µm. The loadcell U9B (Hottinger Baldwin Messtechnik, GmbH) with loading range up to 100 N.

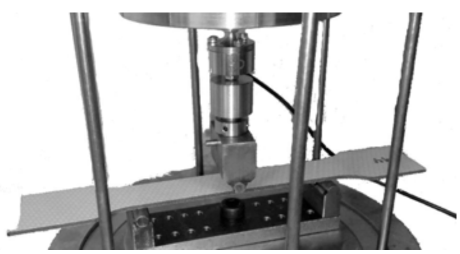

Fig. 3. *Experimental setup for three-point bending. Detail of the grips with load cell in the testing chamber*

The experiment was performed as displacement driven with maximal deflection value 1000 µm. The support span was 120 mm. The Young‘s modulus was calculated using the linear regression.

3.3. Acoustic measurement

Basic principle of acoustic testing is based on a fact, that if it was possible to measure sound characteristics of specimen repeatedly with constant conditions, any measurable change in natural frequency value would be coupled with material degradation indication [5]. Custom-designed testing device was designed and constructed in order to verify this premise.

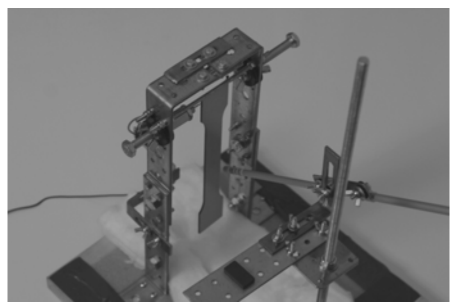

Fig. 4. *Sample fastened in acoustic testing device*

Small steel pellet was passed through tube providing rigid leading to specimen surface. Sound emitted during strike is recorded by microphone fixed to the device and analysed. Using signal processing techniques during the procedure sound was filtered and trimmed to normalized length prior to transformation to frequency domain and determination of peaks pertaining to natural frequencies.

3.4. Photometric stereo method

Photometry is an method for 3D measurement of surfaces with relief. It utilizes a relationship between depth of shadow, determined intensity of light and surface normal orientation towards source of light [6]. Advantage of methods incorporating this principle is their independence on distance between measured object and the measuring apparatus and scalable sensitivity suitable for measurement of relatively flat surfaces like impacted samples with dents of depth around 200µm.

4. Results and discussion

All above presented experimental procedures except ultrasound measurement showed a gradual degradation of the material. Module of elasticity computed from three-point bending elasticity decreased by 15.7 % after 10000 load cycles in case of the samples with impact energy 10J (without significant influence of impactor diameter), the sample was damaged by energy 20 J ruptured after 1227 cycles. For the analysis the 13th mode with natural frequency around 5000 Hz was chosen. In average natural frequency of the impacted specimens fatigued by 10000 decreased by 1.83 % and by 0.75 % for the intact one. Moreover, calculation of natural frequencies standard deviation yielded value of 0.03 %. This confirms proposed testing method to be highly accurate and reliable. Image processing tools, especially local threshold was used for assessment of dent changes propagation from images obtained by photometric stereo. At both sides of the specimen the increase of influenced zone was observed but the method do not fully correlated with changes of material properties yet. To conclude, the data assessed using all presented measurements are suitable for evaluation of material degradation process in C/PPS composite during its fatigue live.

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