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ASSESSMENT OF C/PPS COMPOSITES DEGRADATION INDICATORS USING ACOUSTIC MEASUREMENT

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Abstract: *Changes of mechanical properties, namely of modulus of elasticity, often play a role of damage accumulation indicators in the framework of fatigue behaviour of composite materials. In order to improve the reliability of these indicators for identification of material degradation process it is necessary to eliminate the influence of external loading and volume forces associated with thermal expansion of heterogeneous material at various temperatures. Therefore the paper deals with description of experimental assessment of relation between external load and material stiffness and also studies the dependency of material stiffness on temperature. For the monitoring of degradation process ultrasonic measurement was used. Obtained results are discussed with respect to fatigue testing of material and also interpreted from the micromechanical point of view.*

Keywords: ***Material degradation, acoustic measurement.***

1. Introduction

This paper describes a simple acoustic measurement technique for determination of material's degradation in cyclic loading. Motivation is not only to develop a simple, yet reliable method to examine alternations in mechanical properties of material during fatigue test, but also to measure material's properties at elevated temperatures. Importance of the second point becomes especially urgent when the temperatures, the material can withstand, far exceeds conditions in which electronic devices can operate. Therefore a need for a method capable to work in extreme environments is clearly recognizable. To meet this objective, a simple experimental technique based on specimen's free vibration analysis was developed.

2. Studied material

Studied material is extensively used in aerospace industry and in other hi-tech applications. Its stiffness to density and strength to density ratios allows this material to compete with established alloys. Internal structure of the material can be described as carbon fibres in polyphenylene sulfide (C/PPS) thermoplastics matrix composite. C/PPS is quasi-isotropic, it consist of 8-ply of carbon fabric bonded by thermoplastics matrix. Detailed list of properties of the C/PPS composite can be found in manufacturer's material datasheet (Aims, 2007).

The statistical sample – the whole set of specimens undergoing fatigue testing are prepared in the 'dog bone' shape of identical size as computer controlled water cutting machine is used. Having specimens of identical size and material properties simplifies greatly the task of comparison as a tool for investigation of material degradation not only under fatigue loading, but also impact loading and in wide range of operational conditions.

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3. Comparison of methods

Degradation of material subjected to fatigue loading can be related to the concepts of residual strength or remaining service life (van Paepegem, Degrieck 2002, Degrieck, Paepegem 2001). The degradation summarizes accumulated damage in the form of key indicator that is preferably easily measurable. Some material's property, decisive for its mechanical performance is selected or a property related to measurement technique itself is chosen. Among these parameters longitudinal wave velocity or modulus of elasticity ought to be mentioned.

These phenomenological approaches have to be related to micromechanical explanation of the nature of damage (Vasiliev, Morozov 2001). Long fibre composites resist fatigue damage because load bearing component, carbon fibres, carry the majority of loads while remaining fully elastic. The fact that fibres are not affected during fatigue process implies that the degradation takes part mainly in the thermoplastics matrix. The same conclusion can be drawn from nanoindentation measurement enabling to separate contributions of individual components in the performance of the whole material. Nanoindentation clearly demonstrates that material degradation can be related to the decrease in stiffness of the matrix (Minster 2010). It means that parameters reflecting state of the matrix can be used as sensitive descriptors of degradation process. On the other hand, parameters sensitive to fibre content of composite cannot elucidate processes in the material, are in this sense insensitive.

Tab. 1: Comparison of sensitivity of discussed experimental methods to material's degradation expressed as the ratio of intact and fatigue state's values.

measurement technique	***parameter***	***decrement [%]***
matrix nanoindentation	***Young's modulus***	***37.65***
ultrasonic wave propagation	***attenuation***	***17.91***
3 point bending	***Young's modulus***	***11.60***
modal analysis	***frequency***	***1.03***
ultrasonic wave propagation	***velocity***	***0.48***

In the course of work several investigation methods were deployed for estimation of material's degradation. These experimental methods are listed in Tab. 1. The table also shows influence of cyclic loading on studied parameter when compared to the intact state. This change indicates sensitivity of the given method: if matrix weakening is considered a primary cause, as indicated by nanoindentation, other methods perform differently.

Increasing difference between modulus of elasticity as determined by 3PB and ultrasonically indicates undergoing degradation process (see Fig. 1). As pointed out in (Nagy 1998), formation of discontinuities, voids and microcracks manifests in different response of material on compression and tension. While in compressive loading, microdefects tend to close and inhibit their influence on measured mechanical properties. Such a configuration occurs during ultrasonic measurement, which tests materials via longitudinal pressure waves (Rojek et al. 2007). On contrary, these defects are fully active in the tension and therefore decreasing the overall stiffness of material as happens in 3PB. Shift in free vibration frequencies of the specimen sensitively reflects internal degradation processes as modal shape formation involves simultaneous tension and compression stresses similar to that in 3PB. The great advantage of the applied modal analysis to 3PB is simplicity and almost no instrumentation requirements opening up possibility to examine materials' properties far from laboratory conditions.

In ultrasonic method, attenuation can be deduced from the first amplitude of the train of waves detected by transducer. This amplitude, provided acoustic impedance of contact between transducer/receiver and specimen is maintained for every measurement in a reproducible way, depends on measured length and material's internal damping. Identical dimensions of all specimens excludes the difference in the length as a source of attenuation and the only possible cause – internal flaws of material have to be taken under consideration.

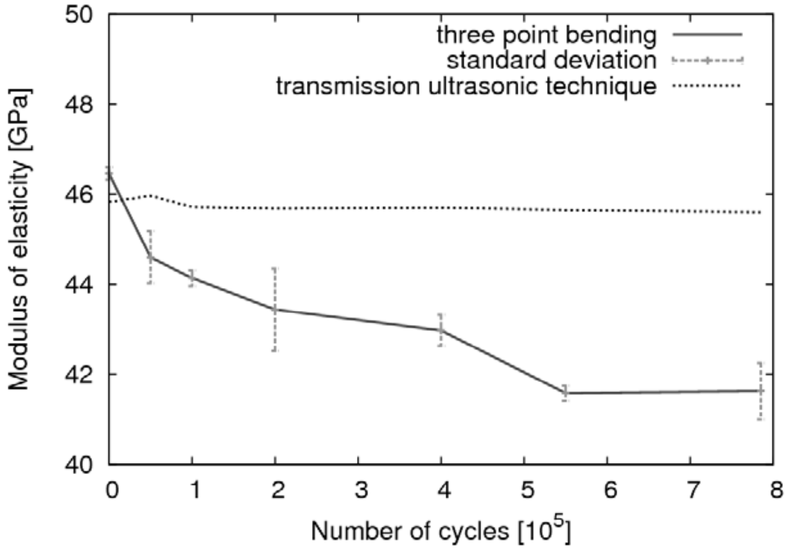

Fig. 1: When two different indirect methods are used for determination of elastic modulus – as in this case ultrasonic and 3PB - results can be dissimilar. The cause of dissimilarity is in different mechanisms involved in the property determination; which can be also used for identification of undergoing degradation process.

However the analysis of free vibration of specimen recorded only 1% difference between fatigued and intact state, it is inherently very precise as it deals with time measurement. The method utilizes only a simple frame for hanging specimen and mechanical rig for exciting vibrations – enabling it to be used at elevated temperatures as the only one among all discussed techniques. Fig. 2 depicts typical frequencies and spectral density peaks, reflecting excitation of modes for specimen vibrations.

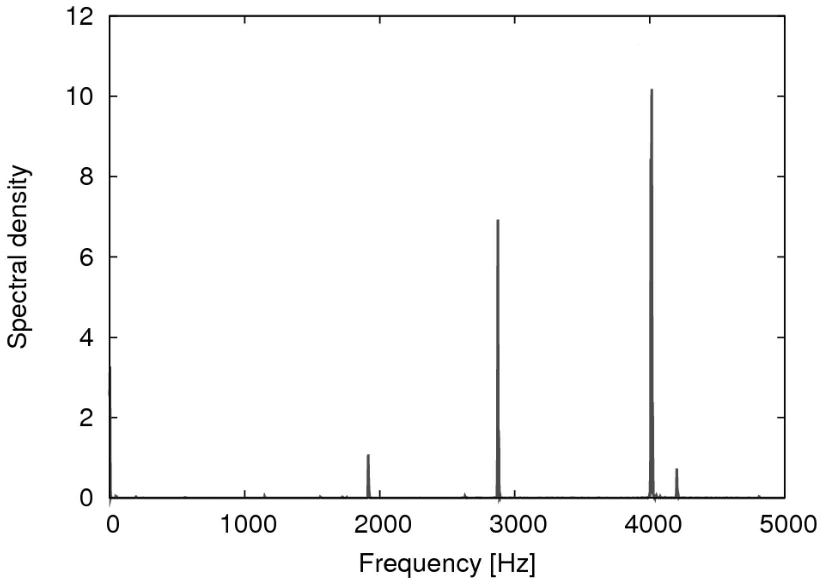

Fig. 2: Acoustically determined natural modes of vibration and their frequencies. Due to precise manufacturing the specimens seem to be nearly identical in their mechanical properties. Any shift in eigenfrequencies can be ascribed to material degradation.

Tab. 2 documents shift in specimen's eigenfrequencies due to material degradation. This decrease occurs for every frequency and can be measured with a high accuracy. Significance of the frequency change is supported by the fact that value of measurements' standard deviation is only a fraction of frequency decrease.

Tab. 2: Documentation of specimen's eigenfrequency decrease as an indicator of advanced degradation of fatigued material. Specimens in upper part of the table are intact while the specimen #2 underwent circa 1 milion of loading cycles.

specimen	*spectral density peak frequencies*			
	1st	*2nd*	*3rd*	*4th*
14	*1170*	*1938*	*2913*	*4064*
13	*1164*	*1939*	*2909*	*4047*
7	*1159*	*1927*	*2893*	*4032*
4	*1153*	*1922*	*2876*	*4011*
Mean	*1161*	*1931*	*2898*	*4038*
Std	*5.53*	*8.92*	*16.63*	*18.20*
2	*1133*	*1883.25*	*2811*	*3915*
freq. dec. [Hz]	*28.25*	*48.24*	*86.69*	*123.14*
freq. dec. [%]	*1.02*	*1.03*	*1.03*	*1.03*

4. Conclusions

Experimental technique based on free vibration of specimen was developed and utilized for investigation of material's degradation. This technique proved effective for detection of material's degradation, because it enhances matrix-dominant properties. Advantage of this technique is its sensitivity and ability to be used at elevated temperatures.

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