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ScienceDirect

Procedia Structural Integrity 5 (2017) 416–421

Structural Integrity Procedia

www.elsevier.com/locate/procedia

2nd International Conference on Structural Integrity, ICSI 2017, 4-7 September 2017, Funchal, Madeira, Portugal

Evolution of a fracture mechanism in a polymeric composite subjected to fatigue with the self-heating effect

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Abstract

In this paper, the authors focused on evaluation of fatigue fracture mechanisms accompanying fatigue of polymeric composites with an occurrence of a self-heating effect. In order to reflect degradation processes and their evolution at various values of a self-heating temperature with a possibility of analyzing an internal structure of cracks and delaminations occurring during fatigue, X-ray computed tomography tests were performed. Specimens made of a GFRP composite were subjected to cyclic loading in order to stimulate a non-stationary self-heating of the structure. The performed tests allow for characterization of morphology of damage occurring during fatigue loading of polymeric composites subjected to dominated self-heating, and, based on the performed observations, determination of a critical self-heating temperature value, which causes appearance of internal fracture in a structure. Moreover, a continuous acquisition of a self-heating temperature and acoustic emission during fatigue allows for connection of fracture events with particular events observed in temperature evolution and acoustic emission signals, which, in turn, allows for better understanding of formation of fracture in a structure in such loading conditions.

Peer-review under responsibility of the Scientific Committee of ICSI 2017

Keywords: fatigue of polymeric composites; self-heating effect; accelerated degradation

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1. Introduction

Fatigue fracture processes occurring in polymeric composites are different than those observed for metallic structures due to occurrence of a self-heating effect, i.e. a phenomenon resulting from viscoelastic mechanical energy dissipation and heat generation in a cyclically loaded structure. The self-heating effect, which may occur in stationary

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Peer-review under responsibility of the Scientific Committee of ICSI 2017
10.1016/j.prostr.2017.07.190

or non-stationary regimes, always influences on the fatigue process and residual life of the structure. In case of the stationary self-heating, when the generated heat is in equilibrium with thermal energy released to the environment, the fatigue life decreases, but without significant acceleration. In contrast to this case, during the non-stationary self-heating, fatigue fracture is significantly accelerated and leads to failure in a very short time period. Therefore, it is essential to investigate a criticality of the self-heating effect in a context of a self-heating temperature generated inside a structure at which damage is initiated as well as a character of development of a fracture mechanism and its development with respect to growing self-heating temperature. This allows for better understanding of physics of fatigue fracture in polymeric composites subjected to self-heating.

Recently, the most accurate and non-destructive testing method of materials, which gives additionally full 3D view of the tested structure including its internal architecture has been the X-ray Computed Tomography (XCT). Due to the very high accuracy XCT is widely used in characterization of internal damage in polymeric composites (see e.g. Schilling et al. (2005), Nikishov et al. (2013), Sisodia et al. (2016)), including damage resulting from fatigue processes (Cosmi and Bernasconi (2013), Yu et al. (2015), Jespersen et al. (2016)). Following the cited studies XCT makes available a detail evaluation of internal damage occurring during fatigue with the self-heating effect and its evolution in a function of a number of cycles to failure and a self-heating temperature measured on the surface of a composite structure during loading. Moreover, due to a possibility of precise inspection of a structure, XCT makes it possible to re-evaluate a criticality of the self-heating effect by detection of initial damage in a structure and determine the related self-heating temperature on its surface. The obtained results can be compared with previously obtained results using approximation of temperature history curves, acoustic emission, residual strength, etc. (Katunin et al. (2017a)) as well as microscopic analysis of surface cracks (Katunin et al. (2017b)).

The specimens made of a GFRP composite were subjected to cyclic loading in order to stimulate the non-stationary self-heating of the structure and obtain a damage state at a certain self-heating temperature. In order to obtain specimens prepared in such a way the cyclic loading was stopped when a certain assumed self-heating temperature value on a surface of a specimen was reached. The observations were performed in a wide temperature range in order to detect initial microcracks as well as to observe their evolution while the self-heating temperature grows until reaching a temperature at which a total failure occurs. The performed tests allow for characterization of morphology of damage occurring during fatigue loading of polymeric composites subjected to the dominated self-heating, and, based on the performed observations, determination of a critical self-heating temperature value, which causes appearance of internal fracture in a structure. The presented results cover 3D visualizations of selected specimens with damage at certain self-heating temperature values and their analysis in the light of damage mechanics as well as comparative studies with the results of critical self-heating temperature values determined using other testing methods.

2. Specimens and testing procedures

The specimens used for fatigue tests were manufactured from a 14-layered unidirectional glass/epoxy composite and supplied by Izo-Erg S.A. (Gliwice, Poland). A description of manufacturing process as well as basic mechanical and dynamic properties of these specimens can be found in Katunin and Gnatowski (2012). The composite sheet of a thickness of 2.5 mm was cut to specific dimensions of the specimens: width of 10 mm and length of 100 mm. An effective length, i.e. the length between specimen holders which participated in loading, of each specimen equaled 40 mm. The specimens were loaded with a constant frequency of 30 Hz. The fatigue tests were performed on the own-designed laboratory test rig with a possibility of continuous measurement of surface temperature by an infrared camera, excitation acceleration of vibrations by a piezoelectric accelerometer, loading force by a piezoelectric force sensor, velocity of vibration of a loaded specimen by laser Doppler vibrometer, and acoustic emission using a sensor glued to the non-loaded part of a specimen. The specimen was clamped on one side and loaded on the other side in the fully reversed cyclic loading mode. A detailed description of the measurement system can be found in Katunin et al. (2017a). The specimens were loaded in such a way that a maximal self-heating temperature on their surfaces reached a certain value in a range of 35÷115°C with a step of 5°C. For each unique maximal self-heating temperature value 4 specimens were tested for obtaining statistically valid results.

After preparing the specimens following the above-described procedure they were subjected to scanning using XCT. The XCT tests were performed on the phoenix v|tome|x m 300 industrial CT scanner with a maximum power of 500 W at 300 kV voltage and a detector with a 400×400 mm active area. The scanning was performed with a