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Domination of self-heating effect during fatigue of polymeric composites

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Abstract

The following study focuses on investigation of influence of a self-heating temperature value on a fatigue process of polymeric composites and, in particular, on a criticality of this effect. A main goal of the study is to find a temperature value at which its growth becomes non-stationary (and thus dominates the fatigue processes) and investigate an influence of selected self-heating temperature values on fatigue life of a composite structure. The investigation is based on experimental studies, during which specimens were subjected to cyclic loading with simultaneous measurement of loading force, deflection velocity, surface temperature and acoustic emission. Such measurements allow for accurate evaluation of differences between particular loading cases as well as determination of characteristic points (moments) of degradation initiation, and finally analysis of all of the measured parameters within a number of cycles to failure. Based on the obtained results it was found that the self-heating effect is possibly dangerous to cyclically loaded composite structures even at relatively low self-heating temperature values and may significantly shorten their structural lifetime.

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

1. Introduction

A self-heating effect, occurring in polymeric composites during vibrations or cyclic loading due to a viscoelastic nature of polymers used for such composites, is a very dangerous phenomenon, which, under certain conditions, may

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dominate the fatigue process and significantly intensify degradation processes of a loaded polymeric structure. Due to dissipative processes of mechanical energy delivered to the structure, an intensive heating occurs there, which is a main part of the dissipated mechanical energy. The heat is additionally stored in the structure since most polymers used in manufacturing of industrial composites are characterized by a very low thermal conductivity. The resulting temperature is strongly related to stress, thus the higher the stress the higher value of a self-heating temperature it is. According to this, the self-heating effect may develop following two scenarios: the first scenario assumes a growth of a self-heating temperature until reaching a specific value, and then, its stabilization or a very slow linear growth (caused by mechanical degradation); while the second scenario assumes domination of the self-heating effect in the fatigue process, which results in sudden degradation of the structure until reaching a limit strength and failure. Both of the mentioned cases are presented in Fig. 1.

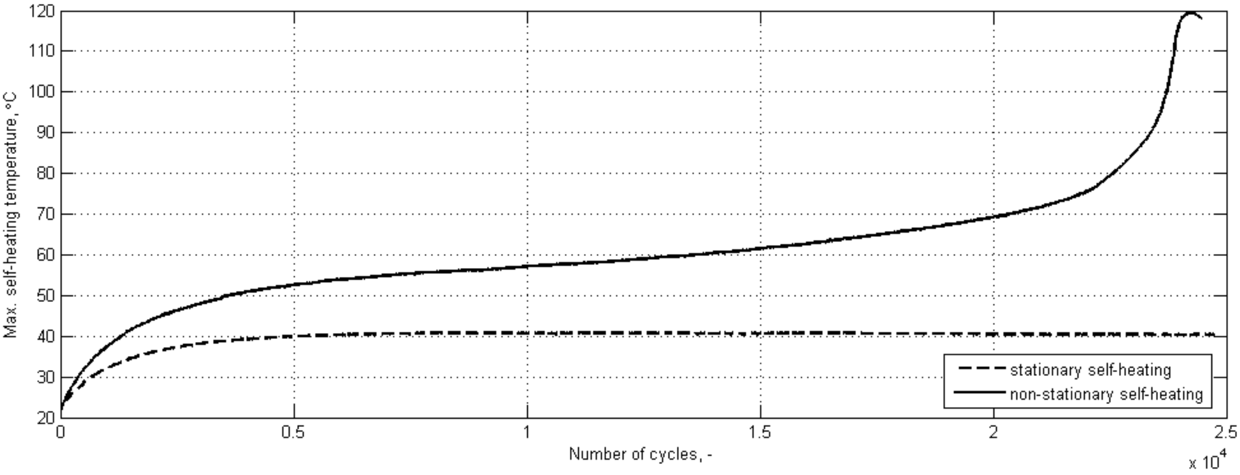

Fig. 1. Experimental data representing possible scenarios of the self-heating effect development.

When the self-heating effect dominates the fatigue process, damage initiation and propagation occurs at much lower value of temperature than the temperature reached during failure, which intensifies this process. Moreover, in case of the non-stationary self-heating, one can clearly observe three characteristic phases of a temperature growth (confirmed in numerous studies – see e.g. Ferreira et al. (1999), Toubal et al. (2006), Naderi and Khonsari (2012), Katunin (2012a)): the first one is heating following the exponential characteristic (according to the thermodynamic laws), the second phase is connected with the temperature stabilization or monotonic linear growth resulting from progressive damage accumulation, and the third phase is connected with an initiation and development of a macrocrack in a location of the highest stress concentration, which, in consequence, leads to a rapid self-heating temperature growth and a failure of the structure. In case of the stationary self-heating, while a relatively low number of cycles (or a short loading time period) is considered, only the first and the second phase of the temperature growth are observed, i.e. after reaching a certain value the self-heating temperature distribution stabilizes. Thus, it can be interpreted that the self-heating effect influences on fatigue, however does not dominate it.

Numerous studies on influence of the self-heating effect on fatigue have been performed to-date. The mentioned duality of evolution of a self-heating temperature, namely, the stationary and non-stationary self-heating, has been observed in many studies (see e.g. Liu et al. (2004), Moisa et al. (2005), Karama (2011), Katunin (2012a)). From practical reasons it is essential to investigate a criticality of the self-heating effect occurring during fatigue of polymeric composites, i.e. a point (or temperature value) at which the self-heating dominates the fatigue process, which leads to the sudden degradation and failure of the loaded structure. Recently, several attempts in evaluation of the self-heating effect criticality have been made by Naderi et al. (2012), Kahirdeh and Khonsari (2014). In their studies they analyzed a temperature history curve together with an intensity of acoustic emission events in order to determine the criticality of self-heating. Previous studies of the author of the present paper focused on evaluation of the criticality of the self-heating effect covered approximation of self-heating temperature history curves (Katunin (2012b)) in order to