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Evaluation of thermally-aged carbon fiber/epoxy composites using acoustic emission, electrical resistance and thermogram

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ABSTRACT

Interfacial and mechanical properties of thermal aged carbon fiber (CF) reinforced epoxy composites (CFRC) were evaluated using acoustic emission (AE), electrical resistance (ER), contact angle (CA) and thermogram measurements. Unidirectional (UD)-composites were aged at 200, 300, and 400 °C to produce different interfacial conditions. The interfacial degradation was identified by *Fourier* transform infrared (FT-IR) spectroscopy after the different thermal aging. AE and ER of UD composites were measured along 0, 30, 60 and 90° directions. Changes in wavespeed, with thermal aging, were calculated using wave travel time from an AE source to AE sensor and changes in ER were measured. For a thermogram evaluation, the composites were laid upon on a hotplate and the increase in the surface temperature measured. Static contact angles were measured after different thermal aging and elapsed times to evaluate wettability. Tests of interlaminar shear strength (ILSS) and tensile strength at transverse directions were also performed to explore the effects of thermal aging on mechanical and interfacial properties. While thermal aging of CFRCs, at all three aging temperatures, was found to affect all of these properties, the changes were particularly evident for aging at 400 °C.

1. Introduction

Due to some of their unique and superior properties, FRPs are being increasingly used in many applications ranging from rehabilitation to construction [1]. Composites are currently being developed for applications in severe environments including cryogenic and high temperature, corrosive environments and exposure to ultraviolet radiation [2,3]. The extent of damage, caused by exposure to such conditions, has been determined using nondestructive evaluation (NDE) procedures, including ultrasonic, radiography, thermography, AE, modal analysis (such as instrumented tap testing) and eddy-current testing [4,5]. Recently, in the area of structural monitoring, polymer conductive composites have received considerable attention due to some of their distinct advantages [6].

AE is an important NDE tool for the investigation of the mechanisms of micro-failure in structural composite materials. It has been used as a reliable tool for the characterization of structural integrity and to help identify damage mechanisms in complex composite structures under various loading conditions [7,8]. AE was applied to assess the behavior of different wavespeed undergoing mechanical impact [9].

The basic principles underlying the electrical resistance (ER) method in electrical conductive composites are rather straight forward. This method is based on the electrical resistance change (ERC) associated with structural and dimensional changes accompanying the application of stress. Prior research has shown that there in a concomitant increase in ERC with increasing stress of conductive composites [10–12]. This method consists of measurements of the changes of resistance with stress in CFRC specimens and has been shown to provide information on the basic failure mechanisms. The method has been found to have several advantages: the possibility of continuous monitoring of CFRC under loading, the ability to simultaneously detect defects throughout the volume of the specimen, and the possibility of locating and investigating failure mechanisms in the composite structure in real time [13].

AE and ER method are well known as NDE methods. However, each evaluation method lacks is some way for ideally diagnosing some materials. AE evaluation requires high-cost and complex equipment and evaluations while the ER method can be used to evaluated only

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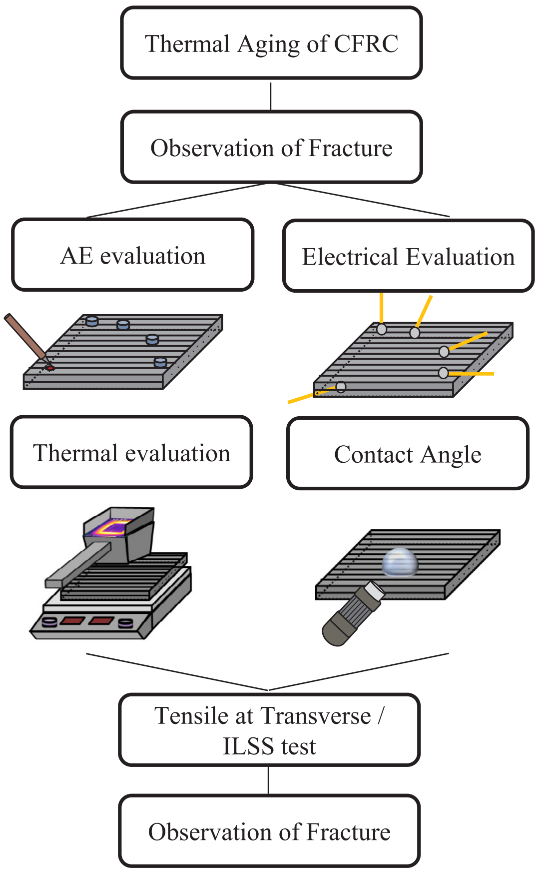

Fig. 1. Schematic arrangement evaluation for the effects of thermal aging on properties of a composite.

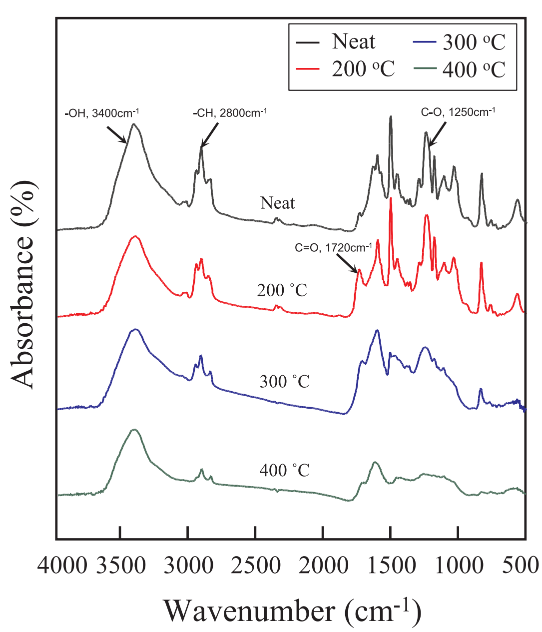

Fig. 2. FT-IR data for CFRC after thermal degradation.

electrically conductive materials. To overcome these problems, various older NDE methods have been applied to monitor the static and dynamic failure conditions inside and on the surface of composite materials. Thermogram methods are based on the heat distribution in a system. Thermogram based temperature measurement techniques offer fruitful information with prompt response times as well as ample

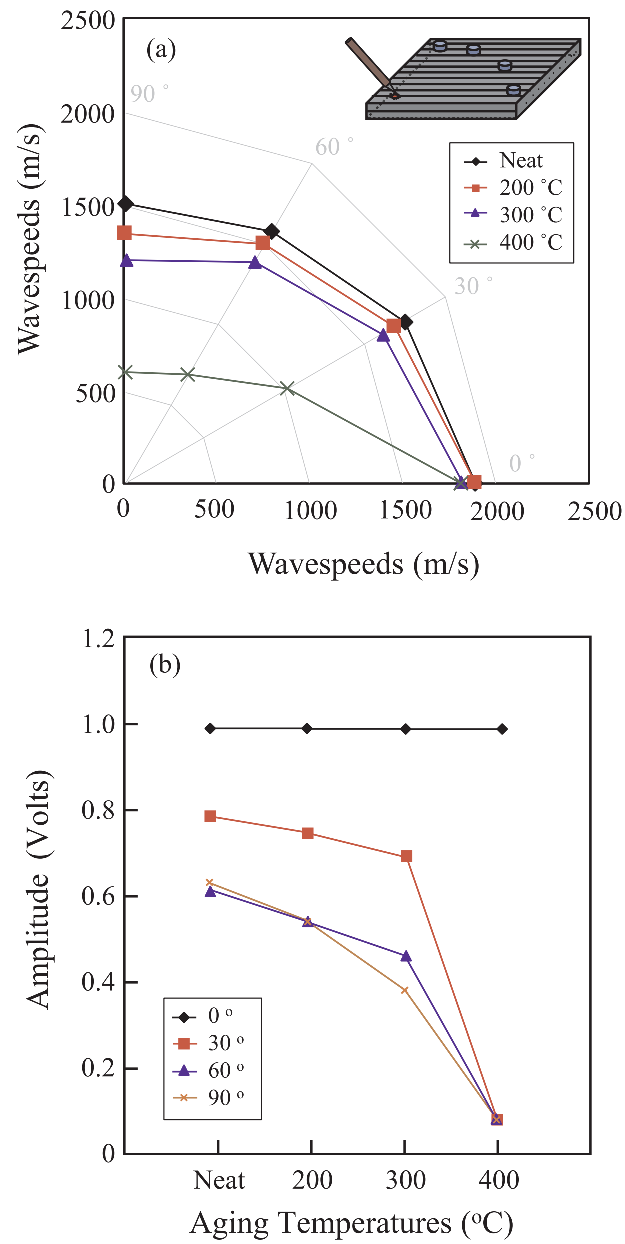

Fig. 3. AE results in the indicated directions in CFRC after different aging treatments: (a) wavespeeds; and (b) amplitude.

temperature ranges [14,15]. Thermographic analysis represents the cheapest, the most advantageous and quick technique to be used in situ to detect defects due to a lack position [16]. Contact angle measurements are widely used for investigating surface characteristics of materials. The wettability of solid surfaces is an important aspect of surface science for a variety of practical applications [17]. Measurement of contact angles quantifies the interactions between solids and liquids which play a key role in understanding the chemical and physical processes in many industries [18].

In this study, the UD-CFRCs were aged at 200, 300, 400 °C with a goal of producing thermal degradation including different interfacial conditions. AE and ER sensors were installed along angles of 0, 30, 60 and 90° to the UD-specimen's axis. The time of travel of waves between the AE source and the AE sensor was used to calculate changes in wavespeed while ER sensors were used to determine the changes in ER, with aging. For the thermogram evaluation, CFRC specimens were laid on a heated hotplate and the increase in surface temperature was measured as the hot plate was heated. Changes in static contact angle