Composites: Part A 90 (2016) 417–423

Contents lists available at ScienceDirect

Composites: Part A

journal homepage: www.elsevier.com/locate/compositesa

Evaluation of dispersion and damage sensing of carbon fiber/polypropylene (PP)-polyamide (PA) composites using 2 dimensional electrical resistance mapping

Dong-Jun Kwon [a], Pyeong-Su Shin [a], Jong-Hyun Kim [a], K. Lawrence DeVries [b], Joung-Man Park [a,b,*]

[a] Department of Materials Engineering and Convergence Technology, Center for Creative Human Resource & Convergence Materials, Engineering Research Institute, Gyeongsang National University, Jinju 660-701, Republic of Korea
[b] Department of Mechanical Engineering, The University of Utah, Salt Lake City, UT 84112, USA

ARTICLE INFO

Article history:
Received 17 February 2016
Received in revised form 16 June 2016
Accepted 8 August 2016
Available online 8 August 2016

Keywords:
A. Polymer-matrix composites (PMCs)
B. Fiber deformation
C. Computational modelling
D. Failure

ABSTRACT

This paper evaluated the potential use of carbon fiber/polypropylene-polyamide (CF/PP-PA) composites in thermoplastic automobile applications. Two dimensional electrical resistance (2D ER) mapping was use to sense and predict damages. The extent of random dispersion of carbon fibers (CF) in PP-PA matrix was evaluated using 2D ER mapping contour charts. ER data collected at 9 different positions was used to evaluate dispersion and micro-damages. The uniformity of dispersion of CF in fractured surfaces was observed for comparison. Pyrolyzed specimens were used to measure CF amount in each part and compared with 2D ER mapping. The differences in ER for tensile and compressive stresses were compared to explore their usage for real time monitoring and sensing of damages. The observation of the fractured surfaces exhibited an acceptable consistency with 2D ER results. Ultimately 2D ER mapping should be useful for evaluating and predicting damages in CF/PP-PA composites under various loading conditions.

1. Introduction

Thermoplastic and thermosetting composites are being extensively studied and developed worldwide for use as automobile components [1,2]. While epoxy resin based thermosetting composites have the advantages of high strength and modulus, they have the disadvantage of requiring rather lengthy curing processes which has restricted their usage for automobile components. Recently, accelerated epoxy resin curing processes have become available that cure thermosetting composites in as short of time as eight minutes [3]. The high temperature and time curing conditions for epoxy formulations results in rather low productivity for such automobile components. Automobile parts using thermoplastic formulations are commonly prepared using more rapid injection molding processes [4,5]. To improve the mechanical properties of such thermoplastic composites relatively long carbon fiber lengths (10–20 mm) are used.

With the incorporation of these chopped carbon fibers into thermoplastic composite it is possible to use rapid injection molding processing methods to produce rather complex automobile component with high reproducibility [6,7]. Today, polypropylene (PP) based thermoplastic composites have been used most for car components but the PP matrix does have the drawback of low interfacial and strength properties. Mixed matrices of PA and PP have also been used for composites for car parts [8,9]. Long term durability is an important parameter for automobile parts and this is dependent on good fiber dispersion, proper fiber arrangements and appropriate fiber surface treatment for the injection molded mixed thermoplastic composite matrix [10–12]. CF mixed thermoplastic pellets have also been used as a type of master batch for injection molding car part composites [13,14]. To assist in the development and refinement of such manufacturing techniques methods of detecting the CF distribution and dispersion are needed, which is a major goal of the research described in this paper.

Nondestructive evaluation (NDE) methods (such as ultrasonic C scanning and acoustic emission (AE) elastic wave detection) are also needed to detect and evaluate damage in automobile thermoplastic composites [15,16]. Rapid and real-time evaluation methods for sensing of fiber dispersion and damage detection would be useful for parts manufactured by injection molding.

The principal underlying the electrical resistance (ER) method used in this research is rather straight forward. It is based on the

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* Corresponding author at: Department of Materials Engineering and Convergence Technology, Engineering Research Institute, Gyeongsang National University, Jinju, Gyungnam 52828, Republic of Korea.
E-mail address: jmpark@gnu.ac.kr (J.-M. Park).

http://dx.doi.org/10.1016/j.compositesa.2016.08.009
1359-835X/

electrical resistance change (ERC) associated with structural and dimensional changes accompanying applied stresses. Prior research has shown that the ERC is concomitant with increasing stress in such composites [17,18]. ER measurements has recently been explored as a NDE method for thermoplastic composite parts [19,20]. The ER method has been used for a variety applications: (a) To detect exterior load and strain in thermoplastic composites [21–23]; (b) to determine the relationship between load, strain and micro-damage in conductive composites [24,25]; and (c) the use of hybrid composite sheets of carbon nanotube [(CNT)/graphene] for conventional nonconductive composite parts. The hybrid sheets were fabricated through surfactant-aided carbon nanomaterial dispersion followed by vacuum-induced filtration. The wide-area strain sensing ability of the polymer-impregnated composite sheets was demonstrated by subjecting composites with multiple electrodes to a flexural load and measuring the piezo-resistivity in situ. [26].

An ER model was developed (which will be described in more detail later in this paper) that facilitated mapping of resistance changes during loading to failure of CF/PP-PA composite specimens [27]. This was then correlated with damage and the development of microcracks. Various loading conditions were investigated including tension, compression flexural, fatigue, impact and cyclic fatigue loading demonstrating that such in-situ detecting of damages using the conductive reinforcement network is reliable [28]. Furthermore, the study which compares electrical mapping with AE for the damage sensing of composites was studied [29]. However, continuous experiments are required because the electrical mapping method needs many electrical probes and measurement time.

In this study, this new method of the 2D ER mapping was used for sensing/detecting damage and verifying the distribution of dispersion of the reinforcing filler in CF/PP-PA composites. To further check the consistency of the 2D ER mapping results burning weight loss and tensile tests were conducted individual parts of specimen and correlated with the ER measurements.

2. Experimental

2.1. Materials and test setting for 2D ER mapping

Pellets of 20 wt% CF/PP-PA composite (Hyundai EP Co. Ltd., Korea) with long CF was made by an injection molding process. This pelletized material was blended to make granules in an injection-molding machine with a co-rotating intermeshing twin-screw extruder (Bau-Tech, Korea). This extruder has a screw diameter of 19 mm and a distance between screw axes of 18.4 mm with L/D ratio of 40. The screw speed was 150 rpm, and the residence time for the melt was about 3 min. The samples for the mechanical testing were injected in the mold at a temperature profile with the steps of 200, 220, 240, and 260 °C.

Tensile tests were performed on CF/PP-PA specimens with the ER measurements. Fatigue tensile tests were conducted, on the CF/PP-PA composite specimens following ASTM D638 using a 400 kgf tensile load for 2000 cycles at a testing speed of 1 mm/min. During the tensile tests damage sensing was performed using the ER signal over 3 cells with a gage length of 100 mm. Flexural fatigue testing was conducted on CF/PP-PA specimens with a thickness of 3 mm, length of 320 mm and a width of 40 mm in 3 point bending with a span length of 100 mm and a cross head speed of 1 mm/min. During these fatigue tests damage sensing was accomplished by 2D ER mapping (which will be described in the results section of the paper) of the ER change over 5 cells. The three-types of tests used were: (1) a conventional tensile test, (2) a tensile fatigue test and (3) a 3-point cyclic bending test.

2.2. Evaluation of CF dispersion and concentration of CF/PP-PA composites by 2D ER mapping

The ER 2D mapping method was used for damage sensing and dispersion evaluation of the CF/PP-PA composite. Fig. 1 shows a schematic outline of the manufacturing steps for the 2D ER mapping specimens. The first step was to fix the 0.1 mm Cu wire to the CF/PP-PA surface using Scotch tape. The second step was to make rectangular spaces on the surface of specimens adjacent to the Cu wire to subsequently be filled with silver paste. Finally, polyimide tape was attached to the probe as illustrated in sketch (d) in the figure.

Fig. 2 shows a schematic sketch of the arrangement of 1 cell used for ER 2D mapping. This cell has a square ER area containing 4 probe connectors located at each corner for connection to a

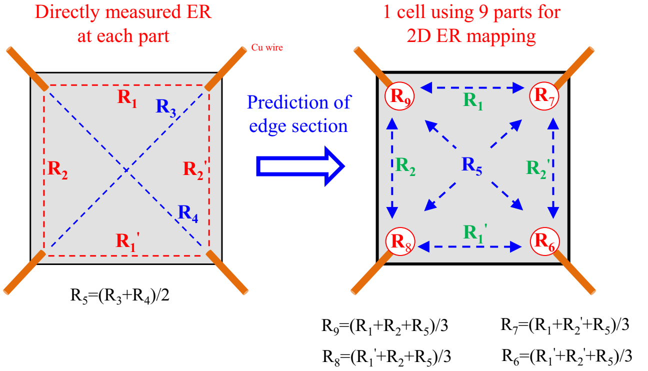

Fig. 2. Arrangement of 2D ER mapping on a 1 cell ER. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

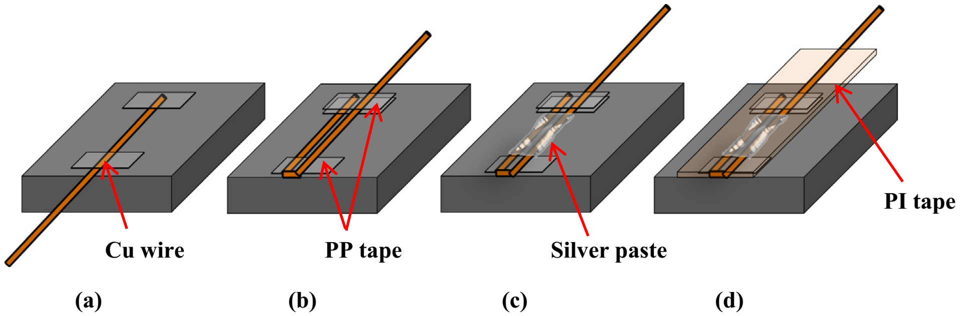

Fig. 1. Steps in the manufacture of contact ER probes on CF/PP-PA. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)