Composites Part B 114 (2017) 121–127

Contents lists available at ScienceDirect

Composites Part B

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

Natural fiber and aluminum sheet hybrid composites for high electromagnetic interference shielding performance

Changlei Xia [a], Jason Yu [b], Sheldon Q. Shi [a,*], Ying Qiu [c], Liping Cai [a], H. Felix Wu [d], Han Ren [e], Xu Nie [c], Hualiang Zhang [f]

[a] Department of Mechanical and Energy Engineering, University of North Texas, Denton, TX 76203, USA
[b] Texas Academy of Mathematics and Science, University of North Texas, Denton, TX 76203, USA
[c] Department of Mechanical Engineering, Southern Methodist University, Dallas, TX 75205, USA
[d] Vehicle Technologies Office, Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy, Washington, DC 20585, USA
[e] Department of Electrical Engineering, University of North Texas, Denton, TX 76203, USA
[f] Department of Electrical and Computer Engineering, University of Massachusetts Lowell, Lowell, MA 01854, USA

ARTICLE INFO

Article history:
Received 9 November 2016
Received in revised form
2 December 2016
Accepted 28 January 2017
Available online 31 January 2017

Keywords:
Natural fiber
Aluminum
Electromagnetic interference shielding
Sandwich structure
Hybrid composites

ABSTRACT

Using natural fiber mats, aluminum sheets and epoxy resin, hybrid composites were fabricated through vacuum assisted resin transfer molding (VARTM) process. With novel sandwich structures, these hybrid composites contain natural fiber-based shells and ultra-thin aluminum sheet core. The hybrid composites offered excellent electromagnetic interference (EMI) shielding performance with good mechanical properties inherited from aluminum sheets and natural fiber-based composites, respectively. Furthermore, the shell material (natural fiber-based composites) provides protection of the aluminum sheets from exposing to atmosphere directly to prevent being corroded. In this study, the EMI shielding effectiveness, microstructure, flexure property, tensile property, and internal bonding strength of the hybrid composites were examined. The excellent EMI shielding performance and good mechanical properties enable the new hybrid composites to be used as engineering materials in the EMI protection fields.

Published by Elsevier Ltd.

1. Introduction

The world today is filled with electromagnetic radiation, such as radio and cellphone signals, which are sent and received by a greatly increasing number of electronic devices and equipment [1,2]. Naturally, this has led to increasing vulnerability in electromagnetic interference (EMI), unwanted electromagnetic radiation that interferes with the usual operation of electronic equipment [1–6]. Electromagnetic pollution brings signal interference to electronic devices and can even damage their internal components that affect the overall performance. Furthermore, the electromagnetic pollution becomes worldwide preoccupation due to the potentially harmful to human health [1], such as insomnia and headaches [7], and even affects DNA [8]. In order to avoid or reduce the electromagnetic pollution, there have been many methods developed to prevent such unwanted electromagnetic radiation both from being emitted by potential sources and from being received by susceptible electronics [6,9,10].

EMI shielding occurs through reflection of the radiation, absorption of the radiation, and multiple reflections (reflections off of various surfaces or interfaces of the EMI shield) [6]. The most popular method of EMI shielding is to use metal sheets or coatings, which work primarily by reflection. Gold, silver, copper, and aluminum are good reflectors of EMI [6,11,12]. Metal sheets are frequently used, however, some drawbacks are their poor mechanical properties and corrosion resistance. Metal coatings such as paints or sputter coatings can be used instead of bulky metal sheets [13], however, they wear out easily [6], and may be inconvenient since the surface to which a coating to be applied may need additional preparation [7]. Another common method for EMI shielding is to use fillers such as metals [7,14], conductive polymers [15], metallic oxides [16–18], fly ash [19], etc. Currently, interests have been arisen to use carbon based materials for EMI shielding purpose due to their advantages, e.g. corrosion-resistance, low density, and environmentally friendly [20–27]. The use of carbon based materials endows the EMI absorption mechanism [28–32], which

* Corresponding author.
E-mail address: Sheldon.Shi@unt.edu (S.Q. Shi).

http://dx.doi.org/10.1016/j.compositesb.2017.01.044
1359-8368/Published by Elsevier Ltd.

they can reduce the secondary electromagnetic pollution [23]. However, this method utilizes the EMI shielding materials inefficiently, because more filler materials are used with less electromagnetic interference shielding effectiveness (EMI SE) effects compared to those of metal coatings. Alternatively, one can choose to embed a layer of metal in a durable, corrosion-resistant polymer matrix composite material, thus overcoming the drawbacks of metal sheets and metal coatings (e.g., low wear, EMI material save, high EMI SE, and corrosion resistance) [7].

As renewable, sustainable, and environmental resources, natural fibers have received arising interest in related products manufacturing, e.g. natural fiber reinforced composites [33,34], automotive applications [35,36], natural fiber reinforced tubes [37], carbon materials [38–41], natural fiber filled cement [42,43], thermal-conductivity enhancing materials [44], etc. Hemp, a variety of *Cannabis sativa L.*, is one of the earliest domesticated plants. It has long been valued for its versatility, e.g. seeds have been used for food and oil, and fibers are strong and have been historically made into rope, paper, and textiles [45–47]. Due to the increasing concern with the environment and sustainability, natural fibers, such as hemp, kenaf, sisal, and jute, are increasingly investigated and utilized thanks to their sustainable, biodegradable, eco-friendly and economic properties as natural resources [36,48–51]. In the previous reports, natural fiber-based composites show excellent mechanical properties comparable to those of glass-fiber sheet molding compound (SMC) [36,47,48,52–54].

By incorporating metal sheets into the natural fiber-based composites, the resulting sandwich-structure composites offer advantages of both metal sheets and natural fiber-based composites, while address the drawbacks for using metal sheets directly. The sandwich-structure composites have an excellent EMI shielding performance contributed from the metal sheets, and the good mechanical properties provided by the natural fiber-based composites. As the core material, the metal sheets are protected to avoid the electrochemical corrosion by the natural fiber composite shell. The sandwich composites allow that the materials can directly be used in structural applications.

In this study, aluminum sheets were introduced into hemp fiber mats to fabricate sandwich-structure composites through vacuum assisted resin transfer molding (VARTM) process. The microstructures, EMI shielding performances, and mechanical properties of the composites were examined.

2. Materials and methods

2.1. Composites fabrication

The hybrid composites were fabricated using hemp fiber mats (Hemp Solution Inc., USA) with an area density of ~60 Kg m^{-2}, aluminum sheets (Reynolds Wrap® heavy duty aluminum foil with a thickness of 0.024 mm) and epoxy resin (epoxy resin 1159 and harder 1160 with a mixture of 2/1 (vol/vol, resin/harder), Composite Envisions LLC., USA) through VARTM process [52,55]. Firstly, the hemp fiber mats and Al sheet were cut into a dimension of 305 × 305 mm (width × length). The assembled hemp fiber mats/Al sheets or hemp fiber mats were placed on a mold with a lay of peel ply (Airtech bleeder lease b coated peel ply) between them, and then another layer of peel ply was placed onto the assembly and covered with a flexible polyethylene vacuum bag (Airtech Wrightlon® wl5400 nylon vacuum bagging film). The resin was infused by a vacuum pump (Vacmobile 20/2 System with Becker U4.20) with a pressure of 1.3–1.6 kPa. The resin-infused preforms were then cured in a hot press at a pressure of 5 MPa, a temperature of 100 °C for 1 h, and then 150 °C for 1 h. Once the fabricated composite cooled down to room temperature, the vacuum bag and peel plies were removed to obtain the composites. Control samples, with no aluminum sheets introduced were also fabricated for comparisons.

2.2. Microstructure analysis

The microstructures of the composites were analyzed using a SkyScan 1172 x-ray micro computed tomography (micro-CT) (Bruker Corp., USA). In order to obtain an optimum attenuation contrast, a source voltage of 60 kV and a current of 167 μA were selected. A set of 1202 projections were obtained with no filter, an angular step size of 0.3° and a 2 K binning mode (with a resolution of 2000 × 1336 pixels). Consequently, the corresponding spatial resolution of the X-ray radiography is about 8.49 μm/pixel. NRexon software was employed to perform the reconstruction of the 3D object, and Data Viewer and CTvox were used for data analysis and visualization.

2.3. Electromagnetic interference shielding tests

The EMI SE measurements with both amplitude and phase properties were performed by an E8363B PNA Network Analyzer (Agilent Technologies Inc., USA) in a frequency ranging from 8 GHz to 12 GHz, presenting the results of the shielding measurements in decibels (dB). The measurements were conducted at an interval of 0.02 GHz, from which 201 points were collected for each measurement. All the specimens were machined to the same dimension (42 × 42 mm) with the corresponding WR90 SMA/F waveguides (Fairview Microwave Inc., USA), which led to the samples exactly fit the size of waveguides. The mode of shielding measurement was a typical transmission measurement (scalar S21 - measurement). The reflecting measurement was to detect the reflecting power (scalar S11 - measurement). The dB value described the level of the incident power or power-flux density decreased after it passed the device during the test. To calculate the dB value from the incident power P_1, respectively, from the arriving electrical field strength E_1 and the transmitted power P_2 or field strength E_2, the following equation was used:

$$SE_{dB} = 10\ \log\left(P_1/_{P_2}\right) = 20\ \log\left(E_1/_{E_2}\right) \tag{1}$$

2.4. Three-point bending flexural tests

Three-point bending tests were performed using a universal testing machine (AGS-X, Shimadzu Corp., Japan) machine in accordance with the procedure described in ASTM D790 standard. Twelve specimens with dimensions of 25 × 160 mm (width × length) from each composite sample were cut by a 9-in Skil benchtop band saw (Robert Bosch Tool Corp., USA). A span of 100 mm and a crosshead speed of 5 mm min^{-1} were used for the three-point bending tests Flexural stress-strain load-deflection curves were obtained from the test data, and flexural modulus, strength, and strain at break of the composites were calculated by Eqs. (2)–(4), respectively.

$$Flexural\ modulus = \frac{L^3 m}{4bd^3} \tag{2}$$

$$Flexural\ strength = \max\left(\frac{3PL}{2bd^2}\right) \tag{3}$$