Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 28(2018) 103−113
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Physical and electromagnetic shielding properties of green carbon foam prepared from biomaterials

Shameel FARHAN[1], Ru-min WANG[1], Ke-zhi LI[2]

1. Department of Applied Chemistry, School of Science, Northwestern Polytechnical University, Xi'an 710072, China;
2. School of Materials Science and Engineering, Northwestern Polytechnical University, Xi'an 710072, China

Received 28 August 2016; accepted 6 November 2016

Abstract: 100% green carbon foam from the fibrous fruits of *Platanus Orientalis*-L (Plane) along with the tar oil as binder has been prepared using a powder molding technique. The objective was to develop a porous monolithic carbon from biomaterials with a considerable strength necessary for various physical, thermal and electromagnetic shielding applications. Fast carbonization was carried out at 1000 °C under the cover of Plane tree pyrolyzed seeds without using any external protective gas. For comparative analysis, some samples were mixed with 5% (mass fraction) iron chloride during the molding process. Iron chloride being a graphitization catalyst and activating agent helped in increasing the specific surface area from 88 to 294 m^2/g with a 25% decrease in flexural strength. Thermal stability was improved due to the incorporation of more graphitic phases in the sample resulting in a little higher thermal conductivity from 0.22 to 0.67 W/(m·K). The catalytic carbon foam exhibited shielding effectiveness of more than 20 dB over the X-band frequency. Absorption was dominant with only 8.26%−10.33% reflectance, indicating an absorption dominant shielding mechanism. The new material is quite suitable for high temperature thermal insulation being lightweight, highly porous with interconnected porous morphology most of which is preserved from the original biomaterial.
Key words: carbon foam; biomass; pyrolysis; powder molding; electromagnetic properties

1 Introduction

Carbon foams are inert materials with numerous applications in water and air purification technology, energy storage, radar absorbing materials, catalyst support, electrode materials, acoustic panel, tooling, and fuel cell humidification etc [1−3]. Most commonly, pitches, coals, and phenolic resin are used as carbonaceous precursors with self or induced foaming [4−6]. Due to importance of bio-based and environment-friendly precursors, tannin, cellulose, lignin and sucrose etc have also been utilized successfully for making such porous carbons [7,8]. Bio-based precursors can be agricultural residues, forestry products or city wastes and the resulting carbon is amorphous in nature. Recently, our research group has developed a novel powder molding method for making carbon foam [9,10]. Carbonaceous precursors containing pore former, binders, filler/additives (if any) in a required mixing ratio can be dry molded, cured and carbonized to make monolithic porous carbon with a desired morphology. In the current investigation, all bio-based carbon foam has been prepared by using powder molding method with carbonaceous precursors derived from non-food/non-feed plant origin. Woody fibrous powder and tar oil were used as pore former and binder, respectively. The Plane trees, the most common being *Platanus Orientalis* L (scientific name) or Wutong/Fatong (local Chinese name) is widely grown in the university campus and is one of the woody perennial trees of temperate regions [11]. The composition and vascular structure are responsible for the porosity development after thermal treatment in controlled environment [12]. Tar oil extracted from the woods becomes refractory after carbonization [13]. In addition, another goal of the current investigation was to produce bio-based carbon foam with a higher surface area using a graphitization catalyst during the carbonization processing. As reported earlier, chemical, physical, and a combination of physical/chemical

Foundation item: Project (CX201627) supported by the Innovation Foundation for Doctor Dissertation of Northwestern Polytechnical University, China
Corresponding author: Shameel FARHAN; Tel: +86-29-88492947; Fax: +86-29-88492943; E-mail: rmwang@nwpu.edu.cn, shameelfarhan@yahoo.com
DOI: 10.1016/S1003-6326(18)64643-6

processes are well-established methods for activation of carbonaceous materials [14−16]. Chemical activation process is simple and efficient as it takes place at a lower temperature with a shorter reaction time [17,18]. The most commonly used chemicals are zinc chloride ($ZnCl_2$), potassium hydroxide (KOH), phosphoric acid (H_3PO_4), sodium hydroxide (NaOH), iron chloride ($FeCl_3$) and phosphoric acid (H_3PO_4) etc [19,20]. For the current investigation, $FeCl_3$ was selected due to two reasons: first as a carbonization/graphitization d-metal catalyst and second as an activation agent [21]. One of the decisive factors, which determine the characteristic behavior of carbon foam, is the graphitization temperature. $FeCl_3$ played a major role in this regard by first dehydrating, then crosslinking and eventually promoting graphitization domains at carbonization temperature. Although many works have been published in recent years on the preparation of activated carbon from various cheaper and alternative agricultural wastes and by-products with chemical activation, there is no study about the preparation of "molded carbon foam" from 100% biomaterials and using $FeCl_3$ as activation/graphitization catalyst in one-step. Some works reported that tannin when being used for making bio-based carbon foam, presents tailor made and versatile properties but is low in density and not very high in strength [22]. Olive stones also resulted into carbon foam after pyrolysis under steam by the mechanism of softening and swelling but not in a bulk monolithic shape [23]. Therefore, the purpose of this work is to develop quasi-carbon foam with considerably high strength, bulk in shape, thermally insulating, shielding for electromagnetic interference (EMI) and extended surface properties. Carbon foams exhibit excellent EMI shielding as well as microwave absorption capacity, which could be closely ascribed to their tailored macrostructure, high electrical conductivity, good electromagnetism attenuation capability and highly porous interconnected framework [5,24,25]. Due to the synergetic effect of conductivity and multiple reflections, it is believed that this bio-based foam has promising shielding applications in harsh aircraft and other electronic enclosures.

2 Experimental

2.1 Preparation of precursors for carbon foam

Plane dried fruits were collected from the main university campus (Northwestern Polytechical University, Xi'an, China) and a part of it was used to make tar oil. Starch and $FeCl_3.6H_2O$ were purchased from Sino-pharm Chemical Reagent Beijing Co., Ltd. The dried fruits were washed with a liquid soap and dried at 110 °C for 24 h. After crushing, grinding and sieving using a 50-mesh screen, the proximate analysis of Plane fruit powder (PFP) showed 12.94% of moisture, 58.48% of volatile matter, 13.84% of ash, 14.74% of fixed carbon. The high contents of organic compounds (74.99%) indicate that it has a potential as a good carbon precursor. Tar oil was made by devolatilization of hard Plane fruit seeds in an enclosed reactor (Fig. 1) in a temperature range of 400−500 °C. The heat was supplied from the outer source and the pyrolysis reaction was started from the bottom side being close to the heat source. Most of the heat was consumed by the endothermic pyrolysis reaction at the wall sides. By this time, the solids at the top of the reactor and away from heat source were heated very slowly and most of carbon was converted into the char. The pyrolytic vapors from the bottom initiated secondary cracking reaction at the top producing more yield of char in this reactor.

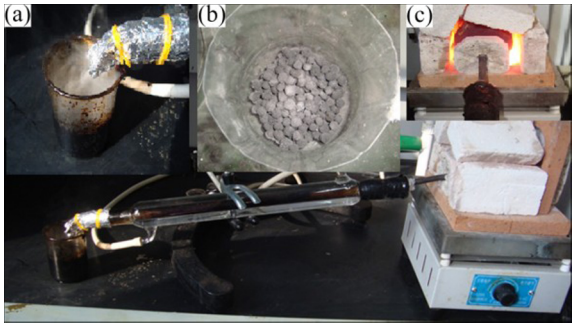

Fig. 1 Tar extraction set-up: (a) Tar oil collection; (b) Carbonized seeds; (c) Heating furnace with heating from one (bottom) side

The non-condensing gases (CO_2, CO, CH_4, H_2, H_2O, and C_xH_y) were escaped and a liquid tar was collected in a beaker. Due to the presence of aldehydes and low molecular-mass acids, the tar oil had a strong smoky odor — a characteristic of liquids obtained by the pyrolysis process. Visual characteristics of the as-prepared char and tar oil are shown in Fig. 1; the physical properties are presented in Table 1. The yield of tar oil and char was calculated based on mass ratios (total yield in mass/total precursor mass × 100%). In this lab scale process, carbonized seeds and tar oil were produced

Table 1 Physical properties of tar oil and char

Sample	Density/(g·cm^{-3})	Yield/%	Water content (mass fraction)/%	Viscosity/(mPa·s)	pH
Tar oil	1.07[a]	35−39	11−15[c]	3.12	3.3−3.5
Char	0.035[b]	25−29	–	–	–

a: Density measurement bottle; b: Density of one seed; c: Karl Fischer titrimetric method