Materials Letters 233 (2018) 59–62

Contents lists available at ScienceDirect

Materials Letters

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

Lightweight flexible graphite sheet for high-performance electromagnetic interference shielding

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ARTICLE INFO

Article history:
Received 23 May 2018
Received in revised form 25 July 2018
Accepted 12 August 2018
Available online 18 August 2018

Keywords:
Carbon materials
Porous materials
Exfoliated graphite
Flexible graphite and EMI shielding

ABSTRACT

Flexible graphite sheet (FGS) is prepared by using exfoliated graphite (EG) without a binder. The compression of EG particles results in mechanical interlocking of each EG particle to form a sheet. Therefore, the synthesis of highly expanded EG materials is neccesary for making FGS. EG has been prepared within one minute using a simple, low cost, one chemical compound-based microwave irradiation technique. FGS in a thickness range of 0.1–0.5 mm has been prepared using the EG. The as-prepared FGS shows an outstanding electromagnetic interference (EMI) shielding effectiveness (SE_T) was found to be 79.4(-dB) at a frequency of 12 GHz for 0.5 mm thickness.

1. Introduction

The rapid increase in usage of electronic devices along with development of communication technology, the electromagnetic interference (EMI) problem has been increasing at an observable rate[1]. Therefore, research on high-performance EMI shielding materials has become an urgent requirement. The fundamental mechanism of EMI shielding is generally reflection. For reflection of the radiation by the shield, the shield material should have electrical conductivity or free mobile charge carriers (electrons or holes) which intermingle with the electromagnetic fields in the radiation. Carbon-based shielding materials with various nano/micro-structures or shapes have been widely prepared to get light weight and high-performance EMI shielding. Chen et al. studied graphene/PDMS foam (1 mm) with shielding effectiveness (SE) up to 23 dB [1]. Yu's group impregnated epoxy into preformed CNT sponge and reported EMI SE of 33 dB [2]. Wan et al. studied large-sized graphene sheets (LG) with iodine doping and achieved SE up to 52.2 dB [3]. Recently Liu et al. studied Graphene enhanced flexible expanded graphite film and obtained SE up to 52.6 dB [4]. However, easily processed, light weight, flexible with high rate of EMI shielding based on unique structured materials is still challenging field of research.

Exfoliated graphite (EG) is the expansion of graphite flakes along c-axis upto several hundred times resulting in a highly porous worm-like material. Flexible graphite sheet (FGS) is prepared by compressing a collection of EG worms without a binder [5]. Compression of the EG worms (like accordions) causes mechanically interlocking to each other, so that a sheet is formed without a binder. Due to the exfoliation and binder free (pure graphite) nature, FGS exhibits larger surface area and high electrical conductivity, making it promising material for EMI shielding [5].The EG used to make a FGS should be easily processed, pure (low residue formation) and well-exfoliated (with high exfoliation volume (EV)). So far, the production of EG has been done using sulfuric acid (H_2SO_4) [6,7], nitric acid (HNO_3) [8] or perchloric acid ($HClO_4$) [9,10]. However, these methods have several drawbacks such as consuming more quantity of chemicals, time and energy; requiring more than one chemical compound; forming residue (lack of purity) and having less exfoliation volume, thereby resulting in poor application performance. We have earlier reported [11] on the synthesis of EG from a single compound based intercalation and in the present letter we discuss the fabrication of flexible graphite sheets from this material and their application for electromagnetic shielding.

2. Experimental procedure

2.1. Synthesis of exfoliated graphite (EG) and flexible graphite sheet (FGS)

0.5gm of natural graphite flakes (99.7% carbon, 500micron particle size) and 0.8gm of diluted perchloric acid (60%$HClO_4$) were mixed for 10 s to form graphite intercalation compound (GIC). The GIC was uniformly distributed in a 250 ml quartz beaker and directly placed in a domestic microwave oven (SAMSUNGCE103VD)

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https://doi.org/10.1016/j.matlet.2018.08.066
0167-577X/

operated at 800 W for 50–60 s. The microwave heating facilitates quick evaporation of intercalated species in the GIC, causing fuming and sparking of GIC, resulting in the production of a highly porous worm-like structured material called exfoliated graphite. The detailed structural and microstructural characterization of the EG material has been discussed earlier [11]. The as-prepared EG material was evenly distributed in a mould, compressed and then rolled to get the desired thickness. By choosing appropriate quantity of material, the density of the sheets was maintained at 1 g/cc.

2.2. Characterization

EG and FGS samples were characterized by field emission scanning electron microscope (FESEM; Zeiss EVO-50) and EMI shielding measurements was carried on an Anritsu MS4642A vector network analyzer (VNA). The electrical conductivity of composites was measured by Kiethley 6221 four probe method.

3. Results and discussion

3.1. Characterization of EG

Surface and cross section of the FGS was observed from FESEM as shown in Fig. 1a and b. It clearly shows the wrinkeled layers in the flexible sheet. Fig. 1c and d show the surface and flexibility of the 0.5 mm thick sheet. On the FGS sheets (0.1–0.5 mm thick) mechanical and EMI shielding characteristics have been studied.

3.1.1. Mechanical characterization

The tensile strength of FGS was measured by ZwickRoell UTM (model Z010) as per the ASTM C565 standards with a cross-head speed of 0.5 mm/min. The dimensions of the FGS was $15 \times 1 \times (0.01\text{–}0.05)$ cm. Tensile properties of FGS were measured parallel to the rolling direction of the sheet. The strength of FGS is related to the properties of the initial graphite and the conditions used in the chemical and heat treatment [12]. The materials having larger surface area posses high EV and are easily bound together under pressure to form FGS with higher tensile strength than the materials possessing lower EV [13,14]. Yang et al. [14] concluded that the tensile strength of the sheet increases as the size of the pristine natural graphite flakes increases only when the flakes are "fully exfoliated", otherwise the strength may decrease with increasing flake size. We studied the underlying relationship of tensile strength to EG prepared at different thickness. Typical stress–strain curves are shown in Fig. 2. It clearly shows that the thickness of the sheet has profound thickness on the relation and the highest tensile strength was obtained to be 16.9 MPa for 0.5 mm thick FGS. This is far better than the previously reported [13,14].

3.1.2. EMI shielding behaviur of FGS

The EMI SE was evaluated from the scattering parameters by the following formulas:

$$T = |S_{12}|^2 = |S_{21}|^2$$

$$A + R + T = 1$$

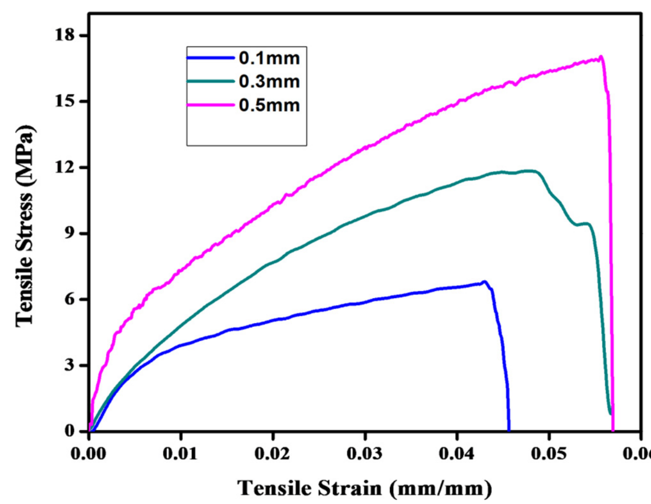

Fig. 2. Tensile properties of FGS at different thickness.

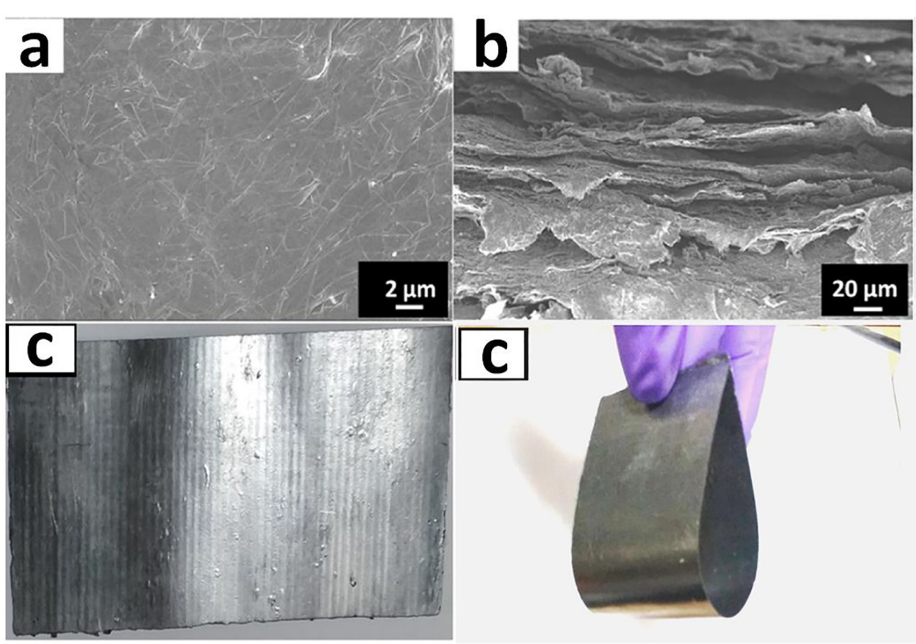

Fig. 1. FESEM images of FGS (a) surface and (b) cross-section, digital photographs of appearance of FGS in (c) surface and (d) flexible mode.