

Effects of functionalized carbon nanofillers on the spectral selectivity behavior of aluminum nanocomposites for solar absorber applications

Mohd Zakuan Zabri^{a, *}, Shaifulazuar Rozali^{a, **}, Nor Afifah Yahaya^b, Siti Shafiah Shazali^a

^a Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

^b Faculty of Mechanical Engineering, Universiti Teknologi MARA, Malaysia

HIGHLIGHTS

- Spectral selectivity behavior of Aluminum (Al) based metal nanocomposites.
- Investigation of the MWCNT/MWCNTCOOH and GNP/GNPCOOH concentration on spectral and optical performances.
- Morphological and optical properties of Al-MWCNT-GNP and Al-MWCNTCOOH-GNPCOOH composites.
- Enhancing dispersibility of the nanofiller in Al with the addition of MWCNTCOOH/GNPCOOH nanofillers.

ARTICLE INFO

Article history:

Received 22 December 2017

Received in revised form

7 March 2018

Accepted 8 March 2018

Available online 16 March 2018

Keywords:

Aluminum nanocomposites

Multi-walled carbon nanotubes

Graphene nanoplatelets

Spectral selectivity ratio

Solar absorbers

ABSTRACT

The effects of functionalized multi-walled carbon nanotubes (MWCNTs) and graphene nanoplatelets (GNPs) on the spectral selectivity behavior of aluminum (Al) nanocomposites were investigated in this study. The attachment of the carboxylic (COOH) functional group on the surface of the carbon nanofillers was confirmed by Fourier transform infrared spectroscopy. The pristine and functionalized MWCNTs and GNPs were introduced into pure Al powder at different concentrations (5, 10, and 15 wt%) to produce Al–MWCNT–GNP and Al–MWCNTCOOH–GNPCOOH nanocomposites. The results show that the dispersion of the carbon nanofillers is better and the spectral selectivity ratios are higher for the Al–MWCNTCOOH–GNPCOOH nanocomposites compared with those for Al–MWCNT–GNP nanocomposites. In addition, the light absorption is significantly enhanced in the ultraviolet, visible, and near-infrared regions (200–2500 nm) whereas the reflectance is significantly enhanced in the near-infrared, mid-infrared, and far-infrared regions (3000–14 000 nm) for the Al–MWCNTCOOH–GNPCOOH nanocomposites. The highest spectral selectivity ratio (27.41) is attained for the Al nanocomposite with 2.5 wt % MWCNTCOOH and 2.5 wt% of GNPCOOH.

© 2018 Elsevier B.V. All rights reserved.

1. Introduction

Solar absorber is one of the key components of solar energy harvesting systems. Solar absorber needs to fulfill the following criteria: (1) high absorption in the ultraviolet (UV), visible (VIS), and near-infrared (NIR) of 200–2500 nm and (2) low emittance in the NIR, mid-infrared (MIR), and far-infrared (FIR) spectra within a wavelength range of 2500–16 000 nm in order to minimize thermal radiation losses, and (3) good thermal conductivity in order to

maximize heat transfer to the exchange medium and maintain a stable operating temperature (>500 °C) [1,2]. It is known that high operating temperatures will lead to problems with the coatings used for solar absorbers. Sathiaraj et al. [3] and Tesfamichael et al. [4] conducted theoretical and experimental studies on the use of metal-dielectric composites such as nickel-pigmented aluminum oxide (Al₂O₃) as solar absorber coatings. However, such metal-dielectric composites degrade over long operating periods due to the oxidation of metal nanoparticles, especially in high-temperature and high-humidity environments [3,4]. At present, high-temperature paints such as Pyromark™ Series 2500 is the standard coating used for solar absorbers in concentrating solar power (CSP) systems. This paint has a high solar absorbance of 0.96 and more importantly, this paint is inexpensive and easy to apply. However, the thermal emittance of this paint is rather high (0.86),

* Corresponding author.

** Corresponding author.

E-mail addresses: zakuanzabri@um.edu.my (M.Z. Zabri), azuar@um.edu.my (S. Rozali).

which leads to large thermal losses during high-temperature operations [5]. In addition, the paint delaminates and degrades over time, which decreases the performance and increases the operating cost for solar absorbers [5]. The main problems of spectrally selective coatings are degradation and delamination of the coatings at high temperatures, inter-diffusion between layers, and oxidation since the coatings are exposed to air at high temperatures. All of these will degrade the performance of the solar absorber [6].

Spectrally selective coatings were originally developed with the intention to enhance the optical properties of the bulk materials. However, with technological advances over the years, it is not really accurate to say that spectrally selective coatings are merely developed to enhance the optical properties of the bulk materials. Nowadays, much effort is being made to develop thin films in addition to testing bulk and solid samples for spectrally selective applications. Even though bulk materials generally have better optical properties, these superior optical properties are achieved only for specific materials and operating conditions. According to Sani et al. [7], the optical properties of spectrally selective absorbers are different, depending on the materials used for the coatings. They fabricated spectrally selective absorbers from zirconium diboride (ZrB_2) and tantalum diboride (TaB_2) using a powder metallurgical process. The optimum TaB_2 pellet was sintered through spark plasma sintering and reactive spark plasma sintering and the results showed that the TaB_2 pellet has a solar absorbance of 0.40 and thermal emittance of 0.12 at 1400 K. In contrast, the ZrB_2 pellet has a slightly higher solar absorbance of 0.47 at 1400 K, whereas the thermal emittance is the same as that for the TaB_2 pellet.

In this study, it is believed that the dispersion of spectrally selective nanocomposites can be improved by incorporating carbon nanofillers (specifically multi-walled carbon nanotubes (MWCNTs) and graphene nanoplatelets (GNPs)) into aluminum (Al). Some of the findings obtained by the previous researchers [8–10] did report the excellent performance of both MWCNT and GNP nanofillers when incorporate together with base material such as metal and polymer. Al is one of the common base materials used for metal-MWCNT nanocomposites and metal-GNP nanocomposites due to its favorable thermal, optical, electrical, and mechanical properties and diverse range of technical applications [8,11–13]. In addition, Al is a lightweight material. The diameter of MWCNTs ranges from 1 nm to a few tens of nanometers and it has been reported that MWCNTs result in plasmon excitations [14], which improves the absorption of solar radiation [15]. Chen and Böstrom [16] investigated the use of MWCNTs in solar selective coatings and the results are indeed promising because the coatings have good spectral selectivity behavior, as indicated by high solar absorbance ($>0.90\%$) and low thermal emittance ($<0.15\%$). Meanwhile, graphene, which is a relatively new carbon material altered from the original structure of single-walled carbon nanotubes (SWCNTs), has garnered much attention from the scientific community because of its excellent thermal, mechanical, and electrical properties [17]. Unlike CNTs, graphene has a two-dimensional sheet-like structure with larger surface area, which makes it a good filler material for composites. In addition, it is relatively inexpensive to synthesize graphene [18].

It is believed that incorporating MWCNTs and GNPs into the Al matrix will improve the optical properties of spectrally selective coatings. However, despite the unique properties of MWCNTs and GNPs, both of these carbon nanofillers are prone to agglomeration during synthesis due to van der Waals forces between the particles. In addition, it is not possible to achieve effective interfacial bonding due to the poor affinity of MWCNTs and GNPs toward Al. In order to address this issue, it is imperative to synthesize Al–MWCNT–GNP nanocomposites which fulfill the following criteria: (1) the MWCNTs and GNPs should be uniformly dispersed within the Al

matrix, and (2) there is sufficient interfacial bonding between the Al, MWCNTs, and GNPs [19]. This can be achieved by implementing a pre-treatment process in order to attach functional groups on the pristine MWCNTs and GNPs.

In this study, the spectral selectivity behavior of Al nanocomposites incorporated with functionalized MWCNTs and GNPs is investigated for the first time, to the best of the authors knowledge. The spectral selectivity behavior of the Al nanocomposites with functionalized MWCNTs and GNPs is compared with that pure Al and Al nanocomposites with pristine MWCNTs and GNPs. All of the samples are produced using the powder metallurgy technique. The effects of the functionalized MWCNTs and GNPs on the microstructure, and reflectance of Al nanocomposites are analyzed and discussed in detail in this paper. It is believed that the findings of this study will be of great interest to the scientific community to explore the potential of carbon nanofillers in enhancing the spectral selectivity behavior of spectrally selective absorbers.

2. Experimental procedure

2.1. Materials

Fig. 1 shows the image of as-received Al powder (brand: Acros Organics, purity: 99%, average particle size: $74\ \mu\text{m}$) purchased from Fisher Scientific (M) Sdn. Bhd., Malaysia, obtained from field-emission scanning electron microscopy (FESEM). Fig. 2(a) shows the FESEM image of the pristine MWCNTs (purity: 95%, outer diameter: 30–50 nm, length: 10–20 μm) whereas Fig. 2(b) shows the FESEM image of functionalized MWCNTs (MWCNTCOOH) after chemical treatment process. As shown in Fig. 2(a), the morphology of pristine MWCNTs is curly and intertwine with each other. The diameter of the pristine MWCNTs still maintain its uniform shape without any deformity on its structure. After the chemical treatment using combination of H_2SO_4/HNO_3 , the diameter of the MWCNTCOOH becomes a little smaller, due to the oxidation of the outer layer of MWCNTs by strong acid combination which can be seen in Fig. 2(b).

Fig. 3(a) shows the FESEM image of the pristine GNPs (average thickness: 2 nm, width: 1–2 μm , surface area: $300\ \text{m}^2/\text{g}$) whereas Fig. 3(b) shows the FESEM image of functionalized GNPs (GNPCOOH) after chemical treatment process. The morphology of pristine GNPs shows a few layers of plane surface stack onto each other as shown in Fig. 3(a). After the chemical treatment using combination of H_2SO_4/HNO_3 , the plane surface of the GNPCOOH becomes a little smaller due to the oxidation of the outer layer of GNPs by strong acid combination which can be seen in Fig. 3(b). The pristine MWCNTs and pristine GNPs were purchased from XG Sciences, Inc., USA.

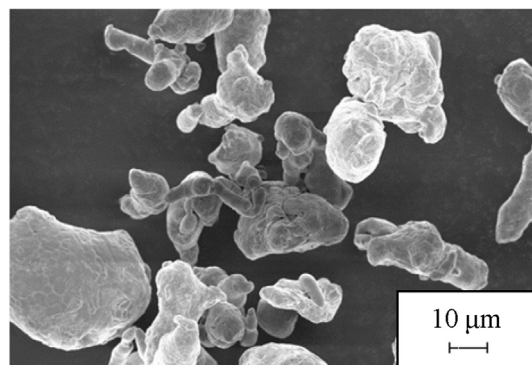


Fig. 1. FESEM image of the as-received Al powder.

Download English Version:

<https://daneshyari.com/en/article/7921708>

Download Persian Version:

<https://daneshyari.com/article/7921708>

[Daneshyari.com](https://daneshyari.com)