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Synthesis of glass fiber-nano silicon carbide composite by using waste printed circuit boards and compact discs as resources

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ABSTRACT

The rapid advances in technology, urbanisation and decrease in life span of electronic equipment have accelerated the generation of electronic waste significantly. Electronic waste is considered as serious social problem and environmental threat and hence sustainable methodology is critically required to recycle e-waste. In this paper, a novel approach to synthesise glass fiber-silicon carbide (SiC) composite by using waste printed circuit boards (PCBs) and compact discs (CDs) as resources is reported. The synthesis is based on carbothermal reduction using non-metallic PCB residue as glass fiber source, waste CD char as carbon source and silicon dioxide as silicon source. SEM, XRD, Raman and FTIR results confirm the formation of glass fiber-SiC composite and XRD signifies the major phases of β-SiC. SiC particles were mainly composed of sphere shaped nanoparticles and glass fiber sizes were in the range of 200–500 um length. This innovative approach of using electronic waste as resources could be an alternative for synthesis of glass fiber-SiC composite and also reduces the dependency on traditional raw materials.

Introduction

Glass fiber-reinforced composites have been increasingly used for numerous engineering applications due to high specific strength and modules. Silicon carbide (SiC) is commonly used as reinforcement due to its high thermal conductivity, wear resistance and lower thermal expansion [1]. The addition of SiC to glass fiber enhanced chemical erosion resistance, thermal shock resistance and mechanical properties [2]. The glass fiber-SiC composite is generally fabricated by using industrial synthesised glass fiber and SiC. The carbothermal reduction or combustion process is widely used in industries to synthesise SiC by using coke and silica as resources [3]. Glass fiber is manufactured by using silica but calcium oxide and alumina is also incorporated to reduce working temperature [4]. Currently, the carbon and silica source is limited to coke and pure silica hence alternative resources should be explored to synthesise glass fiber-SiC composites.

Electronic waste is growing rapidly with a global production of 20–50 million tonnes due to rapid advances in technology, urbanisation and decrease in life span of electronic equipment [5]. Printed Circuit Boards (PCBs) is one of the major components in electronics and contributes significantly to the total electronic waste. PCB comprises 40% metals, 30% organics and 30% ceramics [6]. The focus on recovering valuable metals from waste PCB is encouraged due to higher concentration of metals in addition to treating waste [7]. The recovery of non-metallic, which is larger fraction of PCB is less focused and been discarded as secondary waste to landfills. Fewer studies have reported the use of non-metallic fractions of PCBs to make formative models etc. Compact discs (CDs), another widely used electronic component used for data storage also contributes significantly to the total e-waste. Worldwide production of CDs reached 12 billion units in 2003 and has increased further in present years [8,9]. The combination of polymer and metal coating in CDs makes it difficult to recycle. Recycling technique which is environmentally friendly and also effective in recovering the resources from waste PCBs and waste CDs is essential for the current scenario.

In our group, we have been successful in replacing coke in steelmaking industries by various polymeric and agricultural wastes [10–12]. The synthesis of ferrosilicon by using waste glass and plastic as resources is also reported [13]. In literature, only few studies have made an effort to transform electronic wastes to value added products. In this work, we report the use of waste PCBs and waste CDs as resources to synthesise SiC-glass fiber composite. Recently, we also described the generation of carbon micro fibers and foams from PCB waste [14].

In this study, an innovative approach to *in-situ* synthesise SiC-glass fiber composite by using electronic waste as resources is reported. The

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synthesis was based on carbothermal reduction using non-metallic PCB residue as glass fiber source and waste CD char as carbon source. The morphology and formation of composite have been investigated by various analytical techniques. This innovative approach could be an alternative and environmentally sustainable solution for synthesis of SiC-glass fiber composite.

Experimental

The non-metallic fractions of waste PCBs was obtained by performing pyrolysis at 1000 °C and char from waste CDs at 700 °C for 20 min in an argon atmosphere. The resultant non-metallic fractions of PCBs and waste CD char were characterized by using Elemental, X-ray diffraction (XRD, PANalytical X'Pert Pro multipurpose), Raman spectroscopy (Renishaw inVia) techniques and using Scanning Electron Microscope (SEM).

Non-metallic fractions obtained from waste PCBs and char from waste CDs were used as glass fiber and carbon sources to synthesise composite. Glass fiber source, silica and char were mixed and were made into pellets with the help of a mould. The synthesis of glass fiber-SiC composite was conducted at 1350 °C in horizontal tubular furnace. The synthesized SiC composites were identified by XRD, Fourier transform infrared spectrometry (FTIR, Perkin-Elmer Spotlight 100) and by Raman spectrometry. SEM was also used to study the morphology of synthesized glass fiber-SiC composite.

Results and discussion

PCB's are fabricated using two different base materials i.e. glass reinforced (FR-4 type, widely used in computers, medical equipment) and cellulose paper reinforced with phenolic resin (FR-2 type, widely used in monitors and calculators). In this study, we have used glass fiber reinforced FR-4 type waste PCBs which was collected from end-of-life computers. Elemental analysis of waste computer PCB shows around 40% of glass fiber content. The collected waste PCB was pyrolyzed at 1000 °C for 20 min in argon atmosphere to avoid or minimise the formation of noxious gases. After pyrolysis, the obtained residue was easily separated to non-metallic and metallic fractions. The non-metallic portions of waste PCB was layered white grey hard residues and composed of ~ 90% glass fiber content and ~ 10% carbon and non-metals. SEM image of non-metallic fractions is presented in Fig. 1 and indicates that obtained glass fiber from waste PCB is relatively clean and free from metallic particles and diameter of ~ 10 um.

The properties of carbon source such as surface area, amorphous carbon content and crystallinity are important factors for the formation of SiC nanoparticles. The char obtained by using waste CDs showed very good high surface area of ~ 330 m^2/g. Carbon percentage in char was around 90% and remaining 10% was mainly composed of silica. The morphology of char by SEM studies clearly indicates highly porous nature of char. The presence of amorphous carbon and sp^2 carbon in char is indicated by presence of G-band (~ 1590 cm^{-1}), D-band (~ 1350 cm^{-1}) and valley between G and D bands in Raman spectra [15]. XRD pattern also signifies the amorphous and crystalline content in char (Fig. 2). The porous nature, sp^2 carbons and crystalline size suggest that waste CD can be used as a good carbon source to form SiC composite.

The synthesised glass fiber-SiC composite was black in colour and representative SEM image is shown in Fig. 3. The low magnification image clearly shows the presence of both glass fibers and SiC particles. Glass fiber length varied from 200–500 um and diameter of ~ 10 um. In high magnification image, it was observed that SiC particles were mainly composed of spherical shaped nanoparticles with diameter of 20–100 nm, and few nanoparticles were aggregated into chain like nanostructures.

The XRD pattern of recycled glass fiber from waste PCBs and synthesised glass fiber-SiC composite is shown in Fig. 4a. For recycled glass fiber, the absence of strong peaks shows the amorphous nature of fibers although a low intensity peak ~ 22° was observed. The glass fiber-SiC composite spectrum shows various high intensity peaks matching theoretically predicted phases to β-SiC (International Centre for Diffraction Data, Ref No 01-074-1302). The presence of SiC peak confirms the formation of SiC. Fig. 4b. shows the Raman spectra (200–1200 cm^{-1}) of recycled glass fiber and synthesised glass fiber-SiC composite. Less intense SiO_2 peaks were observed in glass fibers spectra as silica is major component in glass fiber. For synthesised glass fiber-SiC composite, two major peaks were observed around 780 and 950 cm^{-1}, which are characteristic transverse mode (TO) and longitudinal mode (LO) of SiC. In both XRD and Raman spectra of glass fiber-SiC composite, the fact that characteristic peaks of glass fiber were not observed may be due to surface reduction of glass fiber silica.

Fig. 4c. shows the FTIR absorbance spectra of recycled glass fiber from waste PCBs and synthesised glass fiber-SiC composite. The major peak observed at 1050 cm^{-1} in glass fiber is attributed due to Si-O-Si stretching. In synthesized glass fiber-SiC composite, the strong peak at 800 cm^{-1} corresponds to stretching mode of Si-C bond. A small intensity peak was also observed at 1050 cm^{-1} which indicates the presence of glass fiber in synthesized glass fiber-SiC composite.

Here we propose the synthesis of glass fiber-SiC composite by vapour

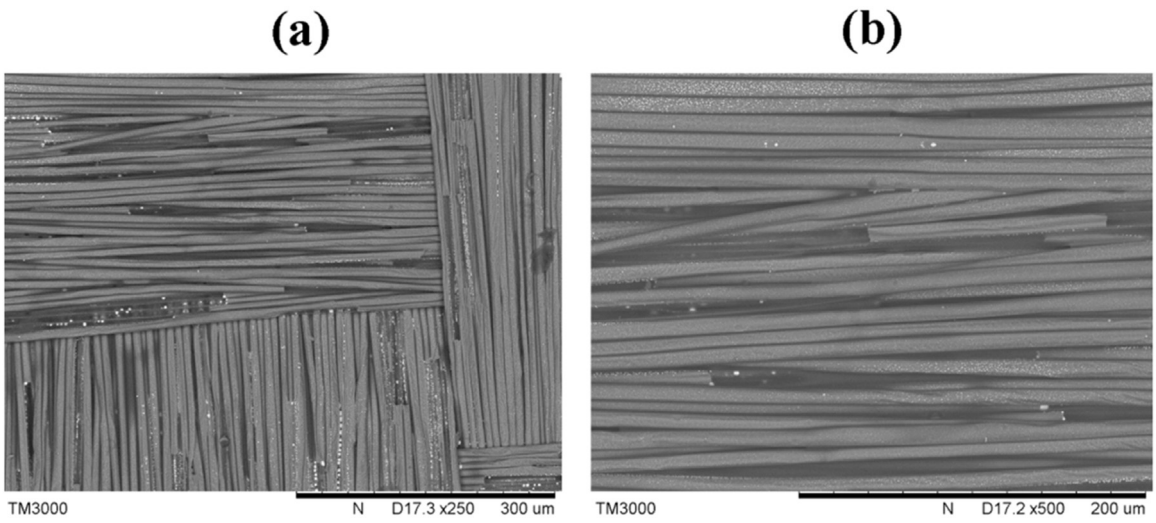

Fig. 1. SEM images of glass fibers recovered from waste PCB.