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Fabrication of conductive carbon nanomaterial from carbonaceous waste

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Abstract

The fabrication of conductive carbon nanomaterial has attracted extensive research due to its promising potential in energy application. However, the conventional fabrication methods, e.g. chemical vapour deposition, are expensive due to high energy consumption, which makes it both economically and environmentally unsustainable. The concept of using carbonaceous waste as a precursor for growing carbon nanomaterial has recently been explored. By using carbonaceous waste, the fabrication of conductive carbon will be more sustainable. In this work, a carbonaceous waste has the potential to be a precursor for the fabrication of conductive carbon nanomaterial. Our previous characterisation work showed that the carbonaceous waste had a nano-particle size distribution and possessed conductive property. Due to its inherent nano-particle size, no further size reduction is required. However, the carbonaceous waste had to be leached to remove the toxic heavy metal. After leaching, the conductive property decreased slightly. This work explores the use of hydrothermal treatment of the leached sample at low temperature to modify the surface area and surface functional groups, so as to enhance the conductive property of the carbonaceous waste. The capacitance of the treated carbonaceous residue was also analysed.

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Keywords: carbanaceous waste; conductive; capacitance; hydrothermal; nanocarbon

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1. Introduction

The excellent physicochemical properties and chemical stability of carbon nanomaterial, and its potential applications as exceptional supercapacitors, catalyst supports, adsorbents and high strength fillers of composite material, have fueled much research interest (De Volder et al., 2013). In particular, the promise of higher conductivity and energy storage in nanocarbon with crystalline structures is enticing to a world that is demanding more energy as technology improves the quality of life. Most of the research is focused on the growth mechanism of carbon nanomaterial to attain the desired nanostructure (Harris, 2009; Tessonnier and Su, 2011). However, current methods of fabrication of carbon nanomaterial, such as laser ablation, chemical vapor deposition and plasma torch, are intensive in energy consumption, which leads to high production cost (Kushnir and Sandén, 2008). Hence, there is a need to search for greener processing methods or sustainable source of carbon as a precursor.

Carbon-based waste, such as agricultural waste, used plastics and tires, and petroleum coke, has recently been widely explored as alternative carbon sources for the synthesis of carbon nanomaterial. Specifically, for electrochemical applications like capacitors and battery electrodes, the use of carbonaceous waste as a precursor is a more sustainable resource due to its abundance. Biswal et al. (2013) converted dead leaves into a supercapacitor in a single-step pyrolysis in argon atmosphere, whereby the end product had a high specific capacitance of 400 F/g. Cassava peel, a common agricultural waste in Indonesia, was made into a capacitor's electrode with a specific capacitance of 264.08 F/g by combining chemical and physical activation (Ismanto et al., 2010). Zuliani et la. (2014) chemically activated oil sands fluid coke (OSFC) using KOH, followed by pyrolysis and obtained a material with capacitance of 160 F/g. In terms of using carbon as an anode in lithium-ion batteries, Naskar et al. (2014) successfully recovered carbon black from used tires, by first digesting the rubber tire in a hot oleum bath and followed by pyrolysis in nitrogen atmosphere at 1000°C.

There are a few factors that influence the conductivity and capacitance of carbon-based material. Conductivity of a carbon material depends on the sp^2 hybridisation and mobility of electrons between the primary particles (Pantea et al., 2001). For capacitance, the performance is based on the amount of charge accumulation on the carbon surface. These factors have driven research to focus on the activation of carbon, preferably with control over the micro/meso pore size distribution (Frackowiak et al., 2006). Besides increasing the surface area, the carbon material should be conductive and has good wettability to promote charge transfer with the electrolyte (Inagaki et al., 2010). However, most of the current fabrication methods employ high temperature treatment, such as pyrolysis, for physical and surface modification of carbonaceous waste. On the other hand, hydrothermal treatment is a process that promises to be a more sustainable approach due to the lower energy input and the established synthesis method (Hu et al., 2010).

In view of meeting both the demand for carbon nanomaterial for the fabrication of electrochemical cells and resolving the waste management of carbonaceous waste, this study explores the feasibility of using hydrothermal treatment at low temperature to fabricate conductive nanomaterial from a carbonaceous waste.

2. Materials and Methods

Carbonaceous solid residue was collected from a local company and dried at 105°C for 24 hr before use. An earlier study has been carried out on the removal of heavy metals from the carbonaceous residue (henceforth referred as leached carbonaceous residue) and the results showed that the leached carbonaceous residue did not show significant toxicity (Dong et al., 2017). The leached carbonaceous residue used in this study was subjected to further hydrothermal treatment using different treatment time and different concentrations of NH_4OH and HNO_3, with deionized (DI) water as a control. NH_4OH and HNO_3 were selected to modify the carbon surface via nitrogen incorporation to basic and acidic characteristic respectively (Titirici et al., 2012). After the completion of hydrothermal treatment, the treated carbonaceous residue was filtered and washed with DI over 0.2 μm membrane filter (henceforth referred as treated carbonaceous residue).

The carbonaceous residue before and after treatment was subjected to Brunauer-Emmett-Teller (BET) surface area and total pore volume analysis using Quantachrome-NOVA-4200e. All samples were degassed at 80°C for around 24 hr before carrying out BET.

The electrical conductivity was measured using the Lucas Lab four-point probe system, connected to a multimeter (2700 Multimeter Data Acquisition system) and Keithley 238 High Current Measurement System. The