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Waste tire derived carbon as potential anode for lithium-ion batteries

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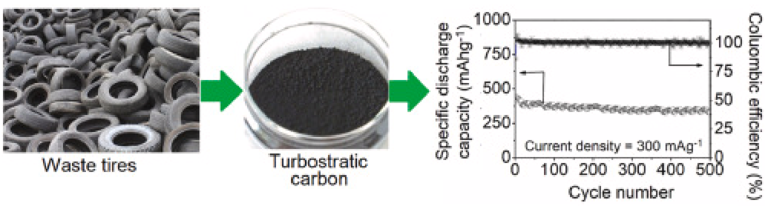
Abstract

The uncontrolled accumulation of end-of-life tires every year leads to serious environmental concerns, rendering setback to the sustainable growth of the society. The most viable solution to overcome this environmental issue is to convert these hazardness waste tires into value added products. In the present investigation, carbonecous based anode materials has been developed by a novel chemical activation strategy involving aqua regia followed by controlled pyrolytic condition in the selective atmospheres. Raman spectroscopic study displayed a graphitic carbon with significant degree of disordered arrangements. The generation of the turbostratic carbon with higher content of broken crystal edges is corroborated using the structural characterization such as X-ray diffraction (XRD). This fact is further corroborated from surface energy results calculated using the contact angles measured by dynamic wicking method. The prepared turbostratic carbon, when used as lithium anode, renders excellent electrochemical performances with reversible specific capacity of 350 $mAhg^{-1}$ (at 300 mAg^{-1}) with 81% capacity retention after 500 cycles. The present research provides new roadmap in recycling the waste tires for energy storage applications.

Graphical abstract



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Introduction

The present state-of-art lithium-ion (Li-ion) batteries have profound impact on the field of portable electronics; however noticeable research attempts are being made in developing new electrode materials with outstanding energy/power densities so as to expand its application aspects in the electric vehicles. Owing to its low specific capacity (~372 $mAhg^{-1}$), the commercial graphite anode, which is dominating now the Li-ion battery market is not an appropriate candidate in meeting the high energy demand, though it has other desirable attributes viz., good cycling stability and low hysteresis. On the other hand, high specific capacity is delivered by inorganic metal/metal oxide anodes; however, electrode pulverization during lithiation/delithiation process is inevitable due to huge volume modification and poor electronic conductivity (Poizot et al., 2000; Reddy et al., 2013; Bruce et al., 2008). To overcome these critical issues, composite anodes based on metal/metal oxide and carbon based nanostructured materials have also been developed (Reddy et al., 2016; Shanmugharaj and Ryu, 2012; Qi et al., 2017; Demirocak et al., 2017). On the contrary, in recent years, much research efforts being focused on the development of the carbon anodes, especially hard carbons, as they exhibit higher lithium intake capacity in comparison to the pure graphitic carbons (Ni et al., 2013). Significant research attempts have been made in recent years on the preparation of hard carbons using various raw materials viz., biomass, polymer precursors and sugar (Hong et al., 2014; Liu et al., 2016; Ghosh et al., 2019; Kumar et al., 2019, 2021abib_Kumar_et_al_2019bib_Kumar_et_al_2021a; Irisarri et al., 2018; Vali et al., 2017). Though biomass is the cheaper source for mass production of carbon, scaling up for the commercial implementation is still a difficult task.

Waste tires, which are being scraped every year is hazardous to the nature and impose severe environmental threat to the public health and safety (Naskar et al., 2014). The possible environmental and health issues include: 1) Vermin generation and insect infiltration, posing severe health problems; 2) Dumped tires often catches fire, resulting in the fire generating dangerous gases, heavy metals, and oil, which can ruthlessly contaminate both the land and aquatic environment; and 3) Increasing waste tires may lead to the landfill maintenance issues (San Miguel et al., 1998). According to Torretta et al. (2015), approximately four billion end-of-life tires are being dumped in the landfills every year due to the non-availability of end users. Recycling the waste tires is the most viable solution to overcome this environmental issue, which can be done by using it as a raw material for the generation of value-added products. Some of key application aspects of waste tire include solid fuels in cement kilns (Marvin et al., 2012), however, generation of toxic gases is inevitable in this process and thus they are not environmental friendly process. Alternatively, waste tires are often used in technologies such as reclaiming, retreading, grinding or as additives in civil engineering applications (Marvin et al., 2012). Among the various waste tire recycling technologies, reclaiming is widely explored, where the three dimensional polymeric structure converted into two dimensional structures. However, obtained products are of poor quality, though the reclaiming technology is a costlier process. On the contrary, granulated rubber derived from the waste tire powder is a low cost alternative, which subsequently used as a compounding material for the preparation of low-grade rubber products (Karger-Kocsis et al., 2013).

An economically viable process, which received wide attention by recycling industries, is the pyrolysis technique that often results in the generation of high carbon content (35–40 wt %) pyrolytic char (Choi et al., 2014). The obtained pyrolytic char has widely been used in the preparing activated carbon that has been used widely as pollutant absorbents (Mui et al., 2004). Alternatively, preparing new electrode materials for energy storage applications using tire derived turbostratic carbon has become subject of interest in recent years (Zhi et al., 2014; Zhao et al., 2015; Boota et al., 2015; Hood et al., 2017; Shilpa, 2018). Tire derived activated carbons with engineered morphology and pore structure showed outstanding electrochemical performances, when used as an electrode in EDLC based supercapacitors (Zhi et al., 2014; Zhao et al., 2015; Boota et al., 2015). The first report on the usage of waste tire derived carbon as a negative electrode material for lithium-ion (Li-ion) battery rendering the reversible capacity of 390 $mAhg^{-1}$ after 100 cycles has been reported by Naskar et al. (2014). The sodium-ion battery anode with enhanced electrochemical performances using tire derived carbon has been reported by Li. et al., (Li et al., 2016). Though, the reported research works provide new insights on the fabrication of electrode materials using waste tire carbon, further work are needed in designing effective treatment techniques for the development of tire derived carbon for Li-ion battery applications.

In the present research, an attempt has been made in preparing high performance carbon anode from waste tires for lithium-ion (Li-ion) batteries. The structural and chemical properties of the pyrolyzed char are modified by treatment with aqua regia followed by carbon-di-oxide (CO_2) activation ensuing in a high specific surface area disordered carbon. While the aqua regia treatment of pyrolytic char removes inorganic impurities, generating mesopore, CO_2 activation effectively tune the surface characteristic of resultant carbon, resulting in an enhanced electrochemical performance with high Li storage.

Section snippets

Preparation of activated carbon from waste tire powder

Waste tire powder, with mesh size of 30μm (waste tire recycling unit, Gummidipoondi, Chennai, India) was treated with aqua regia (3: 1 mol ratio of HCl: HNO_3) for 2 h, followed by repeated washing using distilled water. The sample was then dried at 100 °C and pyrolyzed at 400 °C for 2 h. The resultant powder was then subjected to freeze-drying process using lyophilizer (Lyolab Freeze Lab lyophilizer, Chennai) for 24 h, followed by calcination at 1000 °C in tubular furnace for 1 h in N_2…

Results and discussion

The schematic illustration on the conversion of the waste tires into a battery grade turbostratic carbon is shown in Fig. 1. Waste tire powder consisting of small pieces of granulated rubber with average mesh sizes (~30 μm), prepared by pulverizing the waste scrap tires were procured from a "Waste tire recycling unit in Gummidipoondi, Chennai". The as received waste tire powder was first treated with aqua regia for 2 h, followed by repeated washing using distilled water. Aqua regia treatment of …

Conclusions

In summary, unique turbostratic carbon lithium-ion anode with high surface area is prepared using waste tires as the raw material. Aqua regia treatment and subsequent thermal/CO_2 treatment of the pre-calcined carbon effectively alters the its morphology creating a porous network facilitating enhanced Li insertion in the active sites. The prepared waste tire carbon (WTC) electrode showed an outstanding electrochemical performance providing a high reversible capacity (~350 $mAhg^{-1}$) after 500…

Author contribution

AMS conceived the idea, made the work plan, interpreted the results and wrote the manuscript. TV did the experiments and compiled the data for manuscript preparation. SR and RAK helped in the data interpretation.…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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References (45)

G.G. Choi *et al.*
Fuel Process. Technol. (2014)

J. Gong *et al.*
Prog. Polym. Sci. (2019)

Y. Li *et al.*
J. Power Sources (2016)

N.M. Mkhize *et al.*
J. Anal. Appl. Pyrolysis (2017)

E.L.K. Mui *et al.*
Carbon (2004)

J. Ni *et al.*
J. Power Sources (2013)

D. Pantea *et al.*
J. Anal. Appl. Pyrolysis (2003)

A.M. Shanmugharaj *et al.*
Electrochim. Acta (2012)

A.M. Shanmugharaj *et al.*
J. Power Sources (2011)

V. Torretta *et al.*
Waste Manag. (2015)

Cited by (12)

importantly, PTA-700 solves many problems faced by traditional biomass-derived carbons in commercialization, and provides a feasible strategy for the commercial development of biomass derived carbons in the future.…

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