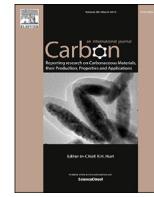
Carbon 98 (2016) 702–707

Contents lists available at ScienceDirect

Carbon

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



Wettability and work of adhesion of liquid sulfur on carbon materials for electrical energy storage applications

Ivan Kaban [a, *], Rafał Nowak [b], Grzegorz Bruzda [b], Lixia Xi [a], Natalia Sobczak [b, c], Jürgen Eckert [a, d, 1], Lars Giebeler [a, d]

[a] IFW Dresden, Institute for Complex Materials, Helmholtzstr. 20, 01069, Dresden, Germany
[b] Foundry Research Institute, Center for High-Temperature Studies, 73 Zakopianska Str, 30-418, Cracow, Poland
[c] Motor Transport Institute, 80 Jagiellonska Str, 03-301, Warsaw, Poland
[d] TU Dresden, Institut für Werkstoffwissenschaft, Helmholtzstr. 7, 01069, Dresden, Germany

ARTICLE INFO

Article history:
Received 1 April 2015
Received in revised form
19 October 2015
Accepted 6 November 2015
Available online 2 December 2015

ABSTRACT

The wettability of glassy, microcrystalline and nanocrystalline carbon materials by liquid sulfur is studied by the sessile-drop technique applying the contact heating and drop-dispension procedures. Liquid sulfur shows a good wetting on all examined substrates just after melting, although the contact angle depends on the type and structure of the carbon material. Sulfur drops remain on the surfaces of glassy carbon and electrographite, whereas the liquid infiltrates into the substrates pressed from carbon micro- or nanoparticles. In the latter case, the infiltration rate increases along with decreasing size of particles used for preparation of the substrates, indicating a role of capillarity. The wetting and adhesion in the sulfur-carbon material systems are determined by the van der Waals interactions.

1. Introduction

Due to a rather large specific charge capacity and a long lifetime, lithium-ion batteries are playing a major role as autonomous electric energy sources in many electronic devices [1–4]. However, the continuously growing demand for reliable rechargeable batteries with high specific energy and low cost for various applications, such as power tools, electric vehicles, or renewable energy applications, urges basic and applied science to search for alternatives. Along this line, the lithium-sulfur (Li–S) system suggested for conversion-type batteries earlier [5–7] has recently received high attention [1–4,8–18]. The theoretical energy density for the $2Li + S \rightarrow Li_2S$ reaction is 2600 Wh kg^{-1} [7], which is four to five times the theoretical specific energy of intercalation-type Li-ion electrochemical systems being in the range of 500–600 Wh kg^{-1} [1–4]. Sulfur is also very attractive for industrial applications due to the low cost and nearly infinite worldwide abundance.

The main issues in utilization of lithium-sulfur batteries are i) keeping sulfur in the carbon-electrode matrix, ii) preventing transport of Li_xS species to the anode, and iii) maintaining electrical contact. Carbon-sulfur composites are considered as promising cathode materials for lithium-sulfur batteries [8–18]. The wetting and the work of adhesion between carbon and sulfur is of high importance for production of the electrodes for Li–S batteries and their performance. To our knowledge, earlier wetting tests [19–21] have been carried out on bulk graphite and graphite felt at temperatures significantly higher than the melting point of sulfur ($T_{melt} \approx 119$ °C [22]) as well as above the sulfur polymerization temperature ($T_{polym} \approx 159.5$ °C [22]). Dujardin et al. [23] reported on wetting of carbon nanotubes (CNT) by sulfur; however, they were not able to determine the contact angle because the sulfur solidified on the CNF surface in various shapes and angles.

In this work, we investigated the wetting behavior of liquid sulfur on different micro- and nanostructured carbon materials using the sessile-drop technique and applying contact heating and drop-dispension procedures. The sessile-drop tests were performed near the melting point of sulfur as well as upon heating to the sulfur polymerization temperature. Contact angles, work of adhesion, and kinetics of wetting and infiltration were determined in dependence on the carbon material, temperature and time.

* Corresponding author.
E-mail address: i.kaban@ifw-dresden.de (I. Kaban).
[1] Present address: Erich Schmid Institute of Materials Science, Austrian Academy of Sciences and Department Materials Physics, Montanuniversität Leoben, Jahnstrabe 12, 8700 Leoben, Austria.

http://dx.doi.org/10.1016/j.carbon.2015.11.022
0008-6223/