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A dual-responsive humidity sensitive-based cellulose paper: A fabrication of smart strip from sustainable nanoclay and graphite-beeswax composite

Abu Hannifa Abdullah [a], Wan Farhana W. Idris [b], Ainizar Mustapa [b], Zulhelmi Ismail [a,b,c,*]

[a] Centre for Advance Intelligent Materials, Universiti Malaysia Pahang, Gambang, Malaysia
[b] Faculty of Manufacturing and Mechatronics Engineering Technology, Universiti Malaysia Pahang, Pekan, Malaysia
[c] Centre of Fluid Flow and Advanced Processes (CARIFF), Universiti Malaysia Pahang, Gambang, Pahang, Malaysia

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ABSTRACT

A highly humidity-responsive paper can detect moisture or OH-attached molecules at the sub-micron or nano level range. Applying hydrophilic nanoclay as an active material for water sensing would reduce the fabrication cost while remaining environmentally friendly. In this communication, we report the preparation of a nanoclay-inspired dual-responsive smart film that can signal humidity levels from mechanical and electrical responses. The paper will bend as the nanoclay layer swells whereas the resulting bending strain will trigger the electrical resistance changes in the hydrophobic electrically conductive graphite-beeswax layer.

1. Introduction

Recently, the development of a humidity-sensitive paper that is able to sense and actuate in the presence of stimulants has attracted great interest from various research communities due to the potential application of smart paper in electronics [1–3], robotics [4], and health [5]. Until now, various materials have been used as sensing materials for smart paper including 2D materials [6], carbon [7], and nanoclay [8], while the substrate class can be made of cellulose paper [9], polymer film [10], and textiles [11]. In this communication work, we propose the design of humidity-sensitive paper that is able to indicate the level of moisture content visually through the actuation of the paper and numerically through the electrical response. The application of a highly hydrophilic nanoclay coating as an active sensing layer will improve the paper's sensitivity towards humidity while the coating of environmentally friendly graphite-beeswax through the writing on paper will produce an electrically conductive layer on the substrate while remaining hydrophobic due to the electrical conductivity of graphite. Although the application of layered silicate materials such as attapulgite [12] and sepiolite [13] for sensing of humidity has been reported, a design of humidity smart paper that utilizes the combination of natural beeswax and nanoclay MMT (montmorillonite) for the fabrication of dual-functional smart paper that is able to mechanically and electrically respond from the changes in humidity level has never been attempted until now, to the best of our knowledge. In this brief work, the effect of the nanoclay coating cycle and graphite content in wax on the sensing/actuation performance had also been reported besides the physical characterization of nanoclay flakes and sensor morphology.

2. Experimental

Nanoclay was purchased from Southern Clay Products, Inc (USA). As received, 1 g of sodium montmorillonite was weighted without any pre-treatment and dispersed in 50 ml of deionized water. The solution was then ultrasonicated for 8 h using a bath sonication. The slurry was then centrifugated at the speed of 500 rpm for 15 min to remove any unexfoliated nanoclay flakes. Meanwhile, the electrically conductive wax consists of beeswax and graphite powder at different ratios (in grams) namely (2:2, 2.1:1.9, 2.2:1.8, 2.3:1.7, 2.4:1.6, 2.5:1.5), which was mechanically prepared. Both beeswax and graphite powder were weighed at a desired amount, thoroughly mixed, and stirred at 80 °C for 30 mins. The conductive wax was consistently applied to the surface of the paper

* Corresponding author.
E-mail address: zulhelmii@ump.edu.my (Z. Ismail).

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