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Short communication

Study of morphology and electrical properties of indium zinc oxide-modified kenaf fiber

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ABSTRACT

Indium zinc oxide (IZO) was successfully deposited onto kenaf fibers (KFs) by a dip-coating method. The novel aspect of this study was the investigation of the electrical conductivity of the resulting indium zinc oxide-modified kenaf fiber (KF-IZO) by emphasizing on its morphology and the dipping rate used for dip-coating. KF was alkalized using a 5% sodium hydroxide (NaOH) solution. The dipping rate was varied from 1 to 30 mm/s. KF-IZO was then annealed at a temperature of 150 °C for 4 h. A modified four-probe method employing a copper metal attachment plate was used to evaluate the electrical properties of KF-IZO. A dipping rate of 5 mm/s, which yielded the highest electrical conductivity of 11.81 S/mm, was found to be optimum. Scanning Electron Microscope/Energy Dispersive Using X-Ray (SEM-EDX) analysis of KF-IZO revealed that the IZO film was uniformly coated on the KF substrates, and no significant thermal damage was observed. KF-IZO showed the potential to be used in smart textiles, electrostatic discharge protection, and as a reinforcement in composites.

1. Introduction

Recently, natural fibers have gained immense attention in manufacturing industries from the view-point of sustainable development. Hence, natural fibers like kenaf, jute, sisal, hemp, and bamboo are widely used in manufacturing industries. Like wood and bamboo, kenaf (*Hibiscus cannabinus* L.) is a traditional third-world crop and is poised to be introduced as a new annually renewable resource for industrial purposes (Abdul Khalil et al., 2010). Kenaf fiber (KF) is cheap, contains low-density materials, and possesses good mechanical properties and recyclability (Raman et al., 2015). However, like other natural fibers, it is hydrophilic in nature. Hence, it is necessary to treat natural fibers in order to make them compatible with hydrophobic materials (Aziz et al., 2005). Alkaline treatment is the easiest surface treatment technique for natural fibers (Gassan and Bledzki, 1999; Mohanty et al., 2000; Ray et al., 2002; Xia et al., 2016). It has been reported that an alkali treatment of natural fibers modifies their surface and increases their adhesion to polymer matrices.

Studies are being conducted on modifying KFs with transparent coating oxide-indium zinc oxide (TCO-IZO) in order to make them suitable for a wide range of applications. TCO-IZO uses ZnO as a precursor and indium as a dopant material and has been successfully used as a conductive material in various industries such as the electronic and semiconductor industries. Moreover, indium zinc oxide (IZO) is one of the best materials that exhibits good transparency in the visible range, low resistivity, and high mobility (Craciun et al., 2014; Lee and Park, 2003; Dehuff et al., 2005). In this study, KF was used as the main medium to carry IZO, which was used as the conductive material. In compounds like IZO, zinc atoms are substituted by trivalent atoms (X^{3+}) such as Al or In. It has been reported that extrinsic donors, which induce doping via dopant atoms, are more stable than intrinsic donors, which induce doping via native defects (Benouis et al., 2007). Most natural fibers have low degradation temperatures (~200 °C) because of which, they cannot be processed at high temperatures (Sgriccia et al., 2008). Hence, the modification of natural fibers with IZO makes them suitable for applications in electrostatic and charge dissipation materials and

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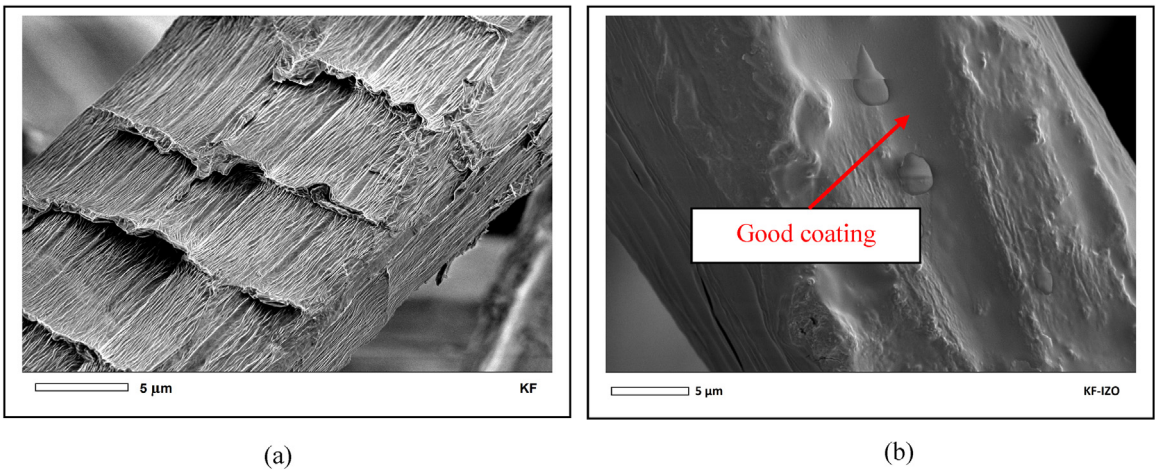

Fig. 1. SEM images for a single KF-IZO fiber (a) before IZO coating (b) after IZO coating at an annealing temperature of 150 °C.

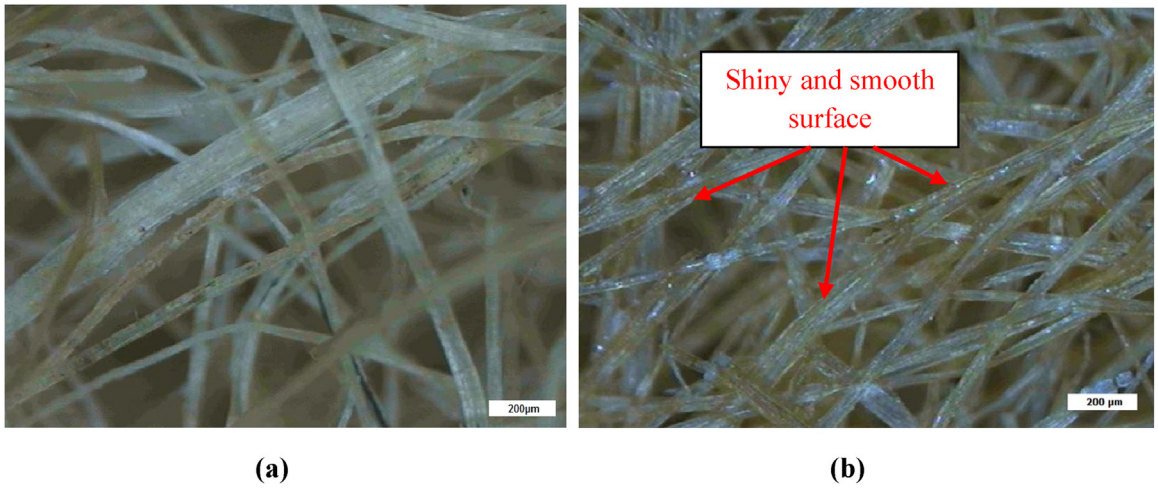

Fig. 2. Optical microscope image (MORITEX–Scopemen series with 166× magnification) of KF-IZO (a) before IZO coating (b) after IZO coating at an annealing temperature of 150 °C.

bio-composite material reinforcements, which require mechanical integrity and biocompatibility.

2. Experimental

Kenaf bast fiber with randomly oriented mats and a surface density of 800 g/m^2 was used. The raw KF mat was alkalized using a 5% sodium hydroxide solution to eliminate the natural grease, pectin, lignin, and stains present in it. The alkalization process was carried out for 48 h by immersing the raw KF mat in the NaOH solution. The mat was then rinsed with deionized water 5 times followed by drying at 70 °C for 24 h. The IZO solution was prepared with an In/Zn ratio of 6%. In order to prepare the IZO solution, zinc acetate dehydrate was dissolved in ethanol (precursor) at 25 °C. The mixture was then magnetically stirred for about 1 h at this temperature. During the process, deionized water, which acted as a stabilizer, was dropped into the mixture by a syringe. Once the dissolution was complete, indium(III) chloride (dopant) was added to the solution. The resulting mixture was then stirred for 1 h at 75 °C. In the end, a clear and homogenous solution of IZO was obtained. IZO was deposited on the KFs using a dip-coating method at 25 °C and a dipping rate of 1–30 mm/s. After the deposition, KF-IZO was dried followed by annealing at 150 °C for 4 h in a vacuum furnace. The electrical conductivity of KF-IZO was measured by a four-probe method using a copper metal attachment plate. This attachment acted as the line contact between the adjacent fibers along the KF-IZO surface area. In addition, a focused ion beam was used to cut the KF cross-section, which was scanned by Scanning Electron Microscope/Energy Dispersive Using X-Ray (SEM/EDX) for qualitative measurements.

3. Results and discussion

3.1. KF-IZO thin layer

Alkalization was used for enhancing the interface adhesion between the KF substrates and the alkoxide groups. As referred to Table 1, it washed out about 25.2% of the impurities like wax, pectin, and lignin which are present in untreated KFs. One of the limitations of natural fibers is their thermal instability. In order to avoid decomposition or degradation by high-temperature processing, the processing temperature is limited to 200 °C and the processing is done for a short duration (Wielage et al., 1999). The KF decomposition results show that about 4–11% of the total KF weight was lost at temperatures in the range of 150–200 °C. The TGA results show that the KFs were strongly decomposed at 220 °C and the weight of the remaining KF sample was 88% of the initial weight. Hence, natural fibers, which are low-temperature application resources, should be annealed at low temperatures (≤200 °C). The surface morphology of KF-IZO was examined to confirm the presence of