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Short communication

Physical, structural and thermomechanical properties of nano oil palm empty fruit bunch filler based epoxy nanocomposites

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ABSTRACT

In this work, we have used a novel flame retardant nano filler developed in our laboratory from oil palm empty fruit bunch (OPEFB) fibre for the fabrication of nanocomposites. The nanocomposites were prepared by dispersing 1, 3 and 5 wt.% nano OPEFB filler in an epoxy matrix using a high speed mechanical stirrer. Physical, structural, and thermomechanical analyses of the obtained nano OPEFB/epoxy nanocomposites were carried out and the results were compared with those for pure epoxy composites. Our findings revealed that the incorporation of the nano OPEFB filler in the epoxy matrix increased the density of the nanocomposites from 1.13 to 1.25 g/cm^3. The XRD pattern of the pure epoxy composites displayed sharp and highly intense peaks at a 2θ value of 21°, whereas all OPEFB/epoxy nanocomposites showed relatively less intense peaks that shifted to lower 2θ values. The coefficient of thermal expansion of the epoxy composites decreased with increasing OPEFB nano filler content up to 3%, while beyond 3% it slightly increased. Overall, the results revealed that the thermomechanical properties reached maximum values for 3% loading, due to homogenous dispersion and improved interfacial bonding between the epoxy and the dispersed nano OPEFB filler.

1. Introduction

Currently, the total amount of oil palm empty fruit bunch (OPEFB) fibre is around 17 million tons produced annually in Malaysia (Saba et al., 2015a). It also estimated that presently Indonesia is largest producer of oil palm in world and produced abundant amount of oil palm fibres as wastes, which can be utilized in polymer composites industries for different applications (Mulyantara et al., 2017). Epoxies are one of the most important thermoset engineering polymeric materials, with broad applications ranging from adhesives to construction or laminate materials (Chiu et al., 2014). However, epoxy resins also display some major constraints because of their extreme brittleness, low fracture toughness (Zamanian et al., 2013), as well as poor thermal and dimensional stability, which urge the need to modify their structure in order to reduce such drawbacks (Li et al., 2016). Many effective attempts have been made by the researchers to overcome these limitations and to meet the growing demand for high performance and multifunctional epoxies by the addition of advanced fillers called nano fillers. A nano filler possesses remarkably higher interfacial area and aspect ratio, which can improve the glass transition temperature, dimensional stability, density and thermal stability of the epoxy polymer. Currently, carbon nanotubes (CNTs), silica particles and layered silicates are the most widely used commercially available nano fillers and are also quite expensive (Saba et al., 2016a).

X-ray diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and for determining the structure of polymer nanocomposites (Ying et al., 2015). Moreover, since the thermomechanical properties and dimensions of composite and nanocomposite materials are altered during heating or cooling, hence it will be imperative to explore their coefficient of linear thermal expansion (CTE) through thermomechanical analysis (TMA) as a function of time or temperature under a defined mechanical force (Corcione and Frigione, 2012).

Researchers attracted to use nano filler from natural fibres due to the advantages of these materials compared to others, such as synthetic fibre composites, including low environmental impact and low cost to support their potential across a wide range of applications(Pickering et al., 2016). Previous research has demonstrated that the addition of nano filler to a polymer results in a lower CTE with respect to that of the unmodified polymer, thus leading to better thermal stability of the

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polymer system. For example, the addition of nano silica particles (Chruściel and Leśniak, 2015), graphene (Ying et al., 2015), and nano oil palm ash (OPA) has been reported to markedly improve thermal stability and density at 3 wt.% filler loading (Abdul Khalil et al., 2013). Such results can be ascribed to a good dispersion of the nano filler, and an efficient stress transfer from the matrix to the nano filler, which ultimately hampers the polymer chain segmental movement (Krump et al., 2006). Cellulose nanofibril (CNF) epoxy nanocomposites with high visible light transmittance and low water sensitivity were fabricated which shows a sufficient water resistance (Qing et al., 2015). All these promising results reported so far in the literature have prompted the present study.

This investigation is a part of our previous work, dealing with the development of a nano OPEFB filler from OPEFB fibres (Saba et al., 2015b). In a previous study, we also investigated the effects of the nano filler on the mechanical and morphological properties of epoxy nanocomposites (Saba et al., 2016b). A literature review has revealed that no research has been reported yet on the addition of a nano OPEFB filler to an epoxy polymer to enhance the thermomechanical properties and density of the latter. Therefore, this study has investigated the effect of different nano OPEFB filler loading (1%, 3%, and 5%) on the density, crystallinity, Tg and CTE of epoxy composites in order to reveal the path for utilizing this green nano filler in the development of renewable and sustainable structural products.

2. Experimental procedure

OPEFB fibres were obtained from MPOB, Bangi, Selangor, Malaysia. Liquid epoxy resin (D.E.R 331) and curing agent Jointamine 905-3S were purchased from Dow Chemical Pacific Singapore; Singapore. All purchased chemicals were used without any further purification (Saba et al., 2016b).

Nano OPEFB filler epoxy nanocomposites with 1%, 3%, and 5% filler loading were fabricated by the hand lay-up technique. The epoxy resin was loaded with the chosen amount of the developed nano OPEFB filler at room temperature for 60 min, using a high speed mechanical stirrer (Saba et al., 2016b). The pure epoxy composite and the OPEFB/epoxy nanocomposites are displayed in Fig. 1.

2.1. Characterization

Density, i.e. the mass per unit volume of the composite samples, was calculated using the ASTM D792 standard. X-ray diffractograms (XRD) of the samples were recorded at an angular incidence of 2°–55° (2θ angle range) at a scan rate of 2°/min. The XRD analyses of the composite samples were conducted with Cu Kα radiation of 1.5406 Å, operating at 30 kV and a current of 20.0 mA. TMA was carried out according to ASTM D696 to investigate the CTE of the composites using a TA Instrument Q400 under nitrogen, and the temperature was ramped from 30 °C to 200 °C at a heating rate of 5 °C/min. Dimensional changes were then measured in the thickness direction to calculate the CTE of the composites.

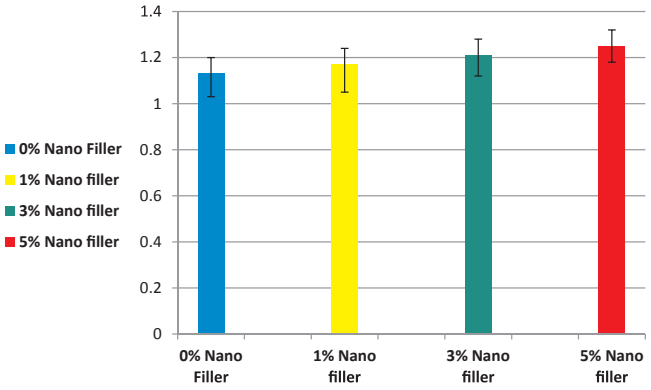

Fig. 2. Effect of nano OPEFB filler loading on the density of epoxy composites.

3. Results and discussion

3.1. Density

The densities of the pure epoxy composites and nano OPEFB/epoxy nanocomposites with different filler loading are shown in Fig. 2. It is evident from the density graph that the incorporation of the nano OPEFB filler considerably increases the density of the pure epoxy, which lies in the range of 1.13–1.25 g/cm^3. The increase in density can be explained considering the fact that the nano OPEFB filler has a relatively denser and harder phase, as compared to the epoxy polymer, and its incorporation increases the cross-link density of the epoxy chains and improves the hardness of the resulting epoxy nanocomposites. Similar trends were observed by other researchers who also reported that the incorporation of a nano filler increases the density of epoxy composites (Gao and Zhao, 2015). However, when the loading of the OPEFB nano filler exceeds 3%, the increase in the density comes along with a decrease in the inter-particle distance, resulting in the aggregation of the added nano filler particles. This leads to poor mechanical and morphological properties because of the increase in the void content in the texture. A similar phenomenon has been perceived in other research works (Abdul Khalil et al., 2013; Saba et al., 2016b).

3.2. X-ray diffractograms (XRD)

The XRD plots displayed in Fig. 3 allow analyzing the structure and morphology of the pure epoxy composites and the nano OPEFB/epoxy nanocomposites. The XRD pattern of the pure epoxy composites display sharp and highly intense peaks at a 2θ value of 21°, whereas all nano OPEFB/epoxy nanocomposites show relatively less intense peaks at lower 2θ values. From this, it can be concluded that the addition of the amorphous nano OPEFB filler to the pure epoxy matrix lowered its crystallinity. The XRD graph indicates that the 1% and 5% nano OPEFB filler loading leads to an intercalated type of structure. When adding the 1% nano OPEFB filler loading, the dispersion is homogenous, but not

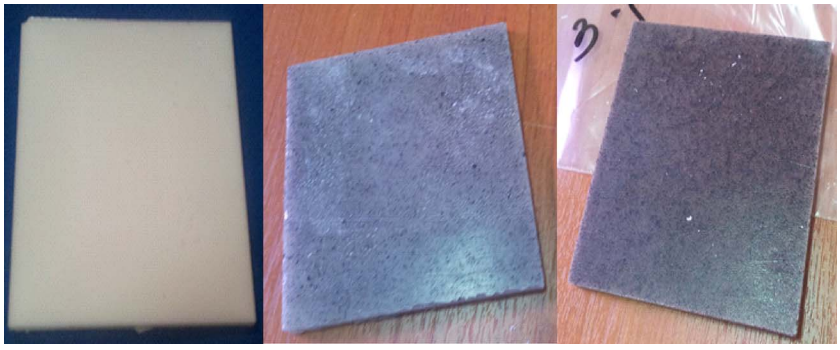

Fig. 1. Epoxy composite, 1% and 3% nano OPEFB/epoxy nanocomposites.