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Sustainable bean pod/calcined kaolin reinforced epoxy hybrid composites with enhanced mechanical, water sorption and corrosion resistance properties

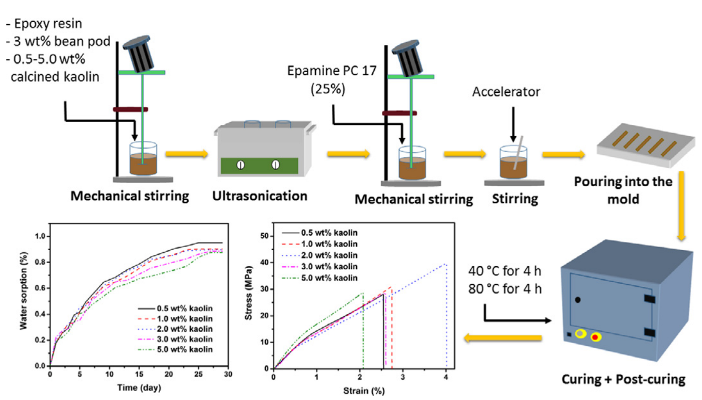
Gulcihan Guzel Kaya, Elif Yilmaz, Huseyin Deveci *

Department of Chemical Engineering, Faculty of Engineering, Selcuk University, Konya 42075, Turkey

HIGHLIGHTS

- Novel bean pod/calcined kaolin reinforced epoxy hybrid composites with enhanced properties were successfully prepared.
- Maximum tensile strength (39.8 MPa) was observed after hybridization of 3 wt% bean pod and 2 wt% calcined kaolin.
- Water sorption percentage was effectively decreased to 0.87% with the addition of 5 wt% calcined kaolin.
- The epoxy hybrid composites showed great corrosion resistance to alkali and salty solutions compared to acidic solutions.

GRAPHICAL ABSTRACT



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ABSTRACT

The industrial and academic world is becoming more interested in advanced composite materials owing to the increasing global awareness on environmental and social issues. From this point of view, novel epoxy hybrid composites were prepared by utilizing bean pod as an agricultural waste and calcined kaolin with the addition of varying ratios (0.5–5.0 wt%) to fixed weight of 3 wt% bean pod. The resulting hybrid composites were characterized by different analyses and tests to evaluate physico-mechanical and thermal properties. X-ray diffraction (XRD) and scanning electron microscopy (SEM) analyses showed uniform dispersion of hybrid filler in the neat epoxy resin which revealed better compatibility between hybrid filler and epoxy resin. Tensile strength of hybrid composite including 2 wt% calcined kaolin (39.8 MPa) was higher than those of the other hybrid composites. The water sorption percentage of the hybrid composites was effectively decreased until 0.87% with increasing amount of calcined kaolin. The hybrid composite including 5 wt% calcined kaolin exhibited highly corrosion resistance to alkali and salty solutions compared to acidic reagents. Thermogravimetric analyses (TGA) and vicat softening temperature (VST) tests revealed that an important improvement was not observed in degradation temperatures of the hybrid composites; however, residue at 650 °C increased up to 21.0% in the presence of calcined kaolin. It can be said that the hybrid composites mentioned above came into prominence with high tensile strength, quite low water uptake and excellent corrosion resistance in alkali and salty environments.

* Corresponding author.
E-mail address: hdeveci@selcuk.edu.tr (H. Deveci).

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1. Introduction

In the recent years, an increase in environmental awareness has brought evaluation of agricultural organic wastes as a filler into the forefront in polymer composite materials [1]. Many biodegradable agricultural wastes such as wood chip, rice husk, groundnut shell, oil palm empty fruit bunch and wheat straw that are low-cost, abundant, lightweight and eco-friendly materials have been utilized to produce various polymer composite materials [2–7]. In spite of their advantages, they have some limitations including high moisture sorption, poor wettability, low mechanical and thermal properties [8]. Therefore, inorganic materials like clay, carbon black, graphene and calcium carbonate have commonly used to increase moisture and thermal resistance, improve interfacial adhesion between matrix and filler, and enhance mechanical performance [9]. The combination of organic-inorganic particles in polymer matrix which is well known polymer hybrid composites has received great attention in different applications such as automotive, aerospace, construction, furniture manufacturing, sports and packaging [10–13]. Especially in civil engineering fields, sustainable epoxy hybrid composites have become effective alternative materials instead of expensive traditional components [14].

Epoxy resin is one of the most commonly preferred thermoset matrix with the benefits of good mechanical strength, high erosion and corrosion resistance, low shrinkage, high thermal stability, excellent adhesion to many surfaces, easy workability and so on [15–17]. Many types of epoxy resin are generally used as modifier, adhesive, binder, coating, thermal and electrical insulator for various structural products including mortars, cements, concretes, asphalts, laminates, furniture, roofing and indoor materials [18–22].

Several researchers have focused on sustainable polymer hybrid composites comprising of organic-inorganic filler lately. Alamri and Low [23] developed epoxy hybrid composites filled with recycled cellulose fibers and nanosilicon carbide particles. An improvement in mechanical strength and thermal stability of neat epoxy with the compatibility of fillers was reported. Raghavendra et al. [24] studied the mechanical and tribological properties of woven jute/glass hybrid epoxy composites with reinforcing of fly ash particles. It was determined that incorporation of fly ash provided synergistic effects on the properties. AlMaadeed et al. [25] successfully prepared date palm wood flour/glass fiber reinforced hybrid composites of recycled polypropylene. Morphological results showed good adhesion between hybrid filler and recycled polypropylene that supported the improvement of mechanical and thermal properties of hybrid composites. Alamri and Low [26] investigated the effect of water absorption on the mechanical properties of nanoclay/recycled cellulose fiber reinforced epoxy hybrid nanocomposites. It was observed that water absorption decreased with the clay addition, and so impact strength and toughness increased in contrast to flexural strength, modulus and fracture toughness. Essabir et al. [27] prepared oil-palm fiber/clay reinforced high density polyethylene with higher thermal, mechanical and rheological properties.

To the best of our knowledge, no work has been reported on hybrid composites based on epoxy resin reinforced with bean pod/kaolin. In this study, it was firstly aimed to reuse of bean pod which is a low-cost, abundant and low health risk agricultural waste in epoxy matrix with leading to decrease waste accumulation. The second aim was the preparation of novel hybrid composites with better physico-mechanical and thermal properties by the calcined kaolin addition which is one of the most commercially and inexpensive naturally occurring silicate material. This study provides a new insight to the industry and scientific community. The most significant thing was that these sustainable bean pod/calcined kaolin hybrid epoxy composites are expected to take important place in many fields of agricultural waste recycling with unique properties compared to traditional composite materials.

2. Experimental procedure

2.1. Materials

Epoxy resin (ER) based on bisphenol A (equivalent weight of 184–190 g/eq) was used as a thermoset matrix. Epamine PC 17 (aliphatic amine structure) and 2,4,6-tris(dimethylaminomethyl)phenol were used as hardener and accelerator, respectively. Hybrid filler was combination of bean pod (230 mesh) and calcined kaolin (average particle diameter 10 μm). The bean pod comprises of cellulose, hemicellulose, lignin and ash, and elemental composition of this waste is C 40%, O 31%, H 11%, Si 6%, N 1%, and small amount of S, K, Ca, Na and Fe. The chemical composition of calcined kaolin was SiO_2 56%, Al_2O_3 39%, Fe_2O_3 0.7%, TiO_2 0.4% and trace amount of impurities. Digital images of bean pod and calcined kaolin are shown in Fig. 1, respectively.

2.2. Preparation of epoxy hybrid composites

First of all, the composite materials were prepared with using only bean pod at varying ratios (1.0–7.0 wt%). The maximum ten-

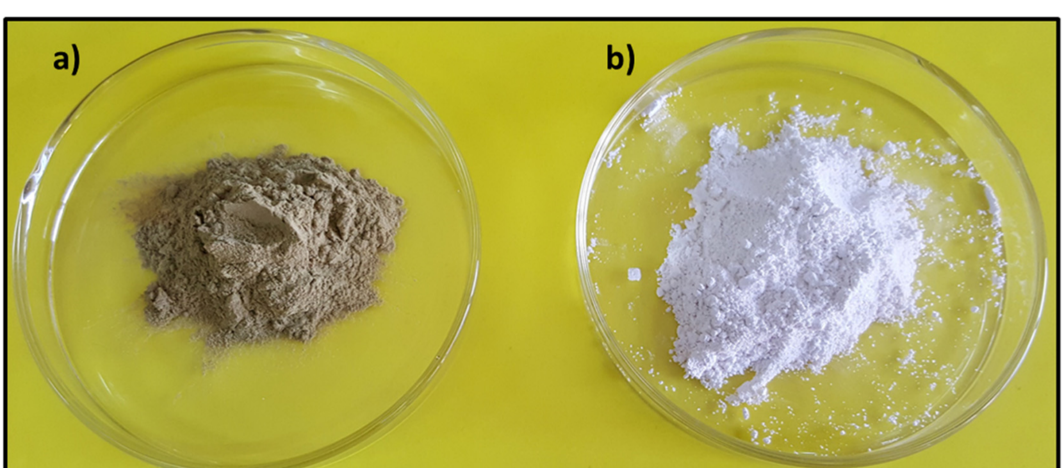

Fig. 1. Digital images of (a) bean pod and (b) calcined kaolin.