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# Influence of redmud on the mechanical, damping and chemical resistance properties of banana/polyester hybrid composites

V. Arumuga prabu [a], M. Uthayakumar [a,*], V. Manikandan [a], N. Rajini [a], P. Jeyaraj [b]

[a] Department of Mechanical Engineering, Kalasalingam University, Krishnankoil 626126, India
[b] Department of Mechanical Engineering, National Institute of Technology, Surathkal 575025, India

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ABSTRACT

A novel hybrid composite was developed with the addition of redmud as secondary reinforcing filler with banana fiber reinforced polyester composites (BFRPCs). The effect of varying parameters such as particle size (4, 6 and 13 μm) and weight percentage (2, 4, 6, 8 and 10 wt%) of redmud were analyzed on static mechanical, free vibration and chemical resistance properties of hybrid composites. The addition of redmud shown enhanced performance compared to the virgin BFRPCs in all the above said properties. The maximum increase of 50% in mechanical strength was observed for the BFRPCs with the addition of redmud having 4 μm particle size and 8 wt% of filler content compared to pure BFRPCs. The increased value of fundamental natural frequencies with associated modal damping characteristics of redmud filled BFRPCs were found using half-power band width method. All the fabricated composites performed well against various chemicals and it indicates that the resistance to the weight loss is due to the uniformly distributed redmud. To study the effect of redmud on interfacial bonding between the banana fiber and polyester matrix the Scanning Electron Microscope (SEM) image analysis was performed.


## 1. Introduction

To alternate synthetic fibers with any naturally derived plant fibers in polymer reinforced composites seems to be very crucial in concerned of green environment [1–3]. According to new environmental regulations and societal concern, it is important to trigger the usage of degradable constituents (both fiber and matrix) for the production of composites at the maximum possible extent. In this regards, some of the engineering applications like sports articles, panel boards, gardening items and food packaging industries are developed from the bio-composites with minimum ecological impact and also they do not require any excellent mechanical properties [4,5]. However, the sacrificing strength of natural fiber composites should be considered into account before the replacement of any composite product fabricated with synthetic fiber particularly in the field of automobile and construction industries [6,7]. Although, the emerging interest of material scientist in the field of composite materials relay on the utility of various natural fibers such as cotton [8], kenaf [9], sisal [10], jute [11], starch [12], sansevieria cylindrica [13] in polymer composites in order to achieve the environment friendly composites. Among various natural fibers, the existence of banana fibers provide accountable contribution to thermoset polymer matrix composites (both polyester and epoxy) for the attainment of various properties such as mechanical, thermal degradation, swelling and dielectric properties [14–16].

Recently, many of the natural fiber reinforced polymer composites (NFRPCs) were produced with the significant strength by changing the surface morphology of fibers with various chemical treatments [17–19]. Besides that, the improved properties of NFRPCs can also be achieved by the addition of fillers as a secondary reinforcing agent i.e. fillers can coming from non-renewable or renewable and biodegradable sources [20,21]. In doing this, the composites are referred to as “hybrid” and it can discover many industrial applications also. Usually, a hybrid composite is made by combining different types of fibers into a polymer matrix to achieve the significant improvement in the ductility of composites. A lot of researchers have studied the hybrid composites using synthetic fiber and polymer matrix towards the improved properties in various aspects. Accordingly, Sathiyamurthy et al. [22] studied the mechanical properties such as tensile, flexural, and impact properties of coir fiber reinforced polyester composites with the effect of calcium carbonate as filler reinforcement. A comparative study between individual and combination of bamboo and glass fiber reinforced hybrid epoxy composites were analyzed with the varying wt% of redmud as secondary filler on mechanical

* Corresponding author. Tel.: +91 4563 289042; fax: +91 4563 289322.
*E-mail addresses:* uthaykumar@gmail.com, m.uthayakumar@klu.ac.in (M. Uthayakumar).

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properties. The performance of erosion test witnessed the potential usage of redmud on hybrid composites [23]. Various hybrid composites such as glass/bamboo, glass/sisal and silk/sisal fibers with polyester composites were analyzed on chemical resistance behavior. All these composites showed their better resistance against various chemicals such as acetic acid, sodium hydroxide, ammonium hydroxide, sodium carbonates, benzene, toluene, carbon tetra chloride and they can be a possible replacement for making chemical resistant products [24–26]. The effect of varying fiber volume fraction determines the mechanical, chemical resistance and thermal properties of Kapok/sisal fiber polyester reinforced hybrid composites were investigated by Reddy et al. [27]. Jawaid et al. [28] prepared the tri layer hybrid composites of oil palm empty fruit bunches and jute fibers with the effect of fiber loading and different layering pattern. All these composites showed their better resistant to various chemicals. They also found that the tensile properties are significantly influenced by the effect of layering pattern of hybrid composites depending upon the skin or core layers. Generally, the composite laminates were prepared in the form of thin plates and it can be served as a structure in various engineering applications [29].

When a structure is subjected to forced vibrations at frequencies near resonance, small exciting forces will induce large vibratory inertia forces so that high-amplitude vibrations and severe dynamic stresses can be caused. The resonant amplitude of vibration is significantly influenced by the modal damping associated with each mode. Generally, the damping in metal structures is low, which results in high amplitudes of the vibrations. Whereas, the damping is higher for the fiber reinforced composite materials and its magnitude is depends on the constitution of the composite materials. Free vibration and damping characteristics of synthetic fiber reinforced composite structures has been investigated using experimental, analytical and numerical methods by several researchers. The initial works on the damping analysis of fiber composite materials were reviewed extensively in review papers by Gibson and Plunkett [30]. Chandra et al. [31] has given a detailed review of the damping studies in synthetic fiber-reinforced composites. They reported that different sources of energy dissipation in fiber-reinforced composites are visco-elastic nature of matrix and fiber, damping due to interphase and damping due to damage. Hong et al. [32] proposed a hybrid method to calculate the structural damping of a composite propeller blade and validated the results experimentally. Vibration studies on glass fiber reinforced polyester composites were carried out with the flyash content of different weight percentages (5, 10, 15 and 20 wt%) and the results showed that the addition of 5 wt% filler increased the internal damping of the structures [33]. Prabhakaran and Sivakandan [34] carried out free vibration studies of glass fiber reinforced epoxy composites with varying stacking sequence. Rajini et al. [35,36] studied the effect of montmorillonite (MMT) clay with naturally woven coconut sheath reinforced polyester composites on mechanical and free vibration properties. The damping properties of coconut sheath/polyester composites were found to be better compared to glass fiber composites for the same wt% of fiber content. The dynamic mechanical and vibration damping properties of polyether urethane and epoxy composites were studied by Weibo et al. [37]. The results showed that the crosslink density can influence the loss factor of polyether urethane material. It also confirmed the improved damping properties from the increase in loss factor value obtained from the dynamic mechanical analysis. However, no significant works have been reported on free vibration studies using the hybrid composites especially keeping any one of the reinforcement as natural fibers.

Redmud is nothing but the industrial waste obtained from the manufacturing of aluminum powder, which was identified as suitable reinforcing filler in polymer matrix reinforced composites [23]. From the earlier investigations [38,39], the hybrid composites has been studied using the redmud as secondary reinforcement filler with varying wt% ranges from 10 to 40 wt% in banana (natural) fiber reinforced composites on mechanical properties. Interestingly, the significant improvement in mechanical strength was found from the banana/polyester composites with the addition of redmud at 10 wt% of filler content. However, there is no relevant work has been reported using redmud as a filler in natural fiber reinforced composites on other properties rather than mechanical and erosion properties. Therefore, the detail studies on redmud effect are further required for the same composites to find its suitable alternate replacement for application especially in the field of structural engineering. Hence, the present work focused the addition of redmud filler with the varying particle size and filler content (values have been chosen at below 10 wt%) on banana fiber/polyester composites. The mechanical, free vibration with associated modal damping and chemical resistance properties of hybrid composites are also studied using the banana fibers under untreated and treated (alkali and silane) conditions.

## 2. Experimental procedure

### 2.1. Materials required

Banana fibers (Musaceae family) were obtained from Sheeba Fibers and Handicrafts, Poovancode, India. The physical properties of banana fiber [40] have already been reported elsewhere. The secondary reinforcement of redmud filler has been collected from the Madras Aluminium Company (MALCO) at Salem, India and that was subjected to the sieving process to obtain three different particle sizes of 4 μm, 6 μm and 12 μm. The chemical composition properties of redmud are given in Table 1. Unsaturated isophthalic polyester resin of commercial grade VBR 4503 was used as the resin. Methyl ethyl ketone peroxide (MEKP) and cobalt naphthenate were used as curing catalyst and accelerator. The polyester matrix, catalyst and accelerator were supplied by M/s. Vasavibala Resins Pvt Ltd., Chennai, Tamil Nadu, India. The chemicals used for the modification of banana fiber surface such as sodium hydroxide, tricholoro vinyl silane were of commercial grade, obtained from M/s Sigma Alridch, Bangalore, India.

### 2.2. Fabrication of the hybrid composites

The banana fibers (untreated/treated with NaOH and silane) were chopped into a length of 30 mm and that was found to be an optimum fiber length from our earlier investigation [39]. The isophthalic polyester resin was mixed with 1.5 ml each of Cobalt Nephthalate (VBR 1204) and Methyl Ethyl Ketone Peroxide (MEKP) (VBR 1201) were used as catalyst and accelerator respectively for room temperature curing reaction. The hybrid composites have been fabricated using compression molding technique for the optimum fiber percentage of 30 wt% by the following process. The polyester redmud mixture was prepared by mixing definite proportion of redmud with polyester resin by hand stirring until all the redmud was evenly dispersed. The sized randomly orientated banana fibers are placed in a mold having a total dimension of 300 × 125 × 3 mm, and it was wetted by pouring the polyester/redmud solution mixed with curing agents on to the randomly disordered fibers and squeezed using a roller to remove the air

**Table 1**
Composition of Redmud (%).

| $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $Na_2O_3$ | CaO |
|---|---|---|---|---|
| 15.21 | 16.8 | 33.8 | 11.87 | 2.45 |