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Material Properties

Comparison on mechanical properties of lignocellulosic flour epoxy composites prepared by using coconut shell, rice husk and teakwood as fillers

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The objective of this work was to investigate the feasibility of using lignocellulosic fillers (coconut shell, rice husk and teakwood) as alternative reinforcement for expensive non-renewable fillers used in conventional composites. Various concentrations of epoxy based bio-fillers composites were prepared and the influences of filler size (75–105 and 106–180 μm) and mass concentration (2.5 and 4.5 wt%) on the mechanical properties were investigated. Properties such as deformability, stiffness, elasticity and strain energy absorption ability of each material combination were determined using single indentation load control, single indentation displacement control and multi-cyclic indentation tests. The results showed that parameters such as filler size, volume content, filler type (chemical composition and shape) dispersion influenced these properties. It was revealed that high lignin content increased the stiffness whereas high cellulose content with high impregnation ability favoured deformability. High cellulose content and surface roughness supported better adhesion due to a large number of hydrogen bonds and high mechanical interlocking, respectively.

1. Introduction

Fibre reinforced plastic (FRP) composite materials are increasingly replacing the conventional metallic materials due to their unique attributes over conventional metals in terms of high stiffness to weight ratio, and tailorability to meet the exact needs of the structures. Due to these attractive attributes, composite materials have gained important applications in aerospace, automotive and marine sectors. Despite having these numerous advantages, laminated composite structures are susceptible to fracture, commonly called delamination. Delamination is always associated with the initiation and propagation of cracks in the interlaminar space which is occupied by matrix material. There are many reported works on techniques to arrest or delay delamination, which include using hybrid systems by using different reinforcements [1], the addition of expensive carbon nanotubes into the matrix material to toughen and deviate the crack [2]. Toughening involves improving the elastic strength as well as ductility in an attempt to have high energy absorbing capability. Investigations have been carried out to find a cheap alternative to carbon nanotubes but, at the same time, also have synergistically good strength, toughness, shear strength and other mechanical properties [3,4].

Furthermore, investigation on inclusion of commercial fillers like carbon nanotube, carbon black (CB), thermally reduced graphite oxide (TRGO), alumina and TiO_2 nano-particles polymer matrix have been carried out [5,6]. The reported works suggest that optimum content of filler improved the mechanical properties such as tensile, flexural and shear strength as well as modulus of the matrix. Properties influenced by material surface like fracture resistance, abrasion, micro and macro hardness were also reported to be increased. Carbon black enabled polymer chain sliding which in turn influenced deformability of matrix, but when added in higher concentrations the properties deteriorated due to agglomeration of fillers, higher viscosity and difficulty in dispersion [7,8].

In recent years, due to ecological concerns, bio-fillers, which are cost effective, provide ecofriendly alternatives to non-renewable petroleum reinforcements and, in many cases, are considered as waste, are being used to modify polymer matrices to acquire improved mechanical properties such as stiffness, elastic modulus, toughness and fracture resistance. Certain bio-filler based

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particulate composites have shown improvement in flexural strength, flexural modulus and thermal stability. The work carried out by Fombuena et al. [9] on seashell waste and Huang et al. [10] on sugarcane based biocomposites suggests that inclusion of seashell and rice husk bio-fillers to epoxy improved hardness, tensile modulus, impact energy, erosion resistance and thermal properties. Remarkable increase in yield stress, tensile strength, toughness and thermal degradation temperature were reported for lignin based date palm wood powder and rice husk filled glass epoxy particulate polymer composites [11,12]. Cellulose in bio-fillers improves mechanical properties whereas lignin, which is rigid, reduced water absorption and improved thermal stability. Also, rod shaped fillers exhibited higher tensile modulus and strength than the elliptical shaped fillers [13–16]. Chemical compositions of various lingnocellulosic fillers have been determined and standard methods for filler preparation and quasi-static indentation and have been discussed [17,18].

In addition, experimental investigations on certain biofillers such as sugarcane bagasse, rice husk, coconut coir, rice straw and egg shell, and the influence of filler content, size, shape and chemical composition on prevalent mechanical properties like tensile, flexural, impact and fracture toughness have been carried out [19–24]. Notwithstanding, there is still a large gap in investigating lignocellulosic fillers resources, their influential parameters and effects on the properties which could possibly be very useful for material evolution. In order to address this gap, this study focuses on three different types of lingo-cellulosic fillers: rice husk, coconut shell and teakwood. They were subjected to indentation testing to study the influence of filler mass percentage, size, shape, surface properties and chemical composition on the important mechanical properties such as elasticity, deformability, stiffness, strain energy absorption and restoring capabilities. The results obtained will provide information about what kind of filler material and filler content will be best suited for applications that require certain tailored material properties like stiffness, ductility and toughness.

2. Materials and methods

2.1. Materials

The matrix material used in the fabrication of composite material was a mixture of Araldite epoxy resin (LY556) and hardener (HY951) mixed thoroughly in mass ratio (10:1). Three different fillers, namely rice husk, coconut shell powder and teak wood powder of two different sizes ranges from 75 to 105 μm and 106–180 μm were used as particulate reinforcements. The fillers were added in different mass percentages of matrix of 2.5 and 4.5 to obtain different levels of reinforcement.

2.2. Processing of fillers

The fillers were obtained by grinding the respective raw materials to fine powders of size ranging in microns using a grinding machine. The grinding process increased surface roughness and contact area of the fillers, which favoured mechanical interlocking with the matrix. Mesh 85, 150 and 200 were used to sieve the fillers according to BS 410-1:2000 [25] to separate them into two different size ranges 75–105 μm and 106–180 μm. Distilled water was used to wash the fillers to remove any dirt, and filtered using clean white cloth. They were then dried in an oven at 120 °C for 4 h to remove the moisture since bio fillers are extremely hydrophilic. The fillers were inspected under a digital optical microscope to study surface roughness and shape. The optical microscopic images of various fillers, as shown in Fig. 1, provide information about the nature and shape of different fillers used. Tapped apparent density of the fillers was measured by pouring the filler in a container and tapping it 100 times in an ultrasonic agitator [26]. Table 1 provides detail information about the shape, density, cellulose and lignin contents of various fillers.

2.3. Preparation of particulate filler composites

The hardener HY951 was added into the epoxy resin LY556 in mass ratio 1:10 and stirred well. Dried filler in different mass percentages of resin as required was mixed with the epoxy-hardener mixture. The mixture was stirred thoroughly for 8–10 min to form a homogenous suspension. Composite material was produced by pouring the resin filler mixture into a mould and curing at room temperature for 24 h. Details of different combinations of composite materials are presented in Table 2.

2.4. Indentation test

Different types of composites were subjected to indentation load with reference to ASTM D 6264 for rigid support configuration [27], as shown in Fig. 2. Specimen size of length × width × thickness (50 × 50 × 10 mm) was used. Single and multi-cyclic loading were performed. Both displacement control and load control modes of testing were used for single loading. A loading rate of 2000 N/min until it reached 8000 N was applied for the load control test. During displacement control test, a feed rate of 0.25 mm/min was applied until 1.5 mm displacement. For multiple indentations, a cyclic load was applied in which a displacement increment of 0.75 mm was given for each cycle with a displacement feed rate of 0.25 mm/min.

3. Results and discussion

3.1. Determination of deformability from indentation load control test

A load of 8000 N was applied at a rate of 2000 N/min and the deformation was measured for all specimens. This provides information about the deformability of the materials. The load applied was the same for all specimens; consequently, the deformation was higher for ductile materials than the stiffer ones. The factors contributing to material stiffness are elastic property of the neat matrix itself, matrix filler interaction and degree of filler impregnation by resin, and total volume content of filler in the composite material. Matrix/filler interaction was influenced by aspect ratio of filler, nature of filler surface and ability of impregnation of filler by resin. Rice husk (RH) is highly impregnable by resin so that it mixed thoroughly with resin, leaving no suspended particles, to form a homogeneous mix, unlike other fillers which were less easy for resin to impregnate. As the filler content increased, the viscosity of resin increased. This resulted in difficulty in impregnation and leaving some particles suspended in the matrix system. Even although teak wood fillers are flat flakes, they are harder than RH which can be seen from the density values in Table 1. It was observed that more particles were suspended in the matrix, but they have rougher surface than the RH and coconut shell (CC) fillers, which aided high particle matrix interaction. Also, TW have more cellulose content, as given in Table 1, which has more hydroxyl groups that favour matrix particle interaction, as proposed in Ref. [9]. The composition of RH, CC and TW were taken from Refs. [18,25]. As for coconut shell with high lignin content, it is highly stiff and rigid. It is difficult to impregnate, but having a rough surface and irregular 3D shape with pointed edges provides high shear and fractures resistance by deviating the crack. As far as the