



Characteristics of kenaf fibre/epoxy composites subjected to thermal degradation



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ABSTRACT

Kenaf fibres are receiving much attention in the natural fibre composite industry due to its potential as polymer reinforcements. However, like all natural fibres, kenaf fibres have lower thermal resistance as compared to synthetic fibres. In this current work, the characteristics of kenaf fibre/epoxy composites, both treated and untreated using alkalization process, exposed to high temperature were studied. Thermogravimetric analysis (TGA) was used to study the thermal decomposition behaviour of treated and untreated kenaf/epoxy composites as well as their components, kenaf fibre and neat epoxy from room temperature up to 600 °C. The weight loss and physical changes of these samples were observed through furnace pyrolysis. Surface morphology of the composites after degradation was observed using scanning electron microscopy (SEM). The results from the TGA showed that the addition of kenaf fibres into the epoxy slightly improves both the charring and thermal stability of the samples. However, it was observed that alkalization causes reduction in these behaviours for the kenaf/epoxy composite. Generally, increased exposure time causes higher weight loss of the composites only up to 150 °C. At higher temperature, duration of exposure has little influence on the weight loss. Fibre-matrix debondings were observed on degraded samples implying mechanical degradation of the composites had occurred.

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1. Introduction

Fibre reinforced polymer composite or more easily referred to as FRP is a relatively new material in the construction industry as compared to steel and concrete. The commonly used synthetic fibres are glass, aramid and carbon [1]. Due to the emerging concept of green-building, the idea of introducing natural fibres in polymer composites has been introduced. The advantages of natural fibres over its synthetic counterparts include low weight, low cost, low density, biodegradable, availability from renewable resources, and good thermal and acoustic insulation properties [2–4]. Also, they are non-abrasive on processing equipment and provide safer and healthier working environment [5].

What makes natural fibre appealing as a composite reinforcement material is its biodegradability which can contribute to the reduction of construction waste [2] thus reduces landfill dependency. However, this very attraction also imposes a great drawback on its durability. The disadvantages of natural fibre include low moisture resistance, inferior fire resistance, limited

processing temperature, lower durability, and variation in quality and price [2,4]. Presence of hydroxyl groups in natural fibres makes them hydrophilic in nature and this generates high moisture absorption that causes composites to fail in wet condition through fibre swelling and delamination [6–9]. In terms of exposure to high temperature, majority of natural fibres have low degradation temperatures which are inadequate for processing with thermoplastics with processing temperatures higher than 200 °C [4].

The major issue that hinders the widespread use of FRP in structural engineering application is the degree of fire resistance of the material and the limited amount of information regarding FRP behaviour in fire. At lower temperature of 100–200 °C, FRP soften, creep and distort causing buckling for load bearing structures while at 300–500 °C, polymer matrix decomposes, releasing heat and toxic volatiles [1]. Decomposition of burning polymers includes the production of combustible gases, non-combustible gases, liquids, solids (usually char), and entrained solid particles (smoke). These outcomes may produce hazards such as the evolution of toxic gases (in the case of PVC), loss of physical integrity, and melting and dripping thereby providing other ignition sources (in the case of polyolefins and polyethylene) [10,11].

For natural fibres, flammability is in part due to differences in chemical composition. Higher cellulose content results in higher flammability while higher lignin content results in greater char

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formation with lower degradation temperature [2,12,13]. Char formation is important during a fire as it protects core of material and structural integrity. Other attributes that provide better fire performance includes the present of silica or ash and higher crystallinity and lower polymerization of fibre microstructure [2]. Among the natural fibres studied, flax fibres are considered the best for thermal resistance due to their low lignin content [12].

Temperature plays an influential role in the thermal stability of natural fibre composite where it causes direct thermal expansion or contraction and affects rate and volume of moisture absorption that leads to fibre swelling [14]. The degradation process of natural fibres includes dehydration combined with emission of volatile components initiating at a temperature of about 260 °C, and rapid weight loss due to oxidative decomposition corresponding to the formation of char as the temperature increased [15]. Thermogravimetric analysis is one of the methods used to study the thermal degradation behaviour of natural fibre/polymer composites and its constituents. Approximately 60% of the thermal decomposition of most natural fibres occurred within a temperature range between 215 and 310 °C with an apparent activation energy of 160–170 kJ/mol [16]. For example, fibres from water hyacinth, reed, sisal and roselle decompose at 290–490 °C [17], bamboo fibres degrade at 250–420 °C [18] and kenaf fibres degrade at 297–434 °C [19].

Kenaf fibres are becoming increasingly popular in Malaysia as one of the natural materials that may contribute to the development of environmental friendly resources for the automotive, food packaging, furniture and sports industries [20]. In recent times, it has been used as an alternative to wood in pulp and paper industries in order to help preserve forests, and as non-woven mats, it has been applied in industries such as automotive, textiles, and fibreboards [21]. In the composite industry, mature kenaf fibres have been employed as fibre reinforcements to various matrices. Studies have shown that the addition of kenaf fibres have improved the mechanical properties of neat polymers. Various polymers were used in a study by Anuar et al. that showed improvement in tensile, flexural and impact strength as well as stiffness of the composites reinforced with kenaf fibres [20]. Nishino et al. have observed that Kenaf sheets using poly-L-lactic acid (PLLA) resin showed large mechanical anisotropies which results in high mechanical performance in tensile strength and Young's modulus [21]. With treatments such as alkalization [22] and coupling agents [20], the improved in mechanical strength of the composites were further increased. Such improvement was also observed for treated kenaf fibres alone whereby the morphological changes provided better tensile strength and modulus of the fibres [23].

In this current work, investigation was carried out to study the degradability behaviour of kenaf/epoxy composite exposed to high temperature in comparison with neat epoxy. The effect of alkalization treatment on the thermal degradation of kenaf fibre/epoxy composite was also observed. It is important to analyse the behaviour of natural fibre/polymer composite subjected to thermal exposure in comparison to its synthetic counterpart in order to draw a conclusion to whether natural fibres are technically capable to replace synthetic fibres.

2. Samples preparation and experimental procedure

2.1. Materials selection

Raw kenaf fibres were supplied by Malaysian Agricultural Research and Development Institute (MARDI). The quality of the kenaf fibre and fibre retting are comprehensively covered by Yeong and Hong [24]. The fibres were soaked in warm water for 3 h and then rinsed with tap water to remove any dirt or debris. The fibres

were combed and then dried for 24 h in an oven at a temperature of 40 °C.

In the fibre treatment process, the cleaned kenaf fibres were cut into an average length of 100 mm. Sodium hydroxide (NaOH) solution was prepared with a 6 wt% concentration. The selected fibres were immersed in NaOH aqueous solution for 24 h at room temperature. After treatment, the fibres were thoroughly washed with tap water until all traces of NaOH were removed from the fibres and then dried for 24 h in an oven at a temperature of 40 °C. The morphology of the untreated and treated fibre surfaces are presented in Fig. 1. It can be observed that alkalization had caused the smooth fibre surface to roughen.

For comparison purposes, glass fibre/epoxy composite was also used in the TGA study only. The glass fibre used was chopped strand mat (CSM) 450 R-glass fibre supplied by Kong Tat Company of Fibreglass Engineering (Malaysia). The fibre length was approximately 20–30 mm with a 450 g/m² mass of fibres.

The resin used in the current work is liquid epoxy (DER 331) which is a liquid reaction product of epichlorohydrin and disponol A. It is suitable for applications such as casting and tooling, composites, and automotive parts. The curing agent used for the selected epoxy is JOINTMINE 905-3S, which is a low viscosity aliphatic amine for room temperature curing. It has good wetting properties and impact resistance.

2.2. Epoxy composites preparation

In the fabrication process, the epoxy resin and hardener, with a ratio of 2:1, was uniformly mixed using an electric mixer and poured into the desired mould. The mould was placed in a vacuum chamber (MCP 004PLC) with a 0.5 bar pressure to get rid of any air bubbles which may have been trapped in the mould in between the fibres. The vacuumed block was kept for curing at room temperature for 24 h. The volume fraction of the fibre in the matrix was controlled to be about 48% Vol. Fig. 2 shows the SEM for untreated and treated Kenaf/epoxy composite with the treated sample having better mechanical interlocking and interfacial adhesion.

2.3. Thermogravimetric analysis (TGA)

Thermogravimetric analysis was conducted using TGA Q500 machine. For the TGA environment, in Ref. [25], it was reviewed that both atmosphere and nitrogen environments have been used to test cellulosic fibres. It was mentioned that there is partial overlapping of this peak with the exothermic peak corresponding to the oxygen reaction with the cellulose. As a consequence, the main TGA peak is shifted to lower temperatures in oxidative atmosphere as compared to the inert one [25]. Moreover, nitrogen is used during TGA testing as recommended by Refs. [4,8,12,13,16,18,19]. Based on this information, the current work was tested in nitrogen environment. Samples were subjected to pyrolysis in nitrogen environment to a maximum temperature of 600 °C at a heating rate of 10 °C/min. The weight loss was recorded in response to increasing temperature, with final residue yield on set of degradation temperature and number of degradation steps reported. Additionally, glass fibre/epoxy composite sample was also tested for comparison.

2.4. Furnace pyrolysis

Rectangular cubes of treated kenaf fibre/epoxy composites, untreated kenaf fibre/epoxy composites and neat epoxy with the dimensions of 10 × 10 × 15 mm were prepared. The initial weights of the samples were taken. Samples were placed into a laboratory muffle furnace and were heated in air atmosphere to maximum

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