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REVIEW OF RESEARCH ACTIVITIES ON KENAF REINFORCED COMPOSITES

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ABSTRACT

In this review, the research activities on kenaf reinforced matrix composite are discussed. The the variety of matrix material including polymer such as polypropylene, epoxy, polyester, polyethylene and polyurethane as well as rubber. Matrix material such as wood and concrete also used inorder to improve the mechanical properties. In general, the mechanical properties of kenaf fiber are deteriorated after the moisture penetrates into the composite. The compressive properties were found to decrease with the increase in the percentage of water uptake. The decay in compression properties is attributed to the plasticization of the fiber–matrix interface and swelling of the kenaf fiber. The hybrid composite was stronger than long kenaf composite. Fabrication methods are critical to maintain optimal thermal and structural characteristics of composites without scarifying their environmental performance. The more the kenaf loading, the less porous the composites and hence the higher shear resistance. Impact strength decreased with increase in fiber content due to is poor fiber/matrix adhesion. The biodegradability of the composites showed a clear trend of increase degradation with increasing kenaf content in the formulation. While water-absorption values for the composites were higher than that of pure LDPE polymer, the addition of polyethylene glycol to the formulation reduced the water absorption of the composites. This shows that kenaf fiber has imparted its tensile strength to the elastomer composite system with good interaction provided by the compatibilizer agent. Scanning electron micrographs (SEMs) revealed that the improvement achieved in mechanical properties was due to the interaction between both matrix systems and kenaf fibre. The research findings indicate that KFRC is a promising 'green' construction material which could potentially be used in a number of different structural applications.

Keywords: *Kenaf fiber, reinforced composite, polypropylene*

Introduction

Processing technology has made great strides since the early years. Kenaf has already been used in commercial applications such as composite boards, automotive panels, insulation mats and geotextiles. Major global corporations such as Toyota Motor Corporation and Panasonic Electric Works have taken the lead in the global kenaf industry. Toyota has developed kenaf fibres for automotive interior applications, and Panasonic, a structural wall board to replace timber-based plywood. The kenaf board is far stronger and lighter than plywood. Recently, there are several research in literature on development of kenaf reinforced composite. Some researchers focused on kenaf reinforced polymer composite such as Kenaf reinforced Polypropylene Composite (John et al., 2010; Bernard et al., 2011; Islam et al., 2011; Asumani et al., 2012), Kenaf-Glass Reinforced Epoxy Composite (Davood et al., 2010; Yousif et al., 2012; Azwa and Yousif, 2013), Kenaf Reinforced Poyester Composite (Rassmann et al., 2010; Nosbi et al., 2010; Ghani et al., 2012; Md. Akil et al., 2010; Salleh et al., 2013), Kenaf Reinforced Polyurethane Composites (Batouli et al., 2014; El-Shekeil et al., 2014), Kenaf Reinforced Polyethylene Composites (Tajeddin et al., 2010), Kenaf Reinforced Elastomer Composites (Anuar and Zuraida, 2011). Other researcher focus on development of Kenaf/Glass Hybrid Composites (Salleh et al., 2012), Kenaf/Rubber Wood Hybrid Composites (Paridah et al., 2014) and Kenaf/concrete (Elsaid et al., 2011). Therefore, this paper attempted to review their works in order to develop a data base for reference to the stake holders in downstream kenaf industries activity.

Kenaf reinforced Polypropylene Composite

John et al. (2010) attempted to develop the Kenaf–polypropylene composites. They study on the use of zein as a coupling agent in natural fibre composites. Kenaf nonwovens were treated with zein coupling agent, which is a protein extracted from corn. The surface characteristics of untreated and chemically treated kenaf fibres were investigated by FTIR, zeta-potential measurements and Energy Dispersive X-ray Spectroscopy (EDS) mapping. Composites were prepared by compression moulding using nonwovens treated with zein solution. The reinforcing properties of the chemically treated composites were compared with that of untreated composites. The viscoelastic and thermal properties of composites were also determined. Composites containing chemically modified kenaf fibres were found to possess improved mechanical and viscoelastic properties. EDS mapping studies revealed the presence of surface functionalities on treated kenaf fibres. Furthermore, Bernard et al. (2011) attempted to study the effect of processing parameters on the mechanical properties of kenaf fibre plastic composite. They focused on the effects of processing parameters, including temperature and speed, have on the mechanical properties of kenaf fibre plastic composite. Kenaf fibre was used to fabricate a composite material along with polypropylene (PP) as a binding material. The composite was manufactured using a newly developed compression moulding machine. Tensile and impact tests were performed on the PP/kenaf composite to characterise its mechanical properties. The tensile properties of PP/kenaf composite increased by 10% after the addition of unidirectional kenaf fibre (UKF). However, its impact properties simultaneously deteriorated. Dynamic mechanical analysis (DMA) was carried out to examine the material properties. Results show that the storage modulus (E') and loss modulus (E'') increase with the addition of UKF. However, its addition decreases the tan δ amplitude. The fracture surface of PP/kenaf composite was investigated by SEM. The newly invented compression moulding machine illustrates a new trend in processing parameters of long kenaf fibre plastic composite. Whereas, Islam et al. (2011) focused on the effect of removing polypropylene fibre surface finishes on mechanical performance of kenaf/polypropylene composites. Natural fibre/polypropylene thermoplastic composites are often produced by compression moulding of a blended preform of polypropylene fibre and natural fibre treated by chemicals or enzymes. Two preform processing routes may be adopted: (1) treating the natural fibre first and then blending it with the polypropylene fibre (the pre-treatment route), and (2) forming a blended preform of the natural fibre and polypropylene fibre first and then carrying out the chemical/enzyme treatment on the blended preform (the post-treatment route). The kenaf/polypropylene composites produced according to the post-treatment route show up to 36% higher flexural strength and up to 63% higher flexural modulus than the composites produced according to the corresponding pre-treatment route. These differences were attributed to the chemical surface finishes of the polypropylene fibre, which have been removed in the post-treatment processing route, but persisted into the final composites in the pre-treatment processing route. Finally, Asumani et al. (2012) focused on the effects of alkali–silane treatment on the tensile and flexural properties of short fibre non-woven kenaf reinforced polypropylene composites. Kenaf fibre reinforced polypropylene composites were manufactured by compression moulding. The kenaf fibre was considered in three forms; untreated, treated with sodium hydroxide solution and treated with sodium hydroxide solution followed by three-aminopropyltriethoxysilane. The effects of these chemical treatments on the tensile and flexural properties of the composites were investigated. Mechanical test results show that alkali treatment followed by three-aminopropyltriethoxysilane treatment (alkali–silane treatment) significantly improves the tensile and flexural properties of short fibre non-woven kenaf polypropylene composites. In particular, the specific tensile and flexural strengths of alkali–silane treated kenaf composites with 30% fibre mass fraction are, respectively, only 4% and 11% lower than those of composites made using glass fibre. Scanning electron microscopy examination shows that the improvements in the tensile and flexural properties resulting from alkali–silane treatment can be attributed to better bonding between the fibres and matrix.

Kenaf-Glass Reinforced Epoxy Composite

Davood et al. (2010) focused on mechanical properties of hybrid kenaf/glass reinforced epoxy composite for passenger car bumper beam. It is estimated that the annual world car production rate will reach 76 million vehicles per year by 2020. New regulations such as the EU End of Life Vehicles (ELV) regulations are forcing car manufacturers to consider the environmental impact of their production and possibly shift from the use of synthetic materials to the use of agro-based materials. Poor mechanical properties and certain manufacturing limitations currently limit the use of agro-based materials to nonstructural and semi-structural automotive components. The hybridization of natural fiber with glass fiber provides a method to improve the mechanical properties over natural fibers alone. This research is focused on a hybrid of kenaf/glass fiber to enhance the desired mechanical properties for car bumper beams as automotive structural components with modified sheet molding compound (SMC). A specimen without any modifier is tested and compared with a typical bumper beam material called glass mat thermoplastic (GMT). The results indicate that some mechanical properties such as tensile strength, Young's modulus, flexural strength and flexural modulus are similar to GMT, but impact strength is still low, and shows the potential for utilization of hybrid natural fiber in some car structural components such as bumper beams. Furhermore, Yousif et al. (2012) attempted to study the flexural properties of treated and untreated kenaf/epoxy composites. In the current work, flexural properties of unidirectional long kenaf fibre reinforced epoxy (KFRE) composites are studied. The kenaf fibres were prepared into two types as untreated and treated (with 6% NaOH). The failure mechanism and damage features of the materials were categorized with the surface observation by scanning electron microscope (SEM). The results revealed that reinforcement of epoxy with treated kenaf fibres increased the flexural strength of the composite by about 36%, while, untreated fibres introduced 20% improvement. This was mainly due to the high improvement of the chemical treatment (NaOH) on the interfacial adhesion of the fibres and the porosity of the composites which prevented the debonding, detachments or pull out of fibres. For untreated KFRE, the fracture mechanisms were debonding, tearing, detachments and pull out of fibres. The developed composite exhibited superior properties compared to the previous composites based on natural and synthetic fibres. Recently, Azwa and Yousif (2013) attempted to investigate on kenaf fibre/epoxy composites subjected to thermal degradation. 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.

Kenaf Reinforced Poyester Composite

Rassmann et al. (2010) attempted to study the effects of processing conditions on the mechanical and water absorption properties of resin transfer moulded kenaf fibre reinforced polyester composite laminates. This paper focuses on the mechanical and water absorption properties of kenaf fibre reinforced polyester laminates manufactured by resin transfer moulding. Varying processing conditions were considered as alternatives to fibre treatments, thereby potentially avoiding additional cost and complexity in the manufacturing process. Laminates were produced by altering fibre moisture content, mould temperature and mould pressure following injection. Tensile, flexural, impact and water absorption tests were conducted. Processing conditions were found to have little effect on properties except for pressurisation which increased tensile and flexural strength and decreased water absorption at low fibre volume fractions. Examinations using a scanning electron microscope showed that all the laminates failed by fibre pull-out. Moreover, Nosbi et al. (2010) investigated the degradation of compressive properties of pultruded kenaf fiber reinforced composites after immersion in various solutions. In their work, water absorption behavior of pultruded kenaf fiber reinforced unsaturated polyester composites was investigated. Residual compressive properties of the composites after immersion were also reported. Composites were prepared using pultrusion method with minimum kenaf fiber content of 70% w/w. Water absorption tests were performed at room temperature under three different solutions, i.e. distilled water, sea water and acidic solution. The diffusion coefficient of water absorption and maximum moisture content were calculated by measuring the water uptake of specimen at regular time interval. Diffusion coefficient and the highest moisture content values were recorded for composite immersed in distilled water followed by acidic solution and sea water. The water absorption of kenaf fiber reinforced unsaturated polyester composites was found to follow a Fickian's behavior where it reach equilibrium. The compressive properties were found to decrease with the increase in the percentage of water uptake. The decay in compression properties is attributed to the plasticization of the fiber–matrix interface and swelling of the kenaf fiber. Wheareas, Ghani et al. (2012) attempted to investigate the mechanical properties of Kenaf/Fiberglass Polyester Hybrid Composite. In a view to reduce the cost of production and the harmful destruction in normal environment, there's a lot of research have been conducted or still ongoing for the possibility of using natural fibers which are wholly degradable in the combination of biodegradable thermoplastic materials. This research will focus on Kenaf that an extremely valuable natural fiber with robust mechanical properties. In their work, kenaf fiber/fiberglass reinforced with unsaturated polyester composites were subjected to water absorption test. Water absorption test were conducted by immersing specimens into three different environmental conditions including sea water, distilled water and rain water (acidic solutions) at room temperature from 1st day until 4th week. The effect of the mechanical strength of the hybrid composties is investigated. In general, the mechanical properties of kenaf fiber are deteriorated after the moisture penetrates into the composite. The strain to failure increases from 1st day until 3rd week followed by a drastically drop at 4th week. The humidity aging is one of the evidence found in SEM micrograph which contributes to the reduction of tensile modulus. Md. Akil et al. (2010) studied the flexural behaviour of pultruded jute/glass and kenaf/glass hybrid composites monitored using acoustic emission. The flexural (before and after cyclic loading up to 50% of ultimate load) and indentation behaviour of pultruded jute/glass and kenaf/glass hybrid polyester composites has been monitored using acoustic emission, and compared with that of kenaf fiber composites. In all hybrids, natural fiber content was 40 wt.%, while glass fiber one was 25 wt.%. Acoustic emission (AE) has been used for real-time monitoring during flexural and indentation loading: the analysis concentrated on AE resuming during reloading (Felicity ratio) and AE activity at low loads during unloading (crack closure effect).The results show that the introduction of this large amount of reinforcement appears quite effective on jute fiber reinforced laminates, although with a significant effect of fiber architecture, whilst it did not yield comparable results in kenaf fiber laminates. This was attributed to the insufficient fiber impregnation and to the need for improving the control of fiber orientation in the laminate. Salleh et al. (2013) investigated the open hole tensile properties of kenaf composite and kenaf/fibreglass hybrid composite laminates. Drilling induced in fibre reinforced polymer resulted in high rate of parts rejection and thus affects the in-service performance of the composite product. Therefore, the tensile testing of hybrid composite with drilled holes is necessary to render them satisfaction in industrial application. The objective of their research is to develop long kenaf composites and long kenaf/woven glass reinforced polyester resin composites. The tensile properties of those composites with drilled holes were investigated. The measurements were taken from the residual tensile strength of impacted specimens and the open hole specimens. From there, the damage area of the composites could be predicted. It is found that the long kenaf composite was more notch sensitive than long kenaf/woven glass hybrid composite. The hybrid composite was stronger than long kenaf composite. However, the damage progression mechanisms in the two materials were similar. Failure for both kenaf composite and long kenaf/woven glass hybrid composite started around the hole. The polymer matrix failed initially followed by fibre–matrix debonding.

Kenaf Reinforced Polyurethane Composites

Batouli et al. (2014) investigated the environmental performance of kenaf-fiber reinforced polyurethane by using a life cycle assessment approach. Outstanding mechanical, thermal and environmental properties of kenaf, as well as successful applications of kenaf-based boards in structural insulated panels (SIPs), inspired the authors to investigate the incorporation of kenaf core in the polyurethane insulation core of SIPs to create environmentally friendly building material. Three composites made of rigid polyurethane (PU) reinforced with 5, 10 and 15 percent kenaf core were prepared and analyzed. The three composites and pure rigid polyurethane were then used as insulation cores of SIPs with the same kenaf-based structural boards. A life cycle assessment (LCA) was conducted to determine the environmental profiles of the four SIPs in 10 and 50° Celsius. It is shown that although kenaf has much less environmental impact than PU, increasing the amount of kenaf core in PU composites does not necessarily result in less environmental impact. In fact with the current practice of making the composites, kenaf core does not replace the PU; instead, it mostly fills the void space, which is initially filled with air and, hence, the kenaf core decreases the porosity of PU composites and increases the density without improving thermal resistance. Structural adequacy of the samples was also examined based on the ASTM C393-00 “three point flexural test”. Results show that the more the kenaf loading, the less porous the composites and hence the higher shear resistance. These findings suggest that fabrication methods are critical to maintain optimal thermal and structural characteristics of composites without scarifying their environmental performance. El-Shekeil et al. (2014) studied the influence of fiber content on mechanical, morphological and thermal properties of kenaf fibers reinforced poly(vinyl chloride)/thermoplastic polyurethane poly-blend composites. Kenaf (*Hibiscus Cannabinus*) bast fiber reinforced poly(vinyl chloride) (PVC)/thermoplastic polyurethane (TPU) poly-blend was prepared by melt mixing method using Haake Polydrive R600 internal mixer. The composites were prepared with different fiber content: 20%, 30% and 40% (by weight), with the processing parameters: 140 °C, 11 min, and 40 rpm for temperature, time and speed, respectively. After mixing, the composite was compressed using compressing molding machine. Mechanical properties (i.e. tensile properties, flexural properties, impact strength) were studied. Morphological properties of tensile fracture surface were studied using Scanning electron microscope (SEM). Thermal properties of the composites were studied using Thermogravimetric Analyses (TGA). PVC/TPU/KF composites have shown lower tensile strength and strain with increase in fiber content. Tensile modulus showed an increasing trend with increase in fiber content. Impact strength decreased with increase in fiber content; however, high impact strength was observed even with 40% fiber content (20.2 kJ/m^2). Mean while; the 20% and 30% fiber contents showed higher impact strength of 34.9, 27.9 kJ/m^2; respectively. SEM showed that there is poor fiber/matrix adhesion. Thermal degradation took place in three steps. In the first step, composites as well as the matrix had a similar stability. At the second step, matrix showed a slightly better stability than the composites. At the last step, composites showed a better stability than the matrix.

Kenaf Reinforced Polyethylene Composites

Tajeddin et al. (2010) studied the effect of polyethylene glycol on the characteristics of kenaf cellulose/low-density polyethylene biocomposites. Toward the development of biocomposites for packaging applications, the possibility of using kenaf cellulose (KC) was investigated in the production of low-density polyethylene (LDPE)/KC/polyethylene glycol (PEG) biocomposites. First, cellulose was extracted from the cell walls of kenaf-bast fibers. Then, different weights of LDPE, KC, and PEG were blended, and the effects of varying the concentrations of KC and PEG on the synthesis process were evaluated, and the resulting composites were characterized with respect to their mechanical, thermal, biodegradability and water-absorption properties. A scanning electron microscope (SEM) was also used to observe the surface morphology of the samples before and after biodegradation tests. The results showed that the mechanical properties of the biocomposites decreased slightly as the KC content was increased from 0 to 50 wt% in the biocomposite formulation; however, there was a good homogeneity between samples with added PEG. The addition of KC improved the thermal resistance of these biocomposites; PEG also had positive role in the thermal behavior of the composites. Based on a soil-burial test, the biodegradability of the composites showed a clear trend of increase degradation with increasing KC content in the formulation. While water-absorption values for the composites were higher than that of pure LDPE polymer, the addition of PEG to the formulation reduced the water absorption of the composites.

Kenaf Reinforced Elastomer Composites

Anuar and Zuraida (2011) attempted to study the improvement in mechanical properties of reinforced thermoplastic elastomer composite with kenaf bast fibre. Their work focused on the development of thermoplastic elastomer composite reinforced with 20 vol.% kenaf fibre. Two types of impact modifier were blended with polypropylene (PP) namely; thermoplastic natural rubber (TPNR) and polypropylene/ethylene–propylene–diene–monomer (PP/EPDM). Both composites were produced via double melt blending method using Haake internal mixer before they were compression moulded. The ratio of thermoplastic:elastomer was 70:30 for both polymer blends. Due to incompatibility between matrix and reinforcement, maleic anhydride polypropylene (MAPP) was added as in the case of treated composite. It was found that the tensile strength for TPNR is about 12% higher than the PP/EPDM matrix. The present of kenaf fibre (KF) and MAPP however has significantly increased the tensile strength of the PP/EPDM composite by approximately 81% while only 55% increment attained in TPNR–KF–MAPP as compared to unreinforced TPNR. Apart from that, flexural properties and impact strength are greatly improved for treated kenaf fibre composite. This shows that KF has imparted its tensile strength to the PP/EPDM system with good interaction provided by the compatibilizer agent. Scanning electron micrographs (SEMs) revealed that the improvement achieved in mechanical properties was due to the interaction between both matrix systems and kenaf fibre.

Kenaf/Glass Hybrid Composites

Salleh et al. (2012) studied the Fracture Toughness Investigation on long kenaf/woven glass hybrid composite due to water absorption effect. Water absorption of natural fiber composite is of serious concerned especially for outdoor application. In their work, long kenaf/woven glass hybrid composite is fabricated in-house using cold press technique. The effect of water absorption on the hybrid composites is investigated at room temperature under three different environmental conditions, i.e. distilled water, rain water, and sea water. The moisture absorption amount is obtained by calculating the different percentage weight before and after the immersion process. The moisture content is found to exhibit non-Fickian behaviour regardless of three different conditions. Liquid exposure of long kenaf/woven glass hybrid composite deteriorates the fracture toughness due to the weakening of interface between fiber and matrix. There are also several recognized modes of humidity aging found through SEM observation.

Kenaf/Rubber Wood Hybrid Composites

Paridah et al. (2014) focused on measurement of mechanical and physical properties of particleboard by hybridization of kenaf with rubberwood particles. Kenaf is one of the potential raw materials available in Malaysia to use for particleboard manufacturing as an alternative solution to balance shortage of rubberwood (RW) supply. In this study, particleboard manufactured from kenaf stem (KS) and RW particle blends at different RW loading (0%, 50%, 70%, 100%) and resin levels (6%, 8%, 10%). Urea formaldehyde resin is used as a binder. The effects of RW: KS ratio and resin content on mechanical and dimensional stability properties of hybrid particleboard were determined. The results indicated that particleboards bonded with 10% resin level and 50:50 (RW: KS) had the highest strength (19.08 MPa) while particleboards made of 70:30 (RW: KS) display better stiffness (2.23 GPa). Statistical analysis using ANOVA and LSD were conducted on the obtained results. The results show that RW: KS ratio has greater influence over thickness swelling (TS) and water absorption (WA) of particleboard than the level of resin content. The relationship between internal bonding (IB) and TS of particleboards were also examined and obtained strong inverse relationship between IB and TS. Hybrid particleboards made from 70%RW and 30%KS with 10% resin content display over all good properties and comparable with 100% RW (control) samples. It concluded that kenaf stem can replace rubberwood particles up to 50% but the resin level must be kept at 10% or more because lower resin level (⩽8%) significantly decrease strength of the particleboard.

Kenaf/Concrete

Elsaid et al. (2011) studied the mechanical properties of kenaf fiber reinforced concrete. Their work presents the findings of an experimental research program that was conducted to study the mechanical properties of a natural fiber reinforced concrete (FRC) which is made using the bast fibers of the kenaf plant. The kenaf plant is quickly developing as a replacement crop for the dwindling tobacco industry in the south-eastern United States. Appropriate mixture proportions and mixing procedures are recommended to produce kenaf FRC (KFRC) with fiber volume contents of 1.2% and 2.4%. The compressive strength, compressive modulus, splitting tensile strength and modulus of rupture of KFRC specimens are presented and compared to the properties of plain concrete control specimens. The experimental results indicate that the mechanical properties of KFRC are comparable to those of plain concrete control specimens, particularly when accounting for the effect of the increased *w*/*c* ratio required to produce workable KFRC. Further, the results indicate that KFRC generally exhibits more distributed cracking and higher toughness than plain concrete. Scanning electron micrographs (SEM's) indicate that a good bond between the kenaf fibers and the surrounding matrix is achieved. The SEM's also provide interesting information regarding the mechanisms which contribute to the failure and post-peak behavior of the KFRC which may be beneficial to future modeling efforts. The research findings indicate that KFRC is a promising 'green' construction material which could potentially be used in a number of different structural applications.

Conclusions

The purpose of this paper was highlight the veriety of the reserch effort on the kenaf. It can be concluded as below:

i. Kenaf can improved the tensile and flexural strength of polyprolylene composite by using special treatment and composition due to better bonding between kenaf fiber and matrix. Whereas with optimum treatment, reinforcement of epoxy with treated kenaf fibres increased the flexural strength due to the high improvement of the chemical treatment (NaOH) on the interfacial adhesion of the fibres and the porosity of the composites which prevented the debonding, detachments or pull out of fibres.

ii. The mechanical properties of kenaf fiber are deteriorated after the moisture penetrates into the composite. The compressive properties were found to decrease with the increase in the percentage of water uptake. The decay in compression properties is attributed to the plasticization of the fiber–matrix interface and swelling of the kenaf fiber. The hybrid composite was stronger than long kenaf composite. Fabrication methods are critical to maintain optimal thermal and structural characteristics of composites without scarifying their environmental performance. The more the kenaf loading, the less porous the composites and hence the higher shear resistance. Impact strength decreased with increase in fiber content due to is poor fiber/matrix adhesion.

iii. The biodegradability of the composites showed a clear trend of increase degradation with increasing kenaf content in the formulation. While water-absorption values for the composites were higher than that of pure LDPE polymer, the addition of polyethylene glycol to the formulation reduced the water absorption of the composites. This shows that kenaf fiber has imparted its tensile strength to the elastomer composite system with good interaction provided by the compatibilizer agent. Scanning electron micrographs (SEMs) revealed that the improvement achieved in mechanical properties was due to the interaction between both matrix systems and kenaf fibre.

iv. Kenaf stem can replace rubberwood particles up to 50% but the resin level must be kept at 10% or more because lower resin level (⩽8%) significantly decrease strength of the particleboard. Further, the results indicate that kenaf fiber reinforced concrete (KFRC) generally exhibits more distributed cracking and higher toughness than plain concrete. Scanning electron micrographs (SEM's) indicate that a good bond between the kenaf fibers and the surrounding matrix is achieved. The SEM's also provide interesting information regarding the mechanisms which contribute to the failure and post-peak behavior of the KFRC which may be beneficial to future modeling efforts. The research findings indicate that KFRC is a promising 'green' construction material which could potentially be used in a number of different structural applications.

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