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Enhancing Mechanical Strength of Materials for Construction using Agricultural Fiber Composites

David, O. Ojo

Dept. of Crop and Horticultural Sciences, Univ. of Ibadan, Ibadan, Nigeria.
do.ojo@ui.edu.ng; ojo.david@nihort.gov.ng

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Abstract

Agricultural biodegradable-filler is cost and environmentally efficient substitute to synthetic-fillers for material engineering applications. Mechanical strengths were therefore studied for agricultural fiber-composites that were made with different amounts of kenaf stem (KS), tamarind shell (TS) and resin (RS). Composites had varied percentage weights of KS (10 - 30%), a mix of TS (10%) and RS (60%). Tensile and impact strengths were carried out in respect to ASTMD3039 (2014) and ASTMD256 (2023) standard protocols respectively. Results indicated a significant correlation between kenaf filler composition and material strengths of the hybrid-composites. Composite of 20%KS possessed the most significant optimal mechanical performance compared to other hybrids. Hybrid composite tensile strength increased from 32.5MPa for 10%KS composite to 38.8MPa for 20%KS hybrid composite when compared with pure epoxy resin (check) 17.8MPa for 100%RS. The impact strength optimally and significantly increased from 2.55J for 10%KS composite to 4.48J for 20%KS composite, compared with check epoxy resin 1.06J for 100%RS. These results indicate significant improvements in hybrid composites mechanical strengths for material engineering applications to accelerate Africa's socio-economic transformation.

Keywords: Agriculture, Waste, Mechanic, Hybrid, Enhancement, Kenaf, Transformation

Introduction

Tamarind (*Tamarindus indica*) fruit has hard seed coat that is discarded as waste during agricultural food processing. Agricultural wastes such as tamarind hard seed coat offer a cost effective and sustainable bio-filler alternative towards mining pollution and safe guarding the environment of synthetic polymers in structural engineering fabrications. Agricultural waste discards could be transformed to mechanical strength usage in composites. There is therefore the need to assess different horticultural waste resources for economically excellent resource use efficiency in order to accelerate Africa's socio-economic transformation.

Significant amount of horticultural wastes are generated during kenaf (*Hibiscus cannabinus* L.) production that are either openly burnt or incinerated causing environmental hazards. Nonetheless, it is known that horticultural wastes as fibre-fillers could be alternative option for generating degradable composites that is environmentally friendly, sustainable, renewable and have a low carbon footprints live-cycle. Research shows that various biodegradable fillers could be used as alternative to synthetic fillers for material engineering (Abdal-hay *et al*., 2012, Amara *et al*., 2021, Sumesh *et al*., 2023). Although Kenaf has one of the most abundant wastes in horticultural production, research is dearth on its use to make biodegradable hybrid-composites that could have significant material engineering and sustainability (Domagała *et al*., 2021; Jing *et al*., 2023; Ayodeji, 2025) which could provide waste management efficiency and reduce air pollution from burning agricultural wastes (Khan *et al.,* 2025; El-Abbasy, 2023).

Research have shown agricultural waste-fibers strengthen properties in hybrid composites (Nguyen and Nguyen, 2021; Carotenuto *et al.,* 2024; Mylsamy *et al.,* 2024). Alkali (NaOH) treated composites produce higher tensile strength than untreated composites, which in turn improved the tensile and impact strengths adhesion properties of treated composites (Pinnell et al., 2005; Bekele *et al.,* 2023). This adhesion properties is attributed to the fibrillation enhancement induced by alkali treatment which in turn increases available surface area adhesion and thus improving adhesion (Sharma *et al.,* 2021). This study therefore evaluated the use of kenaf as a biodegradable filler substitute by evaluating mechanical and physical strength of composites for material engineering applications.

Methodology

The studies sites were located at Ibadan (lat. 7.45538160^{0}N and long. 3.85716511^{0}E, Elev. 180.43m asl.). Kenaf fibers, resin and tamarind seeds were sourced from the Institute of Agricultural Research & Training (IAR&T), Obafemi Awolowo University (OAU) and Ibadan environs.

Harvesting of kenaf stem (stalk) was done at 10 weeks after sowing (Fig.1), followed by retting (soaking in tap water) for 14days to get the bast separated from core fibre (Fig. 2). The kenaf stalks went through water retting and mechanical techniques through immersing the kenaf stalks in tap water such that the stalks underwent decay decomposition; mechanical techniques including cutting of the root system and extracting the bast fiber from the solid core.

Fig. 1: Kenaf freshly harvested

Fig. 2: Processed Bast and Core

The hard seed coat of tamarind after oven drying were ground to pass through a 0.25 mm mesh sieve ensuring uniform particle size that mixes well into the composite matrix. Poly-caprolactone (PCL) polymer used in this study had over 99.9% purity grade. After washing and dried, fibers were centrifugally milled into 10mm fine fragments to pass through a 0.25 mm mesh sieve and washed with alkaline NaOH accordingly (Bekele *et al.* 2023). Resin polymer and tamarind powders was machine mixed with the kenaf powder in varied proportions (Table 1). The Resin-Kenaf-Tamarind powder mixtures were molded by hydraulic press compression under high temperature. Tensile and impact strengths were carried out according to ASTMD3039 (2014) and ASTMD256 (2023) protocols respectively. Hardness was determined by Shore durometer according to ASTMD2240 (2021) standard.

Data were statistically analyzed for mean separation using DMRT probability (P) value of 5%.

Results and Discussion

Composition comparison of the different bio-polymers and fillers for formulating engineering application is as shown in Table 1.

Table 1. Bio-Composite Mixture Composition Formulation

Mix[1]	Fiber Content (%) KS	Bio-Filler (%) TS	Epoxy Resin (%) RS
0 (=Check/Pure Resin)	-	-	100
1	10	10	60
2	15	10	60
3	20	10	60
4	25	10	60
5	30	10	60

[1] Mix = Composition of bio-composites;

[2] KS = Kenaf stem, TS = Tamarind shell, RS = Resin

Tensile examination results indicated that bio-composites comprising kenaf fibers incorporated into PCL polymers at varied percentages showed differences in correlation relationship suitability for engineering fabrication applicability (Table 2). Tensile strength results for composites designations (5, 10, 15, 20, 25 and 30% KS) consistently increased with higher KS till 20%. Starting from a bench mark value 17.8 MPa for pure epoxy resin in table 2, tensile strengths significantly increased from 32.5 MPa for 10%KS to 38.8MPa for 20%KS. This significant increment signifies a positive relationship between KS composite and tensile strength, which therefore shows that as the KS percentage increases in the composite the material's ability to withstand stress increases (El-Abbasy, 2023). This observation proves enhanced structural strength and capacity to withstand deformation which are critical in material engineering. Composites with 20 and 25 %KS exhibited better tensile strength compared to lower 10 and 15 %KS, signifying the potency of kenaf fibre for higher mechanical material performance applications when compared to the epoxy. The significant increase in tensile strength with 20%KS could be due to optimal kenaf addition to material composition, adhesion properties and therefore improved bonding (Dhakal *et al.,* 2024).

Table 2: Composites Tensile Strength

Composite Mix[1]	Tensile Strength (MPa)
M0 (=Check/Pure Epoxy)	17.8e
M1	32.5d
M2	35.7c
M3	38.8a
M4	40.0a
M5	38.0b

[1] Mix = Composition of bio-composites; M0 = Pure Epoxy, M1 – M5 = Varied Composite Composition (Table 1).

The impact strength results clearly showed consistency in enhancement with increasing composite percent of kenaf stem (%KS) when compared with the epoxy value of 1.05J recorded (Table 3). There was a significant increment from 2.56J for 10%KS to 3.56J for 20%KS which signifies improved toughness and resistance to material fracture (Sharma *et al.* 2021). This increment recommends that 20%KS led to better optimal absorption of impact stresses, which is important for material engineering applications when impact resistance is a critical demand for structural engineering design. These significant enhancements are expected with 20%KS due to engineering material composition and refining techniques aimed at enhancing impact properties. The 20%KS composite, having the optimal tensile and impact strengths was due in part to kenaf adhesion properties attributed to the enhancement induced by alkali treatment technology which in turn increases available fibrillation surface area and thus improving adhesion bonding within the matrix.

There is a dearth of knowledge on the mechanisms underlining how factors such as fiber distribution and interfacial bonding influence dissipation of impact energy and energy absorption in materials science (El-Abbasy 2023; Vijay et al. 2021). Well oriented fiber properties with uniform distribution composition could distribute stress efficiently, thereby reducing crack and improve material toughness. Still, bonding between fibers and the matrix composition could facilitate effective external force transfer enhancing the material to withstand impact force. Furthermore, fiber length and aspect ratio properties could bridge cracks from impact forces and reinforce matrix structure. Elucidating these mechanisms could provide innovative technological advancements to drive Africa's socio-economic transformation if this achieved result is replicated consistently and optimized. This information provides engineering insights in optimizing composite formulations for continental if not worldwide innovative transformational applications.

Table 3 illustrates the impact energy results across different composite designations, reinforcing the significance of these findings in materials science and engineering.

Table 3: Composites Impact Strength

Composite Mix[1]	Impact Strength (J)
M0 (=Check)	1.06c
M1	2.55b
M2	3.07b
M3	4.48a
M4	4.44a
M5	3.30b

[1]Mix = Composition of bio-composites; M0 = Pure Epoxy, M1 – M5 = Varied Composite Composition (Table 1).

Conclusion

This presentation elucidates the potency of kenaf stem agricultural wastes as sustainable agricultural biodegradable-fillers for material engineering applications. It has been demonstrated that alkali-treated kenaf significantly improved the tensile and impact strengths of poly-caprolactone (PCL) resin in material science for engineering applications. The results proofed 20%KS composition bio-composites exhibit significant tensile and impact strengths enhancement properties a pathway to mitigate environmental pollution while advancing sustainable material for efficient material cost and sustainable environmental engineering.

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