



Mechanical properties of reinforced polyester and epoxy composites of corn (*Zea mays*) stalk fibre

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ABSTRACT

Utilization of the increased biomass of corn (*Zea mays* L.) after adoption of hybrid cultivars and to avoid problems like residue burning, its textile application can be explored for sustainable agriculture. Extraction of fibre was done by optimizing alkali extraction parameters. The effect of corn stalk fibre loading on the properties of composite material was analyzed. In epoxy resin composite sample, 10 g fibre loading with matrix resulted tensile strength as 4.33 MPa. With the increase in fibre loading in the matrix, material strength of fibre also increased, whereas the differential increase in flexural strength from 10–30 g was seen as 13.23 MPa in epoxy resin composite. The impact strength in epoxy resin composite of 10–20 g fibre loading was 30.92 J/m and 45.67 J/m thickness, respectively whereas at 30 g fibre loading impact strength was maximum i.e. 60.45 J/m thickness. In polyester resin composite, one layered composite sample (10 g fibre's volume) has 7.74 MPa tensile strength while two layered composite material have 15.09 MPa. Impact strength in three layered corn stalk composite material reinforced with polyester was much higher (60.29 J/m thickness) which is very appreciable for high impact/shock applications. From these results it was concluded that 100% corn stalk 3 layered composite sample have better mechanical properties than the other layered composites and can be used in high strength application if the fibre loading is increased in appropriate amount. It was also concluded that the epoxy resin applied specimens have better strength properties as compared to polyester resin specimen.

Key words: Corn stalk fibre, Flexural strength, Impact strength, Tensile strength

A survey by the Ministry of New and Renewable Energy (2009) found that a huge amount approximately 500–550 million tonnes of crop residue is generated annually in India on-farm and off-farm. Although the crop residue is used in many alternative ways such as cattle feed, cooking fuel, organic manure, for animal bedding, etc. Still nearly 234 millin/year is left available as surplus. The increased biomass production due to the introduction of hybrid cultivars pose challenges for its effective utilization in hybrid corn production areas of the country.

Fibre reinforced composites consist of fibre reinforcement and a polymer matrix. Their special advantage is their low cost, low density, good mechanical properties, biodegradability and low toxicity, etc. The hydrophilic nature of the natural fiber and the fiber loading also has impacts on the composite properties (Shalwan 2013, Norul Izani 2013).

High fiber loading is needed to attain good properties of NFPCs (Tawakkal *et al.* 2014.) Generally, the rise in fiber content causes improvement in the tensile properties of the composites (Shinoj *et al.* 2011). Appropriate techniques and parameters should be rigorously chosen to get the best characteristics of produced composite (Pattarachaiyakooop 2013).

The most commonly used polymers in natural fiber composites matrices is polyester resin. Bast fibers, given their high cellulose and low lignin content, are particularly suited to composite applications and are the most promising replacement for glass fibers in composites (Deyholos and Potter 2014). Polyester resin composites were also prepared with Jawar. Experiments of tensile and flexural tests were carried out, and the samples were compared with sisal and bamboo composites. The fibers were extracted by water retting and manual process. The composites present high strength and rigidity, suitable for lightweight applications compared to conventional sisal and bamboo composites (Prasad and Rao 2011).

Panthapulakkal *et al.* (2006) reported that wheat straw fiber reinforced polypropylene composites exhibit significantly enhanced properties compared to virgin polypropylene. These results indicated that wheat straw fibers can be used as potential reinforcing material for making thermoplastic composites. Sain and Panthapulakkal

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(2005) revealed that Plant fiber reinforced thermoplastic composites have gained much attention in structural applications such as building and automotive products. Agricultural residues such as wheat straw, bagasse, and corn stover can also be exploited as readily available natural fiber resources for similar applications. A study was conducted to analyze the mechanical properties of reinforced polyester and epoxy composites of hybrid corn stalk fibre in order to explore its possible application in making composites.

MATERIALS AND METHODS

Reinforcement material: For the effective transfer of load from matrix to the fiber high aspect ratio (length to diameter) is required. Corn stalk fibre was used as reinforcement material for the current study, and it was extracted in the laboratory of NITRA, Ghaziabad.

Matrix materials: Fibers alone are not able to transmit load to one another and require some binding material to transmit the load between them. Matrix serves this function in case of composites. Mechanical properties of composites strongly depend upon the matrix to be used. Matrix is formed basically by combination of some resin and hardener. For the current experiment, samples were prepared by using two different resins i.e. epoxy resin and polyester resin with their respective hardeners. The Epoxy resin- B-11 Bisphenol-A (epichlorohydrin) and polyamide hardener and the base polyester resin, accelerator (Cobalt Octoate) and catalyst (Methyl Ethyl Ketone Peroxide (MEKP)) were obtained from Kailshpati polymers Ghaziabad, Uttar Pradesh.

Experimental calculation for fiber and matrix weight fractions: Fibre and matrix weight fractions were calculated for each category samples. Detailed calculation for each category is explained here.

Epoxy resin sample: Matrix was made by mixing well 75% by weight of B-II Bisphenol-A (epichlorohydrin) epoxy resin and 25% by weight of hardener polyamide by volume fractions respectively.

Amount of B-11 Bisphenol-A-(epichlorohydrin) epoxy resin taken = 18.75ml

Amount of Polymide added = 6.25 ml

Total amount of matrix = Amount of epoxy resin + Amount of Polyamide hardener

= (18.75 + 6.25) ml

= 25 ml

So,

Weight of matrix used (Wm) = 25 gm

Weight of fibre = 10 gm

So,

Weight of composite (WC) = Weight of matrix (wm) + Weight of fibre (wf)

WC = wm + wf

= (25+10) gm

= 35 gm

So, Weight fraction of fibre will be:

WF = wf/WC

WF = $\frac{10}{35} \times 100$

= 28.5%

So weight fraction of matrix will be

WM = $\frac{wm}{WC}$

= $\frac{25}{35} \times 100$

= 71.5%

Polyester resin sample: Sample of second category were made by unsaturated polyester and methyl ethyl ketone peroxide. Matrix was made by mixing well 98% by weight of polyester resin and 2% by weight of hardener polyamide by volume fractions respectively.

Amount of Polyester resin taken = 24.50 ml

Amount of methyl ethyl ketone peroxide (MEKP) added = 0.50 ml

Total amount of matrix = Amount of polyester resin + Amount of methyl ethyl ketone

peroxide (MEKP) Polyamide hardener

= (24.50 + 0.50) ml = 25 ml

So weight of matrix used (Wm) = 25 gm

Weight of fibre = 10 gm

So weight of composite (WC) = Weight of matrix (wm) + Weight of fibre (wf)

WC = wm + wf

= (25+10) gm

= 35 gm

So weight fraction of fibre will be:

WF = $\frac{wf}{WC}$

WF = $\frac{10}{35} \times 100$

So weight fraction of matrix will be

WM = $\frac{wm}{WC}$

WM = $\frac{25}{35} \times 100$

= 71.5%

Method of composite making: Corn stalk fibre was carded one time on carding machine (modal) to obtain smooth web. The web was cut into 10 × 12 inch size mats. 2–3 of these mats were placed on top of each other based on the desired layered composite. Resin and hardener were mixed in different required ratio and applied on each mat one by one. Mats were sandwiched between two aluminum/ Teflon sheets (having applied silicon oil) and set to cut at compression-molded machine to form the composites. Molding was done at 150°C for 10 minutes. After heating, molding was immediately cooled by running cold water followed by keeping it in the refrigerator.

Testing of the developed composite material: Composite material made with blending the fibre with polyester and cotton in different percentages as well as 100% corn stalk fibres were analysed for properties like

tensile strength, elongation at break, flexural strength, and impact strength.

Tensile strength (ASTM D-638): Five dumbbell-shaped test specimens were prepared by die cutting machine in both the directions from the material. The width of the narrow section of the die was 6.00 ± 0.05 mm (0.250 ± 0.002 inch). Before the Testing, specimens were conditioned in accordance at $23 \pm 2^\circ\text{C}$ and $50 \pm 5\%$ relative humidity for 40 h prior to test in accordance with procedure. The width and thickness of each specimen were measured using the applicable test methods. Poisson's Ratio was determined at a speed of 5 mm/min. The specimen was placed in the grips of the testing machine and the grips were tightened evenly and firmly. Biaxial extensometer or the axial and transverse extensometer was attached in combination to the specimen. The test was run at 5 mm/min out to a minimum of 0.5% strain before removing the extensometers.

$$\text{Tensile strength} = \frac{\text{Maximum load (N)}}{\text{Cross sectional area (Width} \times \text{thickness)}} \quad (\text{N/mm}^2 \text{ or MPa})$$

Flexural Strength Test (ASTM D-790): Method 1A three point loading system was used to test the specimen. Micrometers of least count 0.025 mm (0.001 inch) were used for measuring the width and thickness of the test specimen. Test specimens were conditioned at $23 \pm 2^\circ\text{C}$ ($73.4 \pm 3.6^\circ\text{F}$) and 50–65% relative humidity for 40 hrs prior to test in accordance with procedure. The gage length and speed (5mm/min) was set accordance to specimen. Readings were noted down and calculated according to width and length of the specimen.

Flexural Strength

$$s = \frac{3PL}{2bd^2}$$

where, s = stress in the outer fibers at midpoint, MPa [psi], P = load at a given point on the load-deflection curve, N [lbf], L = support span, mm [inch], b = width of beam tested, mm [inch], and d = depth of beam tested, mm [inch]. Unit = N/mm^2 or MPa.

Izod Impact (Notched) ASTM D256: Izod Impact Testing (Notched Izod) ASTM D256 is a common test to understand notch sensitivity in composites. It is a single point test that measures a materials' resistance to impact from a swinging pendulum. Izod impact is defined as the kinetic energy needed to initiate fracture and continues the fracture until the specimen is broken. Izod specimens are notched to prevent deformation of the specimen upon impact. This test can be used as a quick and easy quality control check to determine if a material meets specific impact properties or to compare materials for general toughness.

The specimen is clamped into the pendulum impact test fixture with the notched side facing the striking edge of the pendulum. The pendulum is released and allowed to strike through the specimen. If breakage does not occur, a heavier hammer is used until failure occurs. Since many materials (especially thermoplastics) exhibit lower impact strength at reduced temperatures, it is sometimes appropriate

to test materials at temperatures that simulate the intended end-use environment.

The standard specimen for ASTM is $64 \times 12.7 \times 3.2$ mm. The most common specimen thickness is 3.2 mm (0.125 inch), but the preferred thickness is 6.4 mm because it is not as likely to bend or crush. The depth under the notch of the specimen is 10.2 mm. The standard specimen for ISO is a type 1A multipurpose specimen with the end tabs cut off. The resulting test sample measures $80 \times 10 \times 4$ mm. The depth under the notch of the specimen is 8 mm.

ASTM impact energy is expressed in J/m or ft-lb/in. Impact strength is calculated by dividing impact energy in J (or ft-lb) by the thickness of the specimen. The test result is typically the average of 5 specimens.

ISO impact strength is expressed in kJ/m^2 . Impact strength is calculated by dividing impact energy in J by the area under the notch. The test result is typically the average of 10 specimens. The higher the resulting numbers the tougher the material.

RESULTS AND DISCUSSION

Optimization of epoxy resin and hardener ratio: According to purpose resin to hardener ratio were optimized (Table 1). Optimized samples were assessed by staff of NITRA Institute by manual hand touch method. Based on the observation of the respondents, samples made with the 1:4 (resin:hardener) were selected. Sample was optimum hard with giving good smoothness, below this ratio, composite sample was delicate and flexible and above the 1:4, sample was becoming hard before curing. So, 1:4 ratio of resin and hardener was selected to make the further combination of composite samples.

Mechanical properties of corn stalk fibre composites reinforced epoxy resin: At 10 g fibre loading with matrix resulted in a tensile strength of 4.33 MPa (Table 2). With the increase in the fibre loading in the matrix, the material strength of the fibre also increased. It was found that if fibre loading is increasing, the strength of composite also increases. The similar tendency was also seen in impact strength and flexural strength of the composite material.

Mechanical properties of corn stalk fibre composites reinforced polyester resin

The effect of increasing fibre loading in composite material was tested (Table 3). From the results it was found that as fibre loading is increasing mechanical properties of composite material improves. One layered composite sample

Table 1 Optimization of different resin and hardener ratio

Resin	:	Hardener	Weight of web (g)
1	:	1	10
1	:	2	10
1	:	4	10
1	:	6	10
2	:	1	10

Table 2 Effect of fibre loading on mechanical properties of corn stalk fibre composites reinforced epoxy resin

Fibre loading	Weight of fibre (g)	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (J/m thickness)
One layered	10	4.33	6.33	30.92
Two layered	20	9.56	13.09	45.67
Three layered	30	15.23	19.56	60.45

(10 g fibre's volume) has 7.74 MPa tensile strength. Two layered composite material have 15.09 MPa. As it increases from one to three layer composite material tensile strength increases to 21.20 MPa.

Both flexural and impact strength have trend similar to tensile strength testing results, as fibre loading increases, strength also increases. Flexural strength of 1 layered composite material was 10.96 MPa. As layer of fibre is increased flexural strength also increased upto a certain limit. The impact strength of 1 layered composite was 20.45 J/m thickness which is lower than the other higher layered composites. Impact strength in 3 layered corn stalk composite material reinforce with polyester was found to be 60.29 J/m thickness which is very appreciable for high impact/shock applications.

Tensile strength, impact strength and flexural strength of the corn stalk fibre reinforced epoxy and polyester resin composites showed that these composite materials could be used for high strength applications.

REFERENCES

Deyholos M K and Potter S. 2014. Engineering bast fiber feedstocks

Table 3 Effect of the fibre loading on mechanical properties of 100% corn stalk fibre composites reinforced polyester resin

Fibre loading	Weight of Fibre (gm)	Tensile Strength (MPa)	Flexural strength (MPa)	Impact strength (J/m thickness)
One layered	10	7.74	10.96	20.45
Two layered	20	15.09	19.07	41.03
Three layered	30	21.20	32.25	60.29

for use in composite materials. *Biocatalysis and Agricultural Biotechnology* 3(1): 53–7.

Ministry of New and Renewable Energy report. 2009.

Panthapulakkal S, Zereskian A and Sain M. 2006. Preparation and characterization of wheat straw fibers for reinforcing application in injection molded thermoplastic composites. *Bioresource Technology* 97(2): 265–72.

Prasad A R and Rao K M. 2011. Mechanical properties of natural fibre reinforced polyester composites: Jowar, sisal and bamboo. *Materials & Design* 32(8–9): 4658–63.

Sain M and Panthapulakkal S. 2005. Bioprocess preparation of wheat straw fibers and their characterization. *Industrial Crops and Products* 23(1): 1–8.

Shalwan A and Yousif B F. 2013. In state of art: mechanical and tribological behaviour of polymeric composites based on natural fibres. *Materials & Design* 48: 14–24.

Shinoj S, Visvanathan R, Panigrahi S and Kochubabu M. 2011. Oil palm fiber (OPF) and its composites: a review. *Industrial Crops and Products* 33(1): 7–22.

Tawakkal I S M A, Cran M J and Bigger S W. 2014. Effect of kenaf fibre loading and thymol concentration on the mechanical and thermal properties of PLA/kenaf/thymol composites. *Industrial Crops and Products* 61: 74–83.