

Fracture Behaviour of Walnut Particle (*Juglans regia* L.) and Coconut Fibre Reinforced Biocomposite

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Abstract

In this paper, an edge cracked rectangular specimen subjected to symmetric three-point bending and asymmetric four point bending were used to determine the mode I and mode II fracture toughness of walnut particulate and coconut fibre reinforced biocomposite. Epoxy resin was used as matrix material and 10 wt % of coconut fibre and 20 wt % of walnut shell content were as reinforcing material. Scanning electron microscopy (SEM) shows that the walnut particles were well dispersed in the epoxy resin matrix. Addition of walnut particles increased the modulus of elasticity of the bio biocomposite. The fracture toughness (K_{IC}) and mechanical test were conducted in a servo hydraulic universal testing machine and the results were analysed and discussed.

Keywords: Fracture Toughness, Biocomposites, Walnut particle, Coconut fibre, SEM.

Introduction

The presence of flaws and cracks are very often inevitable in engineering structures and components. The cracks can be generated during the manufacturing processes or due to cyclic loading or environmental causes, etc. Pure mode I and pure mode II are two modes of deformation that take place for a cracked component subjected to in-plane loading. Fracture toughness is usually used for measures of material resistance to extension of a crack. The stress intensity factor is mostly used as a fracture parameter. The material deformation behaviour describes which parameter to be used for fracture toughness and fracture method. For brittle fracture, the fracture toughness is characterized by the stress intensity factor. A limited research on the fracture toughness studies of biocomposites is available in the literature [1-6].

Use of fracture mechanics methods in engineering design and analysis requires fracture toughness to serve as a material property. In this paper, the fracture toughness behaviour under mode I and mode II loading conditions are determined and examined for walnut particulate and coconut fibre reinforced hybrid biocomposite.

Nomenclature

a	crack length
W	specimen width
a/W	crack aspect ratio
KI	mode I stress intensity factor
KII	mode II stress intensity factor
KIc	mode I fracture toughness
KIIc	mode II fracture toughness
P, F	applied load

B	specimen thickness
f_I	mode I geometry factor
f_{II}	mode II geometry factor
L1, L2, L3, L4	distances between loads and crack
M	bending moment at the crack plane
Q	shear force at the crack plane
wt. %	weight percent (%)

Material and Method

In this study 20 wt % of walnut particles and 10 wt% of coconut fibre were added as reinforcing material in epoxy resin CY 230 and hardener HY 951. Hardener was mixed in the solution at 40 °C which were pre heated to 100 °C and hold for 2 hours at 100 °C.



Fig.1. Moulding box for pouring solution

The solution thus obtained was used to cast sheet in a mould of size 300 mm x 250 mm x 10 mm [Fig. 1] made from Perspex sheet. After curing, the composite sheet was used for different tests to fulfil the objectives of the present investigation. Detailed procedure of casting and curing process is described in the reference [7-8]

Mechanical Properties:

Tensile test are conducted in 100 kN universal testing machine (ADMET Make, USA) according to ASTM standard at 0.5 mm/min cross head speed. The specimen geometry used is shown in Fig.2. Different dimensions are L= 50 mm, A= 100 mm².

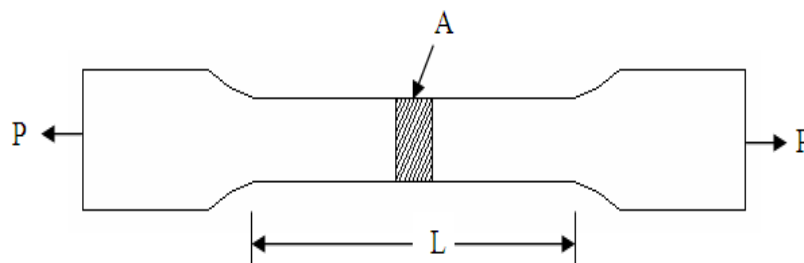


Fig.2. Specimen geometry for tensile test

Stress strain behaviour and micrographs of the tensile fracture surface are shown in Fig. 3 & 4. Ultimate tensile strength of walnut particle and coconut fibre biocomposite yields an average value of 24.43 MPa with coefficient of variance 16.06%.

Table 1. Mechanical Properties for Tensile Test

Properties	Materials					
	Epoxy			Biocomposite		
	Mean (MPa)	Variance	$\frac{\sqrt{S_p}}{x_p} \times 100$	Mean (MPa)	Variance	$\frac{\sqrt{S_p}}{x_p} \times 100$
Yield Strength	5.57	0.12	6.4	4.92	0.20	9.01
Ultimate Strength	44.93	1.43	2.65	24.43	15.38	16.06
Modulus of Elasticity	1632.75	361.81	1.16	1411.22	87467.93	20.96

The ultimate strength obtained by adding 20 wt% walnut particles and 10 wt% coconut fibre in epoxy resin is about 70% of the pure epoxy resin. The modulus of elasticity of biocomposite is found to be 1411.22 MPa as compared to 1632.75 MPa of epoxy resin are shown in Table 1.

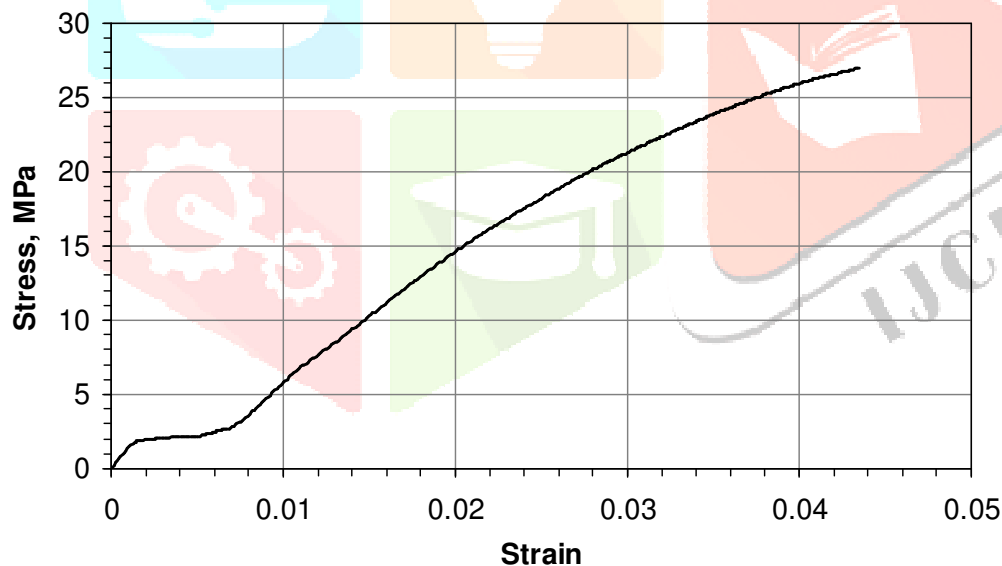


Fig.3. Variation of stress strain curve for tensile strength of Biocomposite material.

These results indicate that though there is a loss of strength due to addition of walnut particles and coconut fibre but the modulus of elasticity remains almost same as of the pure epoxy. The variance coefficients of ultimate strength and modulus of elasticity are 16.06% and 20.96% for biocomposite respectively. These values are at higher side as compared to metals. The higher variance indicates that the composite material made from walnut particle and fibre material failed because of the pullout or breaking of fibre from the matrix material and the dispersion of walnut particles in presence of coconut fibre in epoxy resin. The composite

failure mechanism thus can be attributed to the uniform distribution of fibre and or particles and thus the distribution of both reinforcing material in the epoxy plays a very important role in the load shearing phenomena. This can be seen from the micrographs shown in Fig. 4.

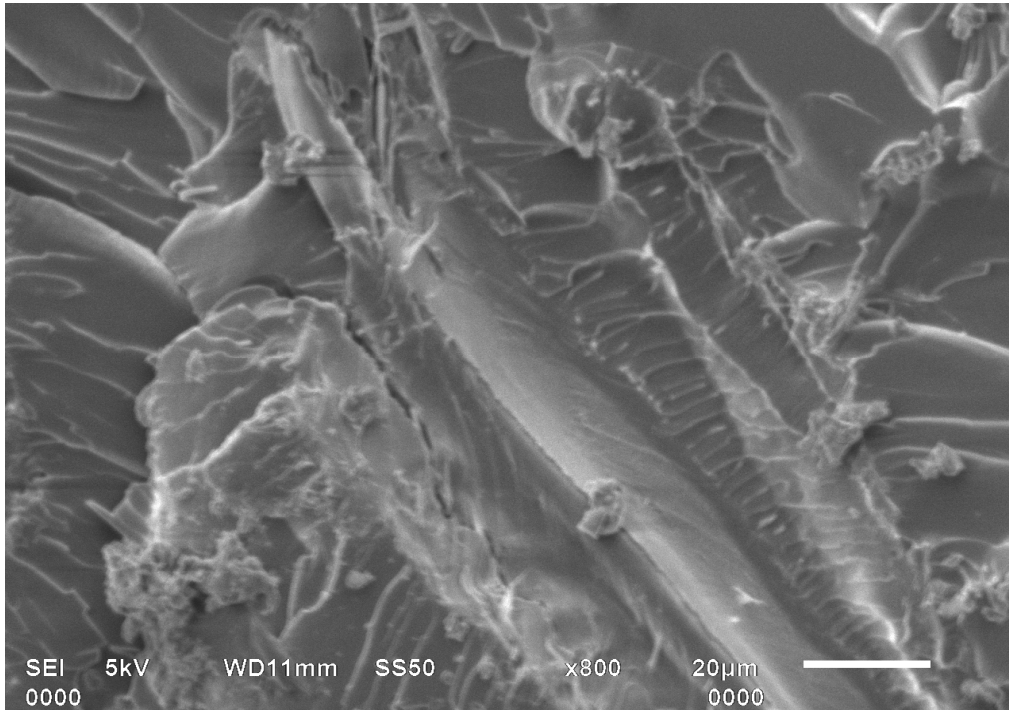


Fig. 4. Scanning electron microscopic (SEM) test for tensile specimen

To get a closer overview of the phenomena, the scanning electron micrographs of tensile fracture specimen are shown in Fig. 4. The Fig. 4 clearly indicates that walnut particles are strongly bonded to the fibre and pull out failure of the fibre.

Fracture Toughness:

The specimens used for fracture experiments are described in this section. The notched three-point bend specimen (Fig. 5a) was employed for mode I fracture experiments and the single-edge notch bend specimen under four-point bend (FPB) loading (see Fig. 5b) was used for determining mode II fracture resistance of the biocomposite. When the FPB specimen is subjected to anti-symmetric loading (i.e. $L1 = L4$ and $L2 = L3$), bending moment vanishes along the crack plane and there is only a shear force at the crack position. This gives the mode II fracture toughness value.

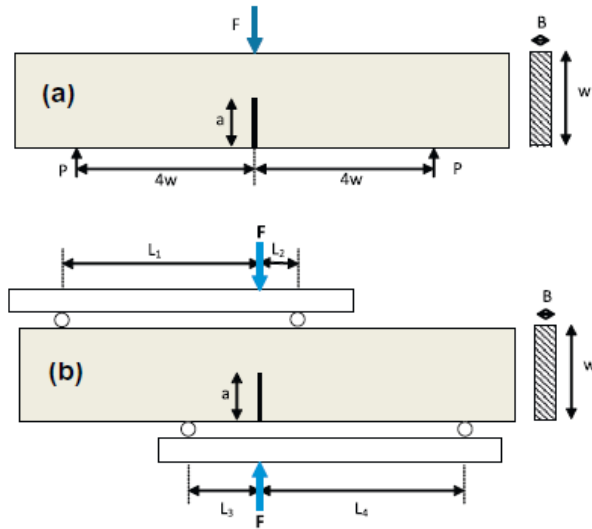


Fig.5. (a) three-point bend specimen (pure mode I) (b) four point bend specimen (mode II).

From the static equilibrium equations, the shear force Q and the bending moment M at the crack plane can be written in terms of the force F as

$$Q = F \left(\frac{L_1}{L_1 + L_2} - \frac{L_3}{L_3 + L_4} \right) \quad (1)$$

$$M = F \left(\frac{L_1 L_2}{L_1 + L_2} - \frac{L_3 L_4}{L_3 + L_4} \right) \quad (2)$$

The stress intensity factors (K_I , K_{II}) for the FPB specimen can be written as

$$K_I = \frac{M}{BW^2} f_I \left(\frac{a}{W} \right) \quad (3)$$

$$K_{II} = \frac{Q}{BW^2} f_{II} \left(\frac{a}{W} \right) \quad (4)$$

where the non-dimensional functions $f_I(a/W)$ and $f_{II}(a/W)$ are called the mode I and mode II geometry factors. On the basis of finite element analyses of the reference problem following relations were presented for $f_I(a/W)$ and $f_{II}(a/W)$ by fitting a fourth order polynomial to the numerical results by [9]

$$f_I \left(\frac{a}{W} \right) = 139.89 \left(\frac{a}{W} \right)^4 - 380.21 \left(\frac{a}{W} \right)^3 + 249.87 \left(\frac{a}{W} \right)^2 - 70.54 \left(\frac{a}{W} \right) \quad (5)$$

$$f_{II} \left(\frac{a}{W} \right) = 10.27 \left(\frac{a}{W} \right)^4 - 16.29 \left(\frac{a}{W} \right)^3 + 10.01 \left(\frac{a}{W} \right)^2 - 1.18 \left(\frac{a}{W} \right) \quad (6)$$

In the present investigation, for $a/W = 0.5$, the numerical values of $f_I \left(\frac{a}{W} \right)$ and $f_{II} \left(\frac{a}{W} \right)$ are obtained from Equations (5) and (6) as -11.59 and 1.69 respectively.

Five tests for each mode I and mode II were conducted. For three point bending, all fracture toughness test were conducted for as crack length a , width W and thickness B are 7.525 mm, 15.05 mm and 10.75 mm respectively. For four point bending, $L_1 = L_4 = 20$ mm and $L_2 = L_3 = 10$ mm, crack length $a = 4$ mm, thickness $B=10$ mm and width $W= 9$ mm were taken. The load

displacement curve under three point bending and four point bending are shown in Fig. 6. Under three point bending, the failure load varies from 108.8 N to 155.2 N whereas under four point bending, the failure load varies from 578 N to 1970 N. Thus the values of K_{IC} under the three point bending are found to be varied between $0.879 \text{ MPa}\sqrt{\text{m}}$ to $1.277 \text{ MPa}\sqrt{\text{m}}$. The values of K_{IC} under the four point bending are found to be varied between $0.75 \text{ MPa}\sqrt{\text{m}}$ to $1.08 \text{ MPa}\sqrt{\text{m}}$.

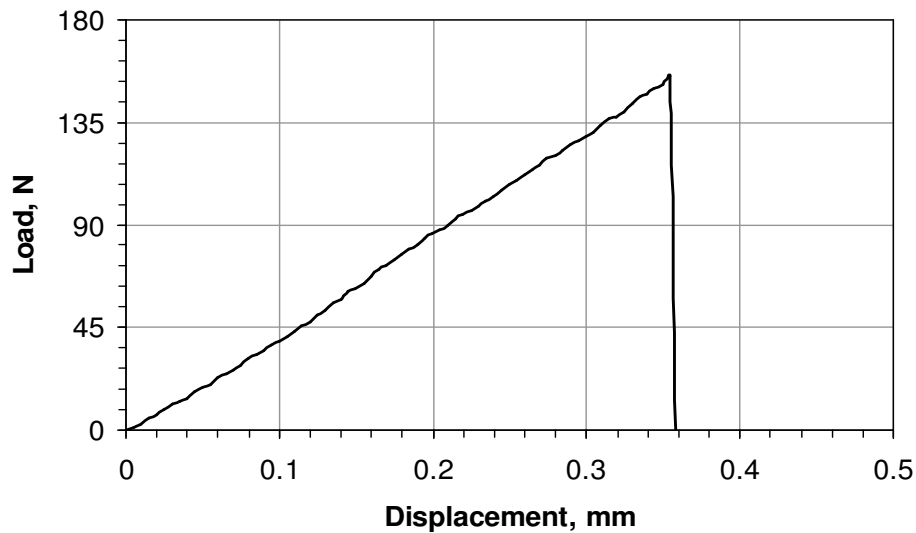


Fig. 6. Variation of load displacement curve for three point bend specimen.

In the three point bending the average, variance and coefficient of variance of K_{IC} are $1.05 \text{ MPa}\sqrt{\text{m}}$, $0.04 \text{ MPa}\sqrt{\text{m}}$ and 19.32% $\text{MPa}\sqrt{\text{m}}$ respectively.

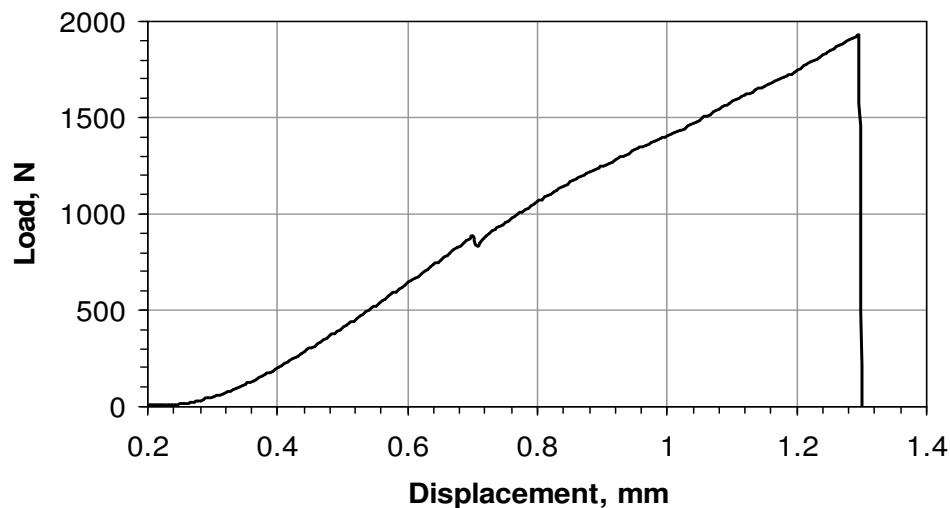


Fig. 7. Variation of load displacement curve for four point bend specimen.

In four point bending the mean, variance and coefficient of variance for K_{IIc} are $0.63 \text{ MPa}\sqrt{\text{m}}$, $0.10 \text{ MPa}\sqrt{\text{m}}$ and 51.05% $\text{MPa}\sqrt{\text{m}}$ respectively. The ratio of K_{II}/K_I are found to varies between $0.58 \text{ MPa}\sqrt{\text{m}}$ to $1.22 \text{ MPa}\sqrt{\text{m}}$ for present material which are very closed to pure epoxy resin or PMMA as reported by other authors [9].

Mode I and Mode II fracture Surface Analysis

Fig.8 shows fracture surface of mode I and mode II specimen tested under three point bending and four point bending respectively. Fig.8 reveals that the failure occurs due to pull out of the particles and fibres without noticeable plastic deformation. The plastic deformation could not be noticed because of the presence of hard walnut particles in the matrix material. The material in front of crack tip under the presence of hard particles of wall nut shell, the crack propagates through the matrix material leaving almost negligible plastic deformation.

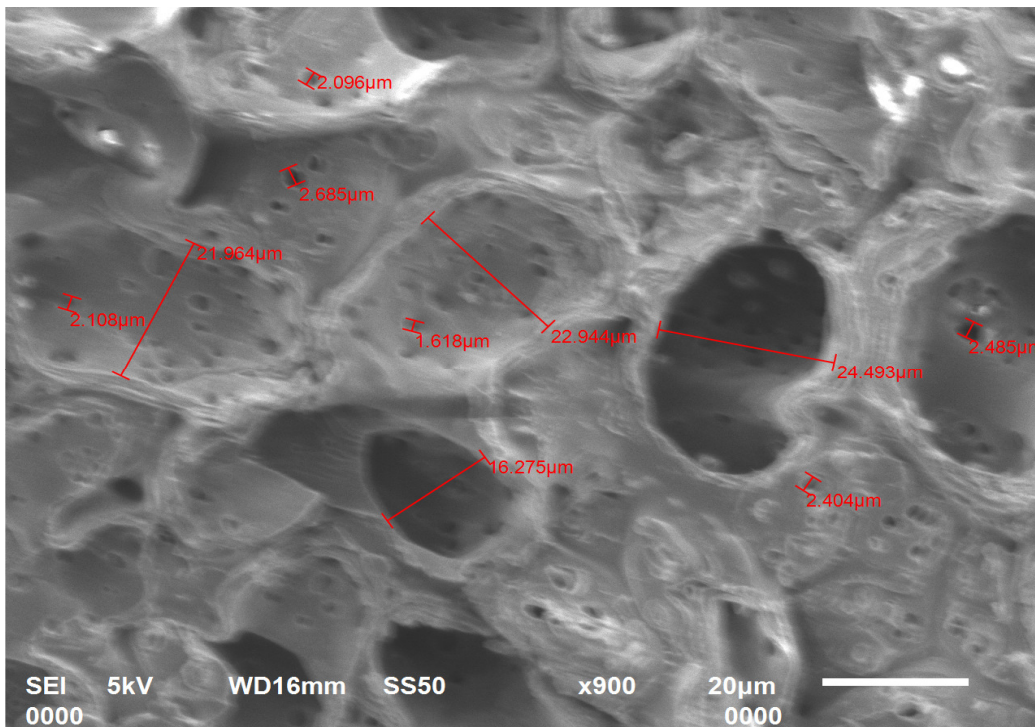


Fig. 8 Scanning Electro micrographs of fracture surface under mode I failure

Fig. 8 shows the fracture surface of four point bend specimen tested under pure mode II condition. Some pullout failure of the fibre and particles are also seen in Fig.8. This type of combination of the failure mode of the fibres may be because of poor interfacial adhesion with matrix material. Thus in four point bending the fibres split into two pieces instead of de-bonding in the crack path.

Conclusions

The present study shows that 20 wt% walnut particle and 10 wt% coconut fibre mixed in epoxy resin improve the mechanical properties as well as fracture toughness. The experimental result of study indicated that about 43% of tensile strength can be retained without lose in modulus of elasticity as compare to pure epoxy resin. In this paper, especial emphasis was placed

on mode I and mode II fracture toughness of epoxy/biocomposite. The average fracture toughness value of mode I and mode II are $1.04 \text{ MPa}\sqrt{\text{m}}$ and $0.76 \text{ MPa}\sqrt{\text{m}}$.

References:

- [1] Shadlou S, Alishahi E, Ayatollahi M.R., Fracture behaviour of epoxy nanocomposites reinforced with different nano-reinforcements, *Composite Structure*, 95(2013), 577-581.
- [2] Xian-Kui Zhu, James A. Joyce, Review of fracture toughness (G, K, J, CTOD, CTOA) testing and standardization, *Engineering Fracture Mechanics*, 85(2012), 1-46.
- [3] Omar F, Andrzej K.B., Hans- Peter Fink, Mohini Saini, Biocomposites reinforced with natural fibres: 2000-2010, *Progress in Polymer Science*, <http://dx.doi.org/10.1016/J.Prog Polym Sci. 2012.04.003>.
- [4] Lim IL, Johnston IW, Choi SK, Boland JN. Fracture testing of a soft rock with semi-circular specimens under three-point bending, part 2 – mixed mode. *Int J Rock Mech Min Sci Geomech Abstr 1994;31(3):199–212*.
- [5] Aliha MRM, Ayatollahi MR, Smith DJ, Pavier MJ. Mixed mode crack path investigation in a limestone rock using two circular shape samples – An experimental and theoretical study. *In: International conference on crack paths (CP 2009). Vicenza, Italy*.
- [6] Lim IL, Johnston IW, Choi SK. Stress intensity factors for semi-circular specimens under three-point bending. *Engng Fract Mech 1993;3:363–82*.
- [7] Vinay Kumar Singh and Prakash Chandra Gope; Silica-Styrene-Butadiene Rubber Filled Hybrid Composites: Experimental Characterization and Modeling, *Journal of Reinforced Plastic and Composites*, Vol. 29, No. 16/2010, pp 2450-2468.
- [8] P.C. Gope and V.K. Singh, Effect of filler addition and strain rate on the compressive strength of silica-styrene butadiene rubber filled epoxy composites, *Journal of Polymer Engineering and Science*, Vol. 51, Issue 6, pp 1130-1136, June 2011.
- [9] M.R. Ayatollahi , S. Shadlou , M.M. Shokrieh, Mixed mode brittle fracture in epoxy/multi-walled carbon nanotube nanocomposites, *Engineering Fracture Mechanics* 78 (2011) 2620–2632.
- [10] Dinesh Kumar Rao, “Tensile, Compressive and Flexural Behaviour with Characterization of Hybrid Bio-Composite Reinforced with Walnut Shell Particles and Coconut Fibres”. *In the proceedings of International Society of Agile Manufacturing, Conference on Advanced and Agile Manufacturing System, KNIT Sultanpur support on TEQIP-II, International Society of Agile Manufacturing (ISAM), Dec 28-29, 2015, p310-314. ISBN:978-93-85777-03-5*.
- [11] Dinesh Kumar Rao, Prakash Chandra Gope, “Fracture Toughness of Walnut Particles (*Juglans regia* L.) and Coconut Fibre Reinforced Hybrid Biocomposite ”. *Journal of Polymer Composites*, 2014, DOI 10.1002/pc.22926, Volume 36, Issue 1, pages 167–173, January 2015, Online ISSN: 1548-0569.
- [12] Prakash Chandra Gope and **Dinesh Kumar Rao**, “Fracture behaviour of epoxy biocomposite reinforced with short coconut fibres (*Cocos nucifera*) and walnut particles (*Juglans regia* L.)” *Journal of Thermoplastic Composite Materials*, pages 1-20, 2November 2014, DOI: 10.1177/0892705714556835, ISSN-ISBN: 1-56676-669-9.
- [13] Prakash Chandra Gope, Vinay Kumar Singh, **Dinesh Kumar Rao**, “Mode I Fracture Toughness of Bio-fiber and Bio Shell Particle Reinforced Epoxy Bio-composites” *Journal of Reinforced Plastics and Composites*, July 2015, Vol. 34 no. pages 131075-1089, Dec 3, 2014, DOI: 10.1177/0731684415586277.

[14] **Dinesh Kumar Rao**, Sanjeev Kumar, “Mechanical Behaviour of Hybrid Bio-composite Reinforced with Walnut (*Juglans regia* L.) Shell Particle and Coconut Fibre”. *In the proceedings of International Journal on Emerging Technologies (Special Issue NCETST-2017) 8(1): 604-608(2017), ISSN No. (Print): 0975-8364, ISSN No. (Online): 2249-3255.*

