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Mechanical, wear & thermal behaviour of Hemp fibre/egg shell particles reinforced epoxy resin bio composite

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Abstract

The aim of this present work is to examine the mechanical, tribological and thermal behaviour of hemp fibre reinforced egg shell epoxy polymer composites. Experiments are carried out to study the effect of fiber and filler volume percentage on mechanical, wear and thermal behaviour of epoxy based polymer composites. The volume of fibre and filler is varied by 30%, 40% & 50% and 0.25%, 0.5% & 1.0%. The specimens are fabricated by using hand layup technique. The specimens are expurgated according to ASTM standards. The mechanical test such as hardness, tensile, impact and flexural strength are evaluated and abrasive wear behaviour of the specimen was investigated using pin-on-disc machine. The thermal stability was evaluated using a thermo gravimetric analyzer. The effect of hemp fibre and filler were examined under different mechanical and thermal conditions. The mechanical results show that the addition of fibre increased the load bearing characters of epoxy resin. Whereas additions of egg shell filler increased thermal stability of composite.

Keywords: PMC; Hemp fibre; Egg shell particles, Mechanical properties.

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1. Introduction

In recent years, natural fibers and fillers are used as reinforcements in polymers, to improve the strength and reduce the cost of the material. Fiber reinforced polymers offer advantages over other conventional materials when specific properties are compared. These composites are finding applications in diverse fields from appliances to space crafts, automotive, aeronautical industries. Natural fibers are lightweight, low cost and strong related to synthetic fibers. Environmental concerns are increasing day by day and the demand of replacing the existing synthetic fibers with low cost natural fibers for fabrication of composite materials increases (Thomas 2010). Similarly the need of natural fillers also increases day by day because of their capability, ease of available nature and easy process parameters (Pedro 2009a and Manoj 2010b). Egg shell could be economical natural filler since it is waste from domestic side and also from commercial sector. The presence of $CaCO_3$ in egg shell enhances the thermal related properties of epoxy resin. Hand layup composite making could be an easy and effective process where limited processes parameters are exist. The tensile & flexural properties could be evaluated by a tensile tester following ASTM D 3039, similarly the impact properties could be evaluated by a mini impactor following ASTM D 256. The micro hardness of filler reinforced epoxy composite could be evaluated by shore-D hardness following ASTM D 2240. The thermal properties could be evaluated by a thermo gravimetric analyzer with temperature up to 600º. Bhoopathi et al (2014) studied the banana-hemp-glass fibers reinforced hybrid composites and to evaluate the mechanical properties such as tensile strength, flexural strength and impact strength. There are three different types hybrid laminates are fabricated by hand lay-up method by using glass, banana and hemp fibers as reinforcing material with epoxy resin. The size of the fabricated laminate is restricted to 300×300×4 mm. it can be observed that the banana-glass fiber reinforced composites are performing better than the other composites tested which can withstand the tensile strength of 39.5MPa followed by hemp-glass

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fiber reinforced composites can hold the strength of 37.5MPa. The maximum flexural strength of 0.51kN hold by the banana to hemp-glass fiber reinforced composites followed by banana-glass fiber reinforced composites which is having the value of 0.50 kN. Banana-hemp glass fibers reinforced hybrid epoxy composites can be used as an alternate material for synthetic fiber reinforced composite materials.

2. EXPERIMENTAL

2.1. Materials

The epoxy resin used for this study was a bis-phenol A type epoxy resin having density of 1.2g/cm^3. It is light yellowish liquid having kinematic viscosity of 12000Cps. Triethelenetetramine an aliphatic hardener having density of 0.9g/cm^{3}a colourless liquid was used as a curing catalyst. Hemp natural fibre woven mat (0-90º) of density 1.9g/cm^3 and specific heat capacity of 0.02 J/g.K was used as fibre reinforcement and procured from Natural fibres and resin Pvt. Ltd. India. Similarly egg shell particles of size 800nm, density of 2.59g/cm^3 and specific heat capacity of 0.8 J/g.K were procured from domestic side and used as secondary phase additions in hybrid composite. All chemicals were used in as-received condition and reinforcements were undergone some thermal pre treatments.

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2.2 Treatment of reinforcements.

The natural fibre and fillers were pre treated with a hot oven to remove acquired moisture. The Hemp natural fibre is subjected to heating up to 100ºC to remove moisture similarly the egg shell particles were pre heated up to 200ºC to remove entrapped moisture. The molecular state of egg shell was maintained at $CaCO_3$ for composite making (Ramesh 2017).

2.3 Composite fabrication

A fixed volume of epoxy resin along with variable volume percentage of hemp natural fibre and fillers were taken for composite making. Curing catalyst was added as 1:10 wt ratio to resin to cure. Silicone rubber moulds of various sizes were prepared and coated with wax. The fibre layers were laid one by one and pressed to remove excess resin which was applied already. All composites were cured at room temperature for 24Hrs and post cured for 48Hrs (Arun prakash 2016a and Devendra 2013b).

2.4 Specimen preparation

The prepared hemp fibre egg shell particles reinforced epoxy hybrid composites were taken from mould and checked for visual defects. Suitable dimensions as per ASTM standards were expurgated using an abrasive water jet machine (Maxiem water jets 1515, Kent, USA) with recommended process parameters (Mohamad 2009a and Sukhdeep 2014b). The designation and composition of hybrid epoxy composites were listed in table 1.

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3. Results and Discussion

3.1 Mechanical properties

Table 2 shows the tensile, flexural, impact and hardness values of hemp natural fibre and egg shell particles reinforced epoxy resin hybrid composite. Five identical specimens were used to take average values in mechanical properties. The tensile results revealed that additions of woven mat hemp natural fibre increased the tensile strength. The improved tensile strength of 21.5%, 35%, 42%, 45%, 48% & 42% were observed for composite designations RF, RF_1, RF_2, RFE_1, RFE_2 & RFE_3 respectively. Similarly the improved tensile modulus of 108, 112, 120, 127, 132 & 113 were observed for composite designations RF, RF_1, RF_2, RFE_1, RFE_2 & RFE_3 respectively. This is because of additions of hemp natural fibres improved the load sharing phenomenon in epoxy matrix. Due to woven mat form the load can share in all directions which lead the composites to with stand for large tensile loads (Shalwan 2013a, Arunprakash 2016b and Dhakal 2017c). It is observed that further additions of egg shell ceramic particles into epoxy resin increased the load bearing capacity. The dispersed fine 800nm egg shell particles were filled the cap in fibre and thus continuing the load sharing behaviour. It is noticed that at larger volume of 1.00 vol% the tensile strength and modulus dropped down. This is because of clustering of high volume fillers in matrix (Yan 2014). Similarly the modulus also improved because of load sharing capability of fibre in epoxy matrix.

The flexural strength results revealed that additions of hemp natural fibre greatly contributed in bending strength of epoxy resin composite. The results shows tremendous improvement near 100% for fibre reinforced epoxy composite. When fibre volume increases the flexural strength also increases. This is because of large load sharing behaviour of bi-directional fibres which could transfer the load in both axial and traverse directions (Weikang 2014). The Table 2 provides the values of impact strength. It is clearly identified that additions of hemp natural fibre increased the sudden loading behaviour of epoxy composite. The improvement of 76%, 78%, 80%, 79%, 76% & 74% were observed for composite designations RF, RF_1, RF_2, RFE_1, RFE_2 & RFE_3 respectively. This is because of improved crack suppression behaviour of reinforced hemp natural fibre. It is observed that a marginal decrement on impact property of egg shell particles reinforced epoxy resin composite. This decrement is because of clustering effect of egg shell particles on matrix and also quick crack propagation through the particles interface in matrix (Tehrani 2013). The hardness values of hemp natural fibre and egg shell particles reinforced epoxy composite shows remarkable changes. The hardness value of fibre reinforced epoxy composite is unchangeable because the macroscopic hemp natural fibre does not improve the hardness of matrix (Suresha 2006) whereas egg shell particles reinforced epoxy matrix composite gives improved hardness values. Average hardness of 2.3 (Shore-D) was recorded for every increase of egg shell filler loading.

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This is because of the hard ceramic particles gives resistance to deform in surface level and also increase of cross linking density (Songqi Ma 2015).

3.2 Wear properties

Figure 1 shows the wear values of hemp fibre and egg shell particles reinforced epoxy composite. The wear rate of pure epoxy measures 4.8micron/sec relatively it is large value. This high wear rate is because of very soft nature of epoxy molecules. It is observed that the additions of hemp natural fibre in to epoxy resin further decreased the wear rate. The improved wear resistance of 10%, 23%, 31%, 41%, 48% & 56% were observed for composite designations RF, RF_1, RF_2, RFE_1, RFE_2 & RFE_3 respectively. This improvement is because of reduced coefficient of friction due to lowering friction force. This lower frictional force is due to the presence of hemp natural fibre which reduced the contact area of resin to abrasion disc (Shalwan 2014a and Ramesh 2014b). Figure 2 shows the coefficient of friction values of hemp natural fibre and egg shell particles reinforced epoxy composite. It is observed that when reinforcement volume increases there is a reduction in coefficient of friction. Hence lower coefficient of friction thereby offering lower frictional force thus lower wear rate is observed. The lowered coefficient friction of 25%, 50%, 62%, 75%, 88% & 90% were observed for composite designations RF, RF_1, RF_2, RFE_1, RFE_2 & RFE_3 respectively.

3.3 Morphology

Figure 3 shows the scanning electron microscopy images of hemp natural fibre and egg shell particles reinforced epoxy resin hybrid composite. In this Figure 3(a) shows pure epoxy resin. The fractured surface shows flat which indicates brittle nature of epoxy resin. Figure 3(b) shows 800nm spherical egg shell particles. They show uniform spherical morphology. Figure 3(c) shows fractured portion of tensile tested hybrid composite. It indicates fibre pull out which says lower adhesion behaviour of hemp natural fibre with epoxy resin

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[Ramesh 2014a and Rahmanian 2014b). Figure 3(d) shows the worn out surface of fibre/egg shell particles reinforced epoxy resin composite which indicates fibre patches thus lowering the COF (Peerapan 2017).

3.4 Thermal properties

Table 3 shows the thermal values of pure epoxy, hemp natural fibre and egg shell particles reinforced epoxy resin composite. The glass transition and decomposition temperatures were noted by a DSC/TGA combined machine NETZSCH STA Jupitar 409 PL Luxx, Germany. It is observed that the mass loss at lower stages (300ºC) the neat epoxy resin gives larger value of 4.29%. Additions of hemp natural fibre into epoxy resin marginally lowering the thermal stability at this stage. The mass loss percentage of 4.6%, 4.9% & 5.2% were noted for composite designations RF, RF_1 & RF_2. This reduction is because of cellulose contain natural fibre could not resist for larger temperature (Mohan 2004). The values of glass transition also get decreased due to lower heat absorption behaviour of fibre reinforced epoxy resin composite. whereas additions of ceramic egg shell particles into epoxy resin matrix gradually increased the initial thermal stability of composite. The lowered mass loss of 4.7%, 4.3% & 3.4% were observed for composite designations RFE_1, RFE_2 & RFE_3. This improvement is because of heat acquisition of ceramic egg shell particles which can consume more heat energy thereby lowering the energy acquisition of epoxy secondary molecules. The glass transition values were increased 30%, 40% and 61% for composite designations RFE_1, RFE_2 and RFE_3 respectively. Since energy absorption is reduced in epoxy secondary molecules they hindered to rotate about its primary C-C chains thus lowering the thermal stability (Zhang and Kumar 2005a, 2015b) subsequently the incremental in thermal stability is observed in middle and final mass losses. Overall comparison the composite designation of RFE_3 shows better thermal stability values than neat epoxy and fibre reinforced epoxy resin.

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Conclusion

The following results are derived from the present study. Hemp natural fibre and egg shell particles reinforced epoxy resin hybrid composite were prepared and characterized. According to the mechanical properties additions of hemp fibre greatly contributes to improve the load bearing capabilities of epoxy resin composite whereas additions of egg shell particles also contributes marginally. The wear results of composites confirmed that additions of reinforcements lowering the coefficient of friction thereby increasing wear resistance. The morphological results shows fibre pull out in fractured composite portion thus indicates poor adhesion of fibre with matrix. the dispersion of egg shell particles on epoxy matrix is gentle and neat. The thermal values says that the additions of hemp fibre does not contribute more on improving the thermal stability whereas egg shell particles showed maximum interest in improving the initial mass loss stability. Thus the natural reinforcements are much useful to derive strengthened composites which useful in structural and industrial applications.

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Table 1. Composition and designation of composites

Material Designation	Epoxy (Vol %)	Hemp fiber (Vol %)	Egg shell (Vol%)	Particle size (nm)
R	100.00	0.0	0.00	-
RF	70.00	30.0	0.00	-
RF_1	60.00	40.0	0.00	-
RF_2	50.00	50.0	0.00	-
RFE_1	49.75	50.0	0.25	800
RFE_2	49.50	50.0	0.50	800
RFE_3	49.00	50.0	1.00	800

Table 2 Mechanical properties of Hemp/Egg shell particles reinforced epoxy resin hybrid composite

Material Designation	Tensile strength (MPa)	σ_{ts}	Tensile modulus (MPa)	σ_{tm}	Flexural strength (MPa)	σ_{fs}	Flexural modulus (MPa)	σ_{fm}	Izod Impact (Joules)	σ_I	Hardness (Shore-D)	σ_h
R	73	4.8	2827	8.4	103	3.9	2043	6.4	0.63	3.2	85	3.8
RF	93	5.2	5882	10.1	197	4.2	5346	6.8	2.62	3.0	85	3.2
RF_1	112	5.1	6002	9.3	209	4.4	5621	5.2	2.98	4.3	85	3.1
RF_2	126	4.3	6231	9.7	228	4.4	5904	5.0	3.21	4.5	85	3.1
RFE_1	133	4.6	6420	10.2	240	3.8	5920	6.1	3.00	3.8	87	3.0
RFE_2	142	5.1	6561	10.1	255	4.0	6130	6.0	2.69	3.1	89	3.2
RFE_3	126	4.7	6016	9.8	197	4.0	5672	6.0	2.50	3.4	92	3.2

σ- Standard deviation

Table 3 Thermal properties of Hemp fibre/Egg shell particles reinforced epoxy composite

Composite Designation	Tg (ºC)	Initial mass loss % (300ºC)	Middle mass loss % (450ºC)	Final mass loss % (600ºC)
R	63	4.28	62	33.7
RF	60	4.64	57	38.3
RF_1	58	4.91	38	57.0
RF_2	58	5.22	42	52.7
RFE_1	82	4.71	51	44.2
RFE_2	88	4.38	52	43.6
RFE_3	102	3.80	50	46.2

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Figure 1 Wear rate of composites

Figure 2 Coefficient of friction of composites

Figure 3 SEM images of (a) pure epoxy, (b) Egg shell particles, (c) Hemp fibre in epoxy fractured surface and (d) fibre patches on epoxy matrix.

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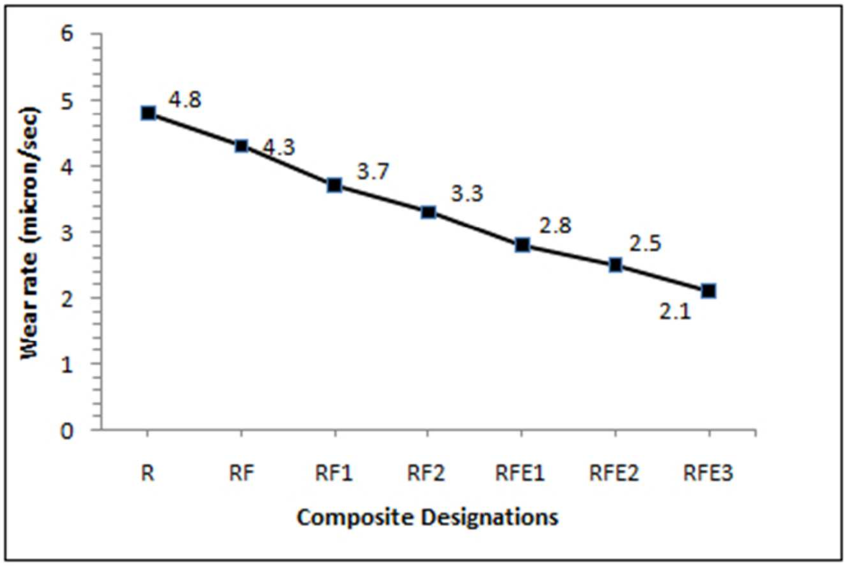

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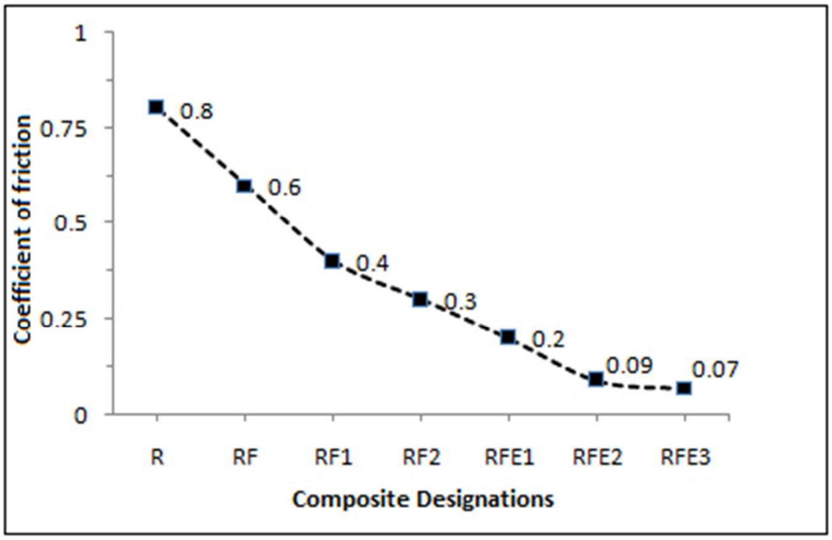

Figure 2 Coefficient of friction of composites

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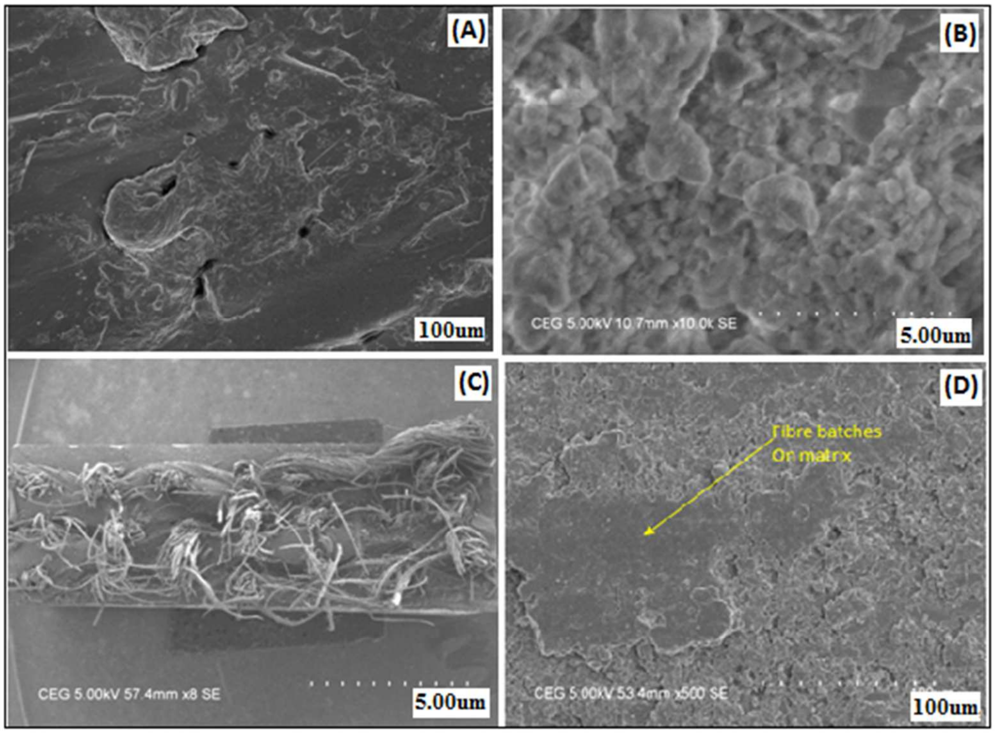

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