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JUTE/EGG SHELL BIOFILLER REINFORCED CEMENT-PAPER COMPOSITE AS SUSTAINABLE MATERIAL FOR APPLICATION IN AUTOMOBILE DASHBOARD: EXPERIMENTAL PERFORMANCE ANALYSIS (EPA)

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Abstract

Alternative automobile dashboard material was developed by incorporation of egg shell biofiller/jute fiber in the proportion of 20/0, 20/1, 20/2, 20/3, 20/4, 20/5 % into paper-cement composite and cured for 10, 20 and 30 days after which they were examined for mechanical and physical properties. It was observed that with increasing fiber proportion and curing ages, abrasion resistance, internal bond, tensile, compressive, screw holding strengths improved. Moisture content, water absorption and surface roughness increased slightly with increasing fiber content but reduced across curing ages. Experimental performance evaluation carried out shows that compliance index appreciated with fiber content and curing ages while effective property index varied as additives and curing ages rose. Performance of composites relative to cost was recorded to improve with jute fiber content and curing duration; of which optimum value (0.74) was attained at 5 % jute fiber proportion and curing age of 20 days.Utilization of 5 wt. % jute fiber and 20 wt. % in cement composite (cured for 20 days) is recommended for automobile paperboard.

Keyword: Cost ratio, Compliance index, Effective performance index, Performance index-cost ratio.

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1. Introduction

Waste papers utilization in boards is a new initiative which involves blending of waste paper with cement. Additives are incorporatedinto the blend for better performance [1]. Paper is porous with hydrophilic nature amounting to high water absorption [2], however incorporation of powder or fillers into matrix are meant to reduce porosity which in turn present better properties [3]. Binder employed for paper pulp in this study is cement. Cement has been used as binder in concrete and sand bricks [4] and due to the binding prowess can be employed in binding of paper pulp with other forms of additives which are jute fiber and egg shell biofiller. Egg shell powder sieved to -75 µm was incorporated for the purpose of filling the pores amounting to reduction in pore sizes and creating stronger bond with cement. Similarly, jute fiber was integrated to enhance bond strength within matrix via strong interfacial adhesion [5]. Utilization of jute fiber is on the basis of the crack arresting abilities of fibers and strong attachment to paper fiber and matrix enhancementwhich consequently results in improvement of strength [6]. In this study, cement and jute fiber were added to paper pulp in the presence of egg shell for the purpose of producing alternative and sustainable materials for automobile dashboard using locally sourced material.

2. Materials used

Materials used are cement, waste paper, egg shell powder and jute fiber cut to 40 mm. The mix blend of cement, waste paper, egg shell powder and jute fiber at constant cement content of 20wt. % of paper pulp, egg shell proportion of 20 wt. % and paper/fiber content of 60/0 %, 59/1 %, 58/2%, 57/3 %, 56/4 %, 55/5 wt. %. Composite samples produced were cured for 10, 20 and 30 days and each composite mix tested for internal bond strength, tensile strength (perpendicular to surface), compressive strength, screw holding strength, abrasion resistance, surface roughness, moisture content and water absorption (24 hours cold water immersion). Property value (Table 1) recorded for each composite mix developed was further evaluated via experimental performance evaluation.

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Table 1: Property values of jute fiber/egg shell powder reinforced cement-papercomposites

	Internal bond strength (MPa)			Tensile strength (MPa)			Compressive strength (MPa)			Screw holding strength (MPa)		
Jute fiber	10days	20days	30days	10days	20days	30days	10days	20days	30days	10days	20days	30days
0	0.3	0.32	0.34	0.73	0.74	0.81	1.96	2.08	2.19	811	831	847
1	0.33	0.36	0.37	0.76	0.78	0.84	2.01	2.32	2.36	848	942	1094
2	0.36	0.39	0.41	0.79	0.86	0.91	2.22	2.41	2.54	912	1087	1206
3	0.39	0.42	0.46	0.81	0.84	0.94	2.34	2.48	2.61	1039	1149	1355
4	0.41	0.44	0.48	0.83	0.81	0.98	2.39	2.50	2.63	1173	1241	1409
5	0.43	0.44	0.53	0.8	0.73	0.92	2.43	2.52	2.63	1211	1321	1489
	Abrasionresistance (%)			Surface roughness (µm)			Moisture content (%)			Water absorption (%)		
Jute fiber	10days	20days	30days	10days	20days	30days	10days	20days	30days	10days	20days	30days
0	0.38	0.36	0.33	1.96	2.32	2.74	9.2	8.4	7.3	16	15	12
1	0.34	0.35	0.31	2.15	2.64	2.83	9.5	9.2	7.4	18	15	13
2	0.34	0.33	0.30	2.41	2.63	2.92	9.5	9.2	7.9	21	16	14
3	0.33	0.31	0.28	2.68	2.93	3.72	10.2	9.4	8.1	22	16	15
4	0.28	0.27	0.25	3.11	3.73	4.21	10.2	9.6	8.2	25	18	17
5	0.25	0.22	0.22	3.78	4.14	4.65	10.4	9.6	8.4	28	22	20

3. Experimental Performance Analysis (EPA)

Performance evaluation was carried out on the values to assess probable service performance of the composites for selection of optimum mix for automobile dashboard composite. This involves evaluation of Performance Indexof the composite employing equations 1a and b.

$$\text{Performance index (PF)} = CI \times PI \quad (1a)$$

$$\text{Performance index-Cost Ratio (PF-CR)} = \frac{CI\ x\ PI}{CR} \quad (1b)$$

CI is compliance index, PI is Effective Property index, CR is Cost ratio

3.1. Compliance index/level and effective property index

In investigating for compliance level, values obtained for each property of the composite was compared with existing standard values. Standards used for bases are as stated in Table 2. For instance, in evaluating for compliance level of internal bond strength, the values of each composite mix werecompared with 0.35 MPa standard value as per EN 312-3 [7]. For property value ≥ 0.35 MPa, composite response value was stipulated to be 1 as expressed in Table 2, while property value < 0.35 was allotted 0.

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Table 2: Standard Values considered for response index

Properties	Standard Value	Source
Internal bond strength	≥ 0.35 MPa	[7]
Tensile strength	≥ 0.8 MPa	[8]
Compressive strength	≥ 2.5 MPa	[8]
Screw holding strength	≥ 1250 MPa	[8]
Abrasion resistance	≥ 0.3 %	[9]
Surface roughness	3.67-5.46 µm	[10]
Moisture content	5-13 %	[11]
Water absorption	≤ 40 %	[8]

Table 3. Response index for composites in comparison with standard values

	Internal bond strength (MPa)			Tensile strength (MPa)			Compressive strength (MPa)			Screw holding strength (MPa)		
Jute fiber	10days	20days	30days	10days	20days	30days	10days	20days	30days	10days	20days	30days
0	0	0	0	0	0	1	0	0	0	0	0	0
1	0	1	1	0	0	1	0	0	0	0	0	0
2	1	1	1	0	1	1	0	0	1	0	0	0
3	1	1	1	1	1	1	0	0	1	0	0	1
4	1	1	1	1	1	1	0	1	1	0	0	1
5	1	1	1	1	0	1	0	1	1	0	1	1
	Abrasion resistance (%)			Surface roughness (µm)			Moisture content (%)			Water absorption (%)		
Jute fiber	10days	20days	30days	10days	20days	30days	10days	20days	30days	10days	20days	30days
0	0	0	0	0	0	0	1	1	1	1	1	1
1	0	0	0	0	0	0	1	1	1	1	1	1
2	0	0	1	0	0	0	1	1	1	1	1	1
3	0	0	1	0	0	1	1	1	1	1	1	1
4	1	1	1	0	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	0	1	1

This procedure was followed for all properties values of the composites and total response index was obtained for each composite mix under respective curing ages. Compliance level was afterwards evaluated using equation 2;

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Compliance Index(CI) = $\frac{Total\ value\ obtained\ \ for\ each\ composite\ \ mix}{Total\ expected\ \ value\ \ (which\ is\ 8\ in\ this\ study\ )}$ (2)

Compliance level = Compliance index x 100% (3)

Performance of composites was evaluated putting into perspective compliance with existing standard as per area of application. This warranted the need to evaluate for compliance index. However, it should be noted that CI has limitation in that it only considers the conformity of values with existing standard value allotting 1 for property value which met standard value and 0 for property value which did not meet standard value.

Effective property index on the other hand focuses on the magnitude of the property value with respect with efficiency ratio. Giving an instance, for internal bond strength, standard value is 0.35 MPa. Property value at 0, 1, 2, 3, 4 and 5 % fiber mix (cured for 7 days) are 0.30, 0.33, 0.36, 0.39, 0.41 and 0.43 respectively. CI allots 0, 1, 1, 1, 1 and 1 for the response index; however in the case of property index, property index believe the composite mix with the maximum property value will have the highest performance in service with respective to efficiency ratio. Therefore while compliance index focuses on meeting standard values, property indexconsiders magnitude of the values with respect to efficiency of the experimental inputs which affects appreciation or depreciation in values relative to reference values.

Property ratio (PR) = $\frac{property\ \ value}{maximum\ \ property\ \ value}$ (4)

Property ratio (PR) = $\frac{minimum\ \ property\ \ value}{property\ \ value}$ (5)

Effective property index for each mix proportion = $\sum_{i=0}^{8}\ ER\ x\ (Pr)/8$ (6)

Equation 4 is used for properties in which its maximum value is beneficial for the composite developed while equation 5 is used for properties which lower value is beneficial. Results of the effective property index are as presented in Table 4 which resultant value for both compliance index and effective property index are in Table 5

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Table 4: Effective property index of composite mix

	Internal bond strength (MPa)			Tensile strength (MPa)			Compressive strength (MPa)			Screw holding strength (MPa)		
Jute fiber	10days	20days	30days	10days	20days	30days	10days	20days	30days	10days	20days	30days
0	0.00	0.04	0.04	0.00	0.01	0.08	0.00	0.05	0.04	0.00	0.01	0.01
1	0.50	0.08	0.06	0.31	0.04	0.03	0.17	0.10	0.07	0.09	0.08	0.21
2	0.49	0.06	0.08	0.31	0.09	0.08	0.76	0.04	0.07	0.16	0.11	0.08
3	0.49	0.06	0.11	0.20	-0.02	0.03	0.42	0.03	0.03	0.33	0.04	0.11
4	0.32	0.04	0.04	0.20	-0.03	0.04	0.17	0.01	0.01	0.35	0.07	0.04
5	0.32	0.00	0.10	-0.29	-0.07	-0.06	0.13	0.01	0.00	0.09	0.06	0.06
	Abrasion resistance (%)			Surface roughness (μm)			Moisture content (%)			Water absorption (%)		
Jute fiber	10days	20days	30days	10days	20days	30days	10days	20days	30days	10days	20days	30days
0	0.00	-0.03	-0.06	0.00	0.16	0.13	0.00	-0.08	-0.13	0.00	-0.05	-0.20
1	0.37	-0.02	-0.04	0.32	0.10	0.02	-0.19	0.08	0.01	0.38	0.00	0.08
2	0.00	-0.04	-0.02	0.36	0.00	0.02	0.00	0.00	0.06	0.43	0.05	0.07
3	0.11	-0.04	-0.05	0.30	0.08	0.14	-0.40	0.02	0.02	0.12	0.00	0.06
4	0.64	-0.11	-0.09	0.37	0.14	0.06	0.00	0.02	0.01	0.29	0.08	0.09
5	0.51	-0.19	-0.12	0.41	0.05	0.04	-0.11	0.00	0.02	0.23	0.12	0.11

Table 5: Effective property index and compliance index

	Compliance index			Effective property index		
Jute fiber (%)	10 days	20 days	30 days	10 days	20 days	30 days
0	0.25	0.25	0.375	0.000	0.014	-0.014
1	0.25	0.375	0.5	0.266	0.054	0.033
2	0.375	0.5	0.75	0.336	0.029	0.051
3	0.5	0.5	1	0.177	0.019	0.049
4	0.625	0.875	1	0.284	0.021	0.023
5	0.625	0.875	1	0.171	-0.011	0.013

3.2 Cost Ratio

Cost is an important aspect of material production and development because cost minimization is the ultimate goal, though not putting aside performance. Therefore, performance-cost relationship is an expedient analysis needed in Engineering in order not to compromise standard and the same time to reduce cost for profit maximization.

Cost ratio was analyzed using equation (7)

$$\text{Cost Ratio (Cr)} = \frac{Cost\ of\ each\ composition}{Total\ cost\ incured\ on\ all\ composition\ \ per\ sample} \quad (7)$$

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Table 6: Cost of each component in each sample

	Cost of Cement (N52/Kg)			Cost of Egg shell powder (N3.1/kg)			Cost of paper pulp (N2.6/kg)			Cost of Jute fiber (N1.1/Kg)		
	10 days	20 days	30 days	10 days	20 days	30 days	10 days	20 days	30 days	10 days	20 days	30 days
0	109.2	109.2	109.2	4.34	4.34	4.34	8.19	8.19	8.19	0.00	0.00	0.00
1	109.2	109.2	109.2	4.34	4.34	4.34	8.19	8.19	8.19	0.08	0.08	0.08
2	109.2	109.2	109.2	4.34	4.34	4.34	8.19	8.19	8.19	0.15	0.15	0.15
3	109.2	109.2	109.2	4.34	4.34	4.34	8.19	8.19	8.19	0.23	0.23	0.23
4	109.2	109.2	109.2	4.34	4.34	4.34	8.19	8.19	8.19	0.31	0.31	0.31
5	109.2	109.2	109.2	4.34	4.34	4.34	8.19	8.19	8.19	0.39	0.39	0.39

Table 7: Cost of composition and Cost ratio for each composite mix

	Cost of composition			Total Cost ratio		
Jute fiber (%)	10 days	20 days	30 days	10 days	20 days	30 days
0	121.73	121.73	121.73	0.043	0.043	0.043
1	121.81	121.81	121.81	0.042	0.042	0.043
2	121.88	121.88	121.88	0.041	0.042	0.042
3	121.96	121.96	121.96	0.041	0.041	0.042
4	122.04	122.04	122.04	0.041	0.041	0.042
5	122.12	122.12	122.12	0.041	0.041	0.041

Implementing equation 1 to evaluate the Performance index-cost ratio, Table 9 depicts the results obtained

	Compliance to cost ratio			Property index-cost ratio		
Jute fiber (%)	10 days	20 days	30 days	10 days	20 days	30 days
0	5.88	5.86	8.72	0.00	0.13	0.29
1	5.91	8.84	11.70	2.71	0.14	0.21
2	9.04	12.01	17.89	4.32	0.10	0.11
3	12.11	12.07	23.97	2.91	0.05	0.18
4	15.17	21.17	24.02	3.21	0.16	0.09
5	15.32	21.37	24.25	2.47	0.21	0.16

Table 8: Performance index

Jute fiber	10 days	20 days	30 days
0	0.000	0.007	0.016
1	0.032	0.011	0.018
2	0.060	0.012	0.020
3	0.066	0.009	0.033
4	0.086	0.027	0.022
5	0.075	0.031	0.031

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Table 9: Performance index-cost ratio

Jute fiber	10 days	20 days	30 days
0	0.00	0.17	0.37
1	0.76	0.26	0.42
2	1.45	0.29	0.47
3	1.59	0.21	0.78
4	0.80	1.05	2.14
5	1.84	0.76	0.74

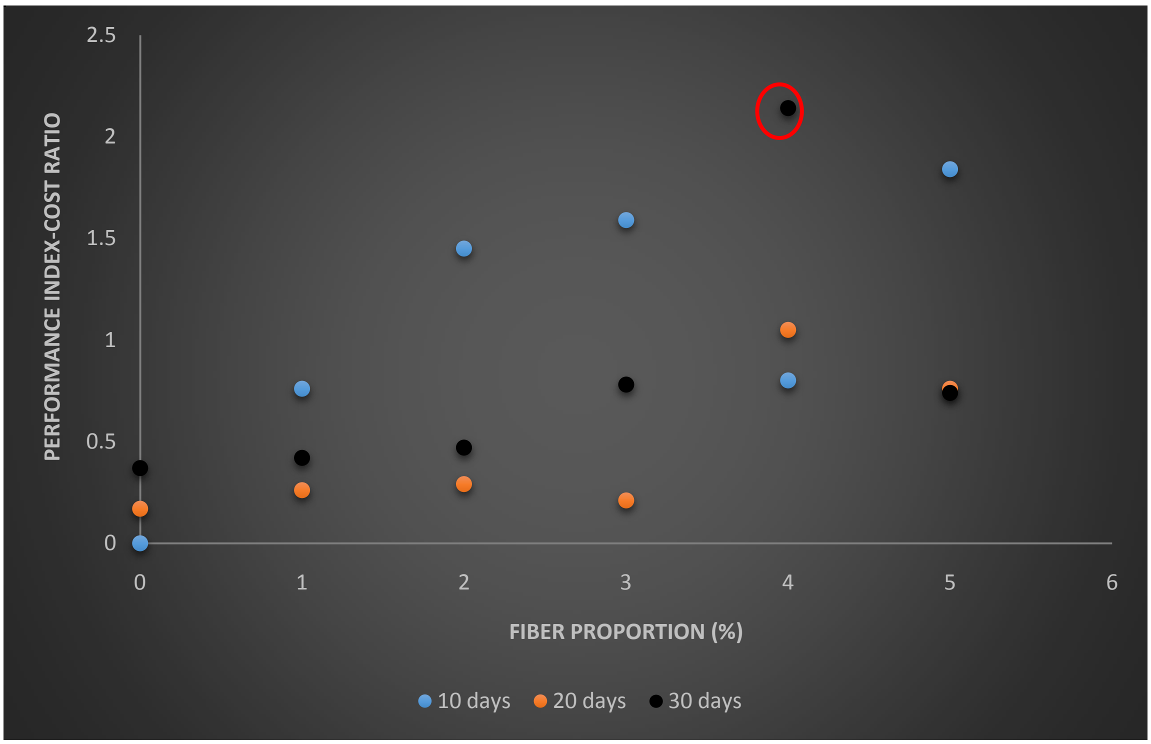

Fig. 1: Performance index-cost ratio at varied fiber proportion and curing days.

Highest Performance index-cost ratio is attained at 4 wt. % fiber with curing age of 30 days.

4. Conclusion

Jute fiber/egg shell cement-paper composite of varied proportion of jute fiber was examined and property value obtained for internal bond, compressive, tensile and screw holding strengths, abrasion resistance, surface roughness, moisture content and water absorption. Experimental Performance Evaluation was carried out in analyzing the property value and it was recorded that compliance level increased with increasing fiber content and curing ages while effective property index varied. Performance of composite mix relative to cost was noted to improve with fiber content and curing duration even though there were variations along the line. For automobile dashboard, jute proportion of 5 % by weight of paper pulp and curing ages of not less than 20 days is hereby recommended. Also, the board made can be coated or waxed with water resisting materials in order to reduce moisture and water uptake.

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