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Mechanical Strength Recovery for Fractured Rice Husks Fibre Reinforced Polypropylene Composites

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ABSTRACT

Environmental conservation issues and the need to find sustainable alternatives to timber have led to an increased interest in plant fibre reinforced polymer composites. Moreover, value addition to wastes through reprocessing into new products is a key component in industrial growth. Rice husk fibres are among agricultural wastes widely used as reinforcement for polymer matrices to form plant fibre reinforced polymer composites. This is specifically due to its short renewable cycle. In this research, rice husk fibres were procured and prepared by hammer milling, heated to reduce moisture content and surface modified to increase adhesion with the matrix. Polypropylene wastes were collected, shredded and used as matrix. Test pieces were produced by injection moulding. Application of excessive stresses through destructive mechanical tests failed the materials by fracture yet there is no known repair method for them such as welding (to repair metals) or reheating to re-create the frictional or chemical bond. Repair through healing by resin infiltration was investigated for test pieces fractured by tensile, impact and compressive destructive tests. Healing was done by use of healing agents and the healed test pieces were tested for recovered respective mechanical strengths. The recovered strengths were: tensile strength 69MPa, bending strength 50MPa, compressive strength 151MPa and impact strength 60 J/ mm^2.Percentage recovered mechanical strength from tensile, impact and compressive strength tests were 81, 98.36 and 85 respectively. It was established that % fibre weight fraction, cooling time for test pieces, healing agents and healing time influenced mechanical strength of the composite. The recovered strengths were sufficient to conclude that healed rice husks fibre reinforced polypropylene composite materials could be reused for their original structural functions.

Key words: Reinforced composites, Healing, Strength recovery

INTRODUCTION

There is a rapid expansion in research and innovation in the natural fibre composite (NFC) area. Interest is warranted due to the advantages of these materials compared to others, such as synthetic fibre composites, including low environmental impact and low cost which support their potential across a wide range of applications [1].

Traditional engineering materials such as metals, ceramics, timber among others have been used for various applications from the stone age time but they have functional limitations in areas where versatile engineering materials such as composites would best fit [2]. Engineering structures now encompass a wide range of technologies from materials development, analysis, design, testing, production, maintenance and recycling [3]. Degradation, damage, and failure are natural consequences of material applications.

A rice husk fibre reinforced polypropylene composite has rice husk fibre as the discontinuous phase and polypropylene as a continuous phase or matrix [4]. The composite forms a chemical or frictional bond whose strength largely depend on strength of the interface [5]. The fibre is the load bearing constituent. Such composites have applications as fencing posts, particle boards, roofing tiles, car and aircraft interiors among many others [6].

A rice husks fibre reinforced polypropylene composite once loaded beyond elastic limit fails by various mechanisms including disbonding, fibre pullout, interfacial cracking etc [7]. Such a composite would be rendered unserviceable and of no further engineering use. For metals, repairs are commonly done by welding, brazing or soldering. This is impractical for plant fibre reinforced polymer composites of which rice husks fibre reinforced polypropylene composite belong. They would easily burn or decompose under such high jointing temperatures.

For plant fibre reinforced polymer composites (rice husks fibre reinforced polypropylene composites included), typical structural repairs often result in damaging practices, where material is ground away and holes are drilled to secure patches, which can act as new sites for damage [8].

This research aimed at finding a solution to the problem of repair of fractured rice husk fibre reinforced polypropylene composite by re-introducing necessary desirable strengths through injection of healing agents to the fractured surface (damaged volume).

By injection repair, mechanical interlocks would be created at the fracture surface thus helping in the strength recovery. It is more of functionally creating a new rice husk fibre reinforced polypropylene composite from one which had fractured through repairing the composite which is analogous to welding together two separate broken metal pieces. Thus, a natural plant fibre reinforced polymer composite material, of which rice husk fibre reinforced polypropylene composite is an example, could directly benefit from extended service life by incorporating a repair strategy such as healing [3].

MATERIALS AND METHODS

The methodology used included sourcing and preparation of composite constituents: rice husks from West Kano Rice Mills in Ahero, (Kenya) and polypropylene matrices from dumpsites in Nairobi, (Kenya). Laboratory work and workshop involved fabrication of moulds and fixtures to be used to produce test pieces and also actual production of rice husk fibre reinforced polypropylene composites. Material testing was done in materials testing laboratory in Multimedia University of Kenya.

Material Preparation

Rice husks were hammer milled and sieved to average fibre size of between 0.5 by 5 mm. The size of fibre was measured using optical measuring equipment (Universal projectile). The fibres were then mixed with diazonium salt in alkali media (sodium hydroxide) for surface modification purposes. In order to have diazonium salt in alkali media (Ph 10.5), 200 ml of 5% sodium hydroxide was mixed with 300 ml of water in a beaker. 500 gm of hammer milled rice husks was submerged into the solution for 10 minutes in an ice bath (at 5 ^{0}C). Solution of benzene diazonium salt (90 ml) was poured into the mixture while continuously stirring for 10 minutes. Rice husks were then removed and washed with soapy water (to remove any oils on fibre surface) before finally washing with distilled water while checking ph values of the wet rice husks. Washing of chemically treated rice husks was stopped when the filter paper showed ph of 7. The rice husks were then dried in the sun for 8 hours before final drying in an oven at 105 ^{0}C for 24 hours [9; 10]. The chemicals were procured from Synresins – Makungi close and Henkel in Industrial area, Nairobi, (Kenya).

Polypropylene wastes were cleaned, shredded to 1.5 mm by 1 mm pieces and then dried in an oven at 85^{0}C for 24 hours [5]. The two composite constituents were then ready for homogeneous mixing, heating and composite production.

Test Piece Production

Several sample test pieces were produced by varying fibre content (between 10 to 90 % by weight fraction) in the mixture with void fraction fixed at 2%. The mixture of rice husk fibres and polypropylene wastes (matrix) were poured into a heating chamber of an injection moulding equipment. Polytetrafluoroethylene mould release was applied to prevent the composite from sticking to the die walls. Temperature and injection pressure was appropriately set so as to produce short test pieces as well as long dumbbell shaped test pieces depending on mould cavity used. For injection moulding process, the composite constituents were heated at a temperature of 210^0 C for 10 minutes [11]. The composite hot product was then injected at a pressure of 20 KN/ mm^2 [11]. The composite products were cooled for between 1 to 24 hours as per trials based on Taguchi full factor factorial model and subsequently cut to size as per respective test standards and then tested. Test piece sizes of 250 mm by 25 mm by 10 mm were cut for tensile and three point bending tests had test pieces produced of size 6.2 mm by 74 mm by 201.6 mm, while test pieces of 140 mm by 12 mm by 10 mm were cut for compressive strength tests [12]. Test pieces for impact strength tests were produced using the same procedure as for the above but having the mould reversed so that the shorter cavity was used. The test piece sizes were 55 mm by 10 mm by 10 mm for charpy impact testing [13].

The test pieces produced were five for every destructive test, giving a total of (5×9×24 = 1080 test pieces per destructive test) totaling to a maximum of 4320 test pieces for tensile, compressive, bending and impact pristine tests.

Design of Experiments

Taguchi full factor factorial array DoE was used in composite production process in which % fibre weight fractions were varied at 9 levels and cooling time was varied at 24 levels (varied per hour of cooling time for the composite during production). The test pieces were coded appropriately for ease of testing.

Test pieces destroyed through destructive testing were healed in fabricated fixture. The healing process was also conducted as per Taguchi full factor factorial model in which four healing agents were used and 24 levels of healing time were also used in steps of 5 minutes. The healed test pieces were coded appropriately for retesting [14].

Experiments were designed to;

i) investigate the influence of fibre weight fractions on mechanical strengths and determine the optimum fibre weight fraction for highest strength.

ii) investigate influence of cooling time, before destructive test, on mechanical strength of pristine composite test pieces

iii) investigate the influence of variation of healing time and healing agents on recovery of mechanical strengths and use analytical tools to determine any relationship.

Hypothesis

Ho. Variation of % fibre weight fraction has no influence on mechanical strength of pristine rice husk fibre reinforced polypropylene composite and any differences are due to chance. i.e.

$W_1 = W_2 = W_3 = \ldots\ldots = W_9 = 0$. …….. (1)

H_1 Alternative

ii) Ho. Cooling time of pristine test pieces before destructive testing has no influence on mechanical properties and observed differences are due to chance. i.e $T_1 = T_2 = T_3 = \ldots T_{24} = 0$. ……..……..... (2)

H_1 Alternative

Model : $y_{ij} = \mu + W_i + T_j + \varepsilon_{ij}$……..…… (3)

iii) $H_{O.}$ The healing agents; bisphenol E cyanate ester, Epoxy resin, ethyl cyanoacrylate and Tannin gum do not influence the strength recovery of rice husk fibre reinforced polypropylene composite and observed differences are due to chance i.e. $\tau_1 = \tau_2 = \tau_3 = \tau_4 = 0$. ……..……..……...… (4)

H_1 Alternative

iv) $H_{O.}$ Healing time for the fractured rice husk fibre reinforced polypropylene composite does not affect recovery of mechanical strength and any observed difference are due to chance.

$\beta_1 = \beta_2 = \beta_3 = \ldots = \beta_{24} = 0$. ……..… (5)

Model: $y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij}$ ……..…. (6)

Mechanical Properties for Pristine Test Pieces

Impact Strength Tests

Test pieces of size 55 mm by 10 mm by 10 mm had a notch cut on them at 27.5 mm length from one end. The notch was 2.5 mm wide, 2 mm deep with 45^0angle as per established standards. A charpy impact testing machine having pendulum impact energy of 142 Joules was used to fracture the specimens. The tests were conducted as per ASTMA 370 test standards.

The material was placed in the test equipment horizontally with the notch facing away from the striker (having a line – pointed shape). The hammer travelled from 140^0. Five test pieces of composite were tested for every combination of % fibre weight fraction and cooling time range of between 1 and 24 hours. Each test results recorded was a mean for five tests.

Tensile strength test

The tests were conducted as per ASTM D 3039– 15 test standards. The test pieces were fitted into the upper and lower jaws of a universal mechanical testing machine. The test piece sizes were 250 mm by 25 mm by 10 mm. Test results recorded in each case were a mean for five tests

Compressive strength test

The tests were conducted as per ASTM D 6641 – 14 test standards. Each test piece was fitted between flat circular metal plates. The test pieces were 140 mm by 12 mm by 10 mm in size. The test results recorded were a mean for five tests.

Bending strength tests

Test pieces of size 201.6 mm in length, width of 74 mm and thickness of 10 mm were produced and were fitted one at a time, into a Universal Mechanical Testing Machine. The tests were conducted as per ASTM D 7264 - 15 test standards. Bending supports were spread a part according to gauge length chosen during the test. The test pieces were loaded to failure at cross-head speed of 5 mm/min at 24 ^{0}C. A mean strength was recorded for every group of five test pieces tested.

Healing of fractured test pieces

Test pieces fractured by various destructive tests were healed while being held in a fabricated fixture. Epoxy resin, ethylcyanoacrylate, tannin gum and bisphenol E cyanate esters were manually injected into the fractured

surfaces and given sufficient healing time as elaborated in design of experiments. Healed test pieces were retested for mechanical strengths and test results and graphs were recorded as captured during testing.

RESULTS AND DISCUSSION

Mechanical strength test results for pristine test pieces

The mean strengths of composite tested for every destructive test were recorded as shown in tables 1 (a) up to 4 (b) in the supplement information. It was noted that in each of the test types, the mechanical strength test results were lower for % fibre weight fractions lower than 40% as well as for % fibre weight fractions higher than 40 %.Graphs for highest strengths of composite obtained per fibre weight fractions were as shown in fig. 1 to 6.

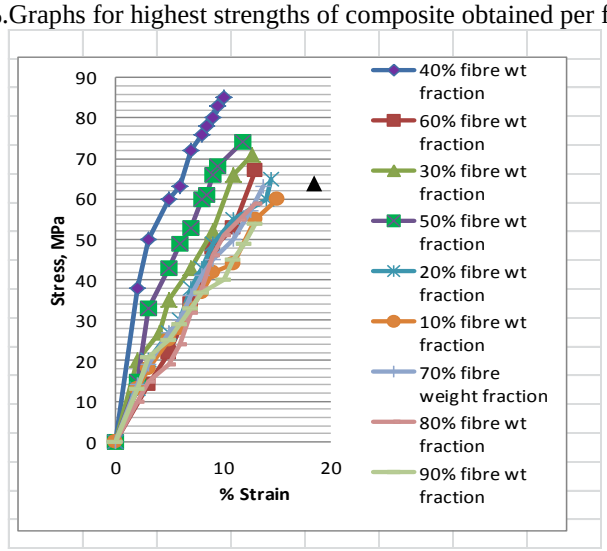

Fig. 1 Tensile strength for pristine test piece

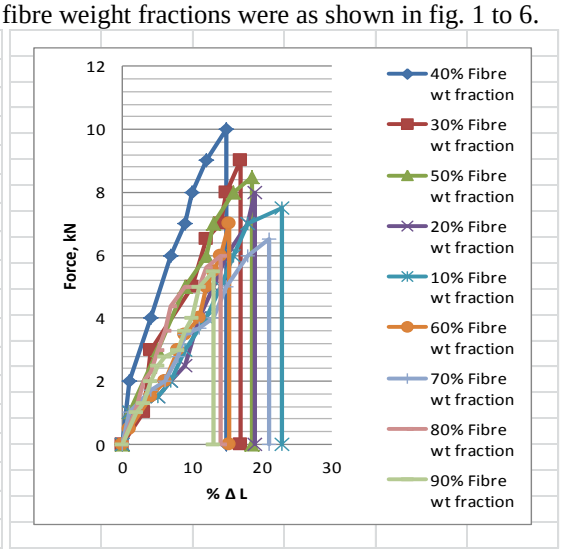

Fig. 2 Tensile load – extension graph

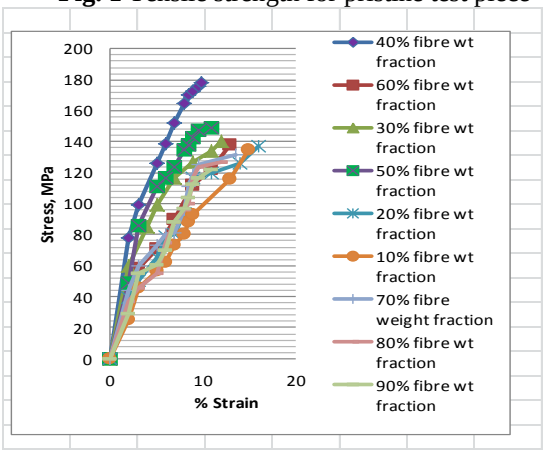

Fig. 3 Compressive strength for pristine test piece

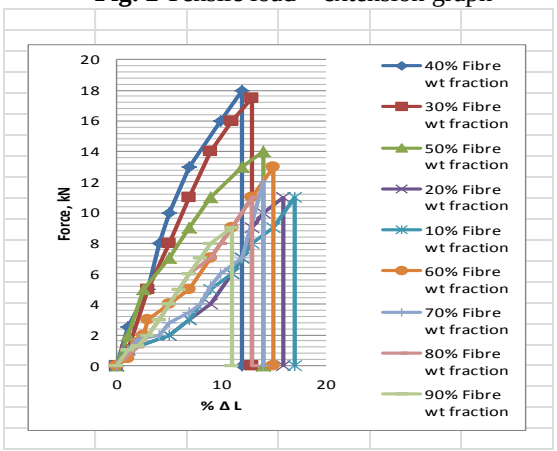

Fig. 4 Compressive load – displacement graph

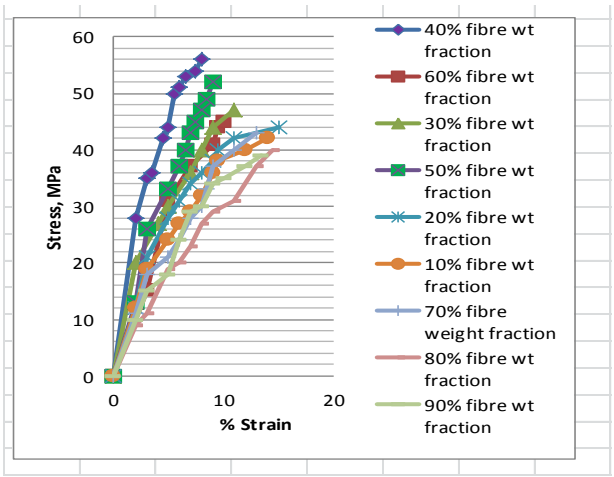

Fig. 5 Bending strength graph for pristine test piece

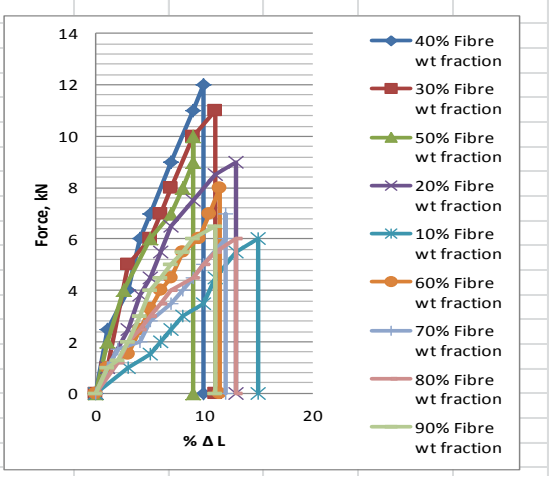

Fig. 6 Load – displacement graph for bending strength test

From the graphs, test pieces with 40 % fibre weight fraction gave the strongest composite material. This was due to optimal fibre packing and homogeneous mixing with matrices. Lowest strengths were obtained from test pieces with either 10 % or 90 % fibre weight fraction. At such higher or lower % fibre weight fraction, the composite strength was adversely affected by phase migration during composite production, fibre dispersion and fibre orientation. Weaker interfacial bond strength resulted due to non-optimal matrix fibre mixing during production for all % fibre weight fractions other than the optimal value of 40 %. At % fibre weight fractions higher than 40%, mechanical strength test results were also lower. This was due to higher probability of fibre agglomeration resulting in more regions of stress concentration and hence requiring less energy for crack propagation before fracture.

The test results per destructive test were as shown in tables1 (a) up to 4 (b) and were used in the software for data analysis using analysis to evaluate hypothesis.

ANOVA Results for Pristine Test Pieces

Table -1 ANOVA for impact strength of pristine test pieces

	ANOVA							
Source of Variation		*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	***Decision***
	Rows	7369.593	8	921.1991	43.18161	2.31E-38	1.989011	Reject Ho
	Columns	12835.7	23	558.0741	26.15997	4.15E-46	1.588161	Reject Ho
	Error	3925.296	184	21.33313				
	Total	24130.59	215					

From impact strength test data in supplementary information (table 1 a and 1 b), ANOVA was conducted. The results indicated that the rows (% fibre weight fraction) influenced pristine impact strengths of the test pieces, columns (cooling time) for test pieces also influenced impact strengths. The decision criteria was based on the comparisons of F_{ratios} (calculated F_{ratio} and that of table values) at specific degrees of freedom and 5% level of significance [15].

For % fibre weight fractions (rows), calculated F_{ratios}= 43.18. Table value of F_{ratios} at 8 degrees of freedom and 5 % level of significance was 1.989. Therefore, $F > F_{critical}$ and null hypothesis was rejected. This implied that the % fibre weight fraction influenced impact strength of the rice husks fibre reinforced polypropylene composite.

F_{ratios} for cooling time (columns) = 26.15997. Table value of F_{ratios} at 23 degrees of freedom and 5 % level of significance was 1.588161. $F > F_{critical}$ and null hypothesis was rejected. This implied that cooling time of composite test piece before testing influenced impact strength of the rice husks fibre reinforced polypropylene composite.

Table -2 ANOVA for tensile strength tests for pristine test pieces

	ANOVA							
Source of Variation		*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	***Decision***
	Rows	9376.037	8	1172.005	224.4351	1.25E-90	1.989011	Reject Ho
	Columns	20642.15	23	897.4847	171.8654	1.7E-111	1.588161	Reject Ho
	Error	960.8519	184	5.222021				
	Total	30979.04	215					

The results indicated that the rows (% fibre weight fraction) influenced pristine tensile strength of the test pieces, columns (cooling time) for test pieces also influenced tensile strengths. The decision criteria was based on the comparisons of F_{ratios} (calculated F_{ratio} and that of table values) at specific degrees of freedom and 5% level of significance.

For % fibre weight fractions (rows), calculated F_{ratios}= 224.4351. Table value of F_{ratios} at 8 degrees of freedom and 5 % level of significance was 1.989. Therefore, $F > F_{critical}$ and null hypothesis was rejected. This implied that the % fibre weight fraction influenced tensile strength of the rhfrpc.

F_{ratios} for cooling time (columns) = 171.8654 Table value of F_{ratios}at 23 degrees of freedom and 5 % level of significance was 1.588161. $F > F_{critical}$ and null hypothesis was rejected. This implied that cooling time of composite test piece before testing influenced tensile strength of the rice husks fibre reinforced polypropylene composites.

Table -3Anova for compressive strength test results for pristine test pieces

	ANOVA							
Source of Variation		*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	***Decision***
	Rows	23057.17	8	2882.146	24.47889	2.15E-25	1.989011	Reject Ho
	Columns	84934.29	23	3692.795	31.36397	1.35E-51	1.588161	Reject Ho
	Error	21664.17	184	117.74				
	Total	129655.6	215					

The results indicated that the rows (% fibre weight fraction) influenced pristine compressive strength of the test pieces, columns (cooling time) for test pieces also influenced compressive strengths. The decision criteria was based on the comparisons of F_{ratios} (calculated F_{ratio} and that of table values) at specific degrees of freedom and 5% level of significance.

For % fibre weight fractions (rows), calculated F_{ratios} = 24.47889. Table value of F_{ratios} at 8 degrees of freedom and 5 % level of significance was 1.989. Therefore, F >$F_{critical}$ and null hypothesis was rejected. This implied that the % fibre weight fraction influenced compressive strength of the rice husks fibre reinforced polypropylene composites.

F_{ratios} for cooling time (columns) = 31.36397. Table value of F_{ratios} at 23 degrees of freedom and 5 % level of significance was 1.588161. F >$F_{critical}$ and null hypothesis was rejected. This implied that cooling time of composite test pieces before testing influenced compressive strength of the rice husks fibre reinforced polypropylene composite.

Table -4 ANOVA for bending strength tests for pristine test pieces

ANOVA

Source of Varia	SS	df	MS	F	P-value	F crit	Decision
Rows	5463.333	8	682.9167	28.23322	2.38E-28	1.989011	Reject Ho
Columns	8999.625	23	391.288	16.17668	6.65E-33	1.588161	Reject Ho
Error	4450.667	184	24.18841				
Total	18913.63	215					

The results indicated that the rows (% fibre weight fraction) influenced pristine bending strength of the test pieces, columns (cooling time) for test pieces also influenced bending strengths. The decision criteria was based on the comparisons of F_{ratios} (calculated F_{ratio} and that of table values) at specific degrees of freedom and 5% level of significance.

For % fibre weight fractions (rows), calculated F_{ratios}= 28.23322. Table value of F_{ratios} at 8 degrees of freedom and 5 % level of significance was 1.989. Therefore, F >$F_{critical}$ and null hypothesis was rejected. This implied that the % fibre weight fraction influenced bending strength of the rice husks fibre reinforced polypropylene composite.

F_{ratios} for cooling time (columns) = 16.17668. Table value of F_{ratios} at 23 degrees of freedom and 5 % level of significance was 1.588161. F >$F_{critical}$ and null hypothesis was rejected. This implied that cooling time of composite test piece before testing influenced bending strength of the rice husks fibre reinforced polypropylene composites.

Mechanical Strengths Results for Healed Test Pieces

Recovered impact, tensile and compressive strengths were as shown in tables 5 a and b, 6 a and b, and 7 a and b. Data in each of these tables were used to conduct analysis of variance to find out the influence of the factors (healing agents and healing time) on recovered mechanical strengths.

ANOVA software was used and the results were applied in accepting or rejecting the null hypothesis.

It was noted that healed test pieces subjected to bending retest gave inconsistent results. This could be attributed to slight deformation which could have occurred during destructive testing of the pristine test pieces before healing and retest.

Recovered Mechanical Strengths

Recovered impact strengths were as shown in table 5 a and b, tensile strength in table 6 a and b and compressive strength in table 7 a and b of the supplement information. The recovered strengths were used to conduct analysis of variance. Shown in tables 5, 6 and 7. Graphs of maximum recovered tensile and compressive strengths as well as load –extension graphs were as shown in fig. 7, 8, 9 and 10.

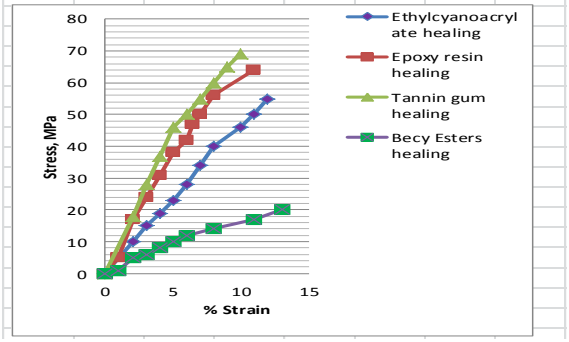

Fig. 7 Tensile strength for healed test piece

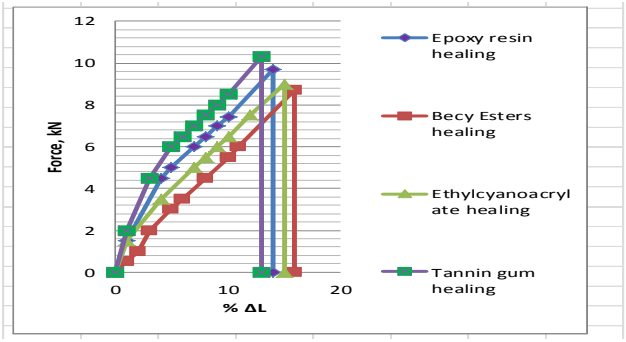

Fig. 8 Tensile load – displacement graph for healed test pieces

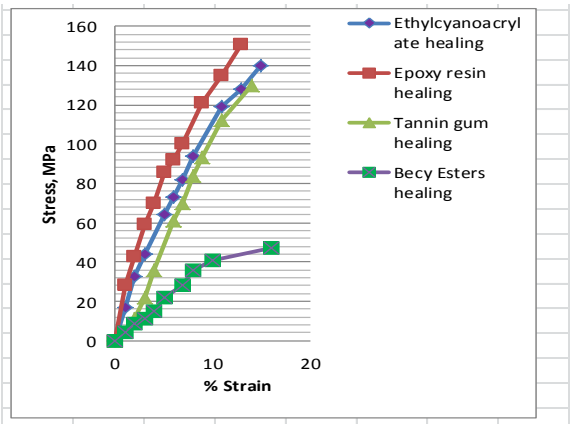

Fig. 9 Compressive strength for healed test piece

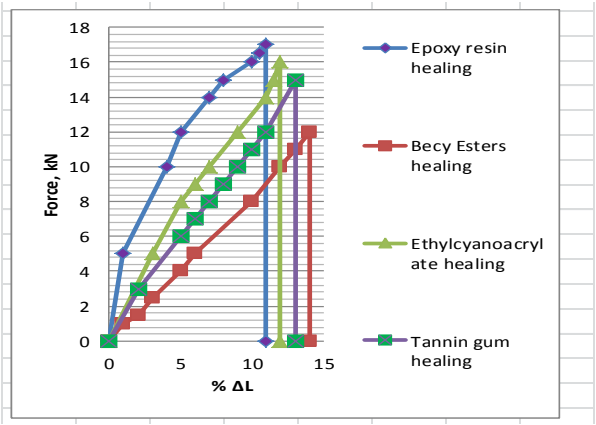

Fig. 10 Compressive Load – displacement for healed test pieces

Table -5 ANOVA for recovered impact strength

ANOVA							
Source of Varia	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	***Decision***
Rows	15282.42	3	5094.139	463.9695	1.19E-45	2.737492	Reject Ho
Columns	3456.5	23	150.2826	13.6876	1.5E-17	1.686897	Reject Ho
Error	757.5833	69	10.97947				
Total	19496.5	95					

From comparison of calculated F_{ratio} and F_{ratio} table values at specified degrees of freedom and 5 % level of significance for the healing agents (rows), $F_{ratio\ (calculated)}$ = 463.9695 and $F_{ratio\ (critical)}$ = 2.7375. Therefore null hypothesis was rejected because $F_{ratio\ (calculated)} > F_{ratio\ (critical)}$ [12]. This implied that the rows (healing agents) influenced impact strength of the composite

Also calculated F_{ratio} and F_{ratio} table values at specified degrees of freedom and 5 % level of significance for the significant healing time (columns)), $F_{ratio\ (calculated)}$ = 13.6876 and $F_{ratio\ (critical)}$ = 1.6869. Therefore null hypothesis was rejected because $F_{ratio\ (calculated)} > F_{ratio\ (critical)}$. This implied that the columns (significant healing time) influenced impact strength of the composite.

For tensile strengths tests, composite test pieces healed by use of epoxy resin healing agent gave the highest recovered impact strength of 60 J.mm^2.

Table -6 ANOVA for recovered tensile strength

ANOVA							
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	***Decision***
Rows	19901.58	3	6633.861	166.3035	1.65E-31	2.737492	Reject Ho
Columns	9004.5	23	391.5	9.814466	6.78E-14	1.686897	Reject Ho
Error	2752.417	69	39.8901				
Total	31658.5	95					

From comparison of calculated F_{ratio} and F_{ratio} table values at specified degrees of freedom and 5 % level of significance for the healing agents (rows), $F_{ratio\ (calculated)}$ = 166.3035 and $F_{ratio\ (critical)}$ = 2.7375 Therefore null hypothesis was rejected because $F_{ratio\ (calculated)} > F_{ratio\ (critical)}$. This implied that the rows (healing agents) influenced tensile strength of the composite.

Also calculated F_{ratio} and F_{ratio} table values at specified degrees of freedom and 5 % level of significance for the significant healing time (columns), $F_{ratio\ (calculated)}$ = 9.8145 and $F_{ratio\ (critical)}$ = 1.6869 Therefore null hypothesis was rejected because $F_{ratio\ (calculated)} > F_{ratio\ (critical)}$. This implied that the columns (significant healing time) influenced tensile strength of the composite.

For tensile strengths tests, composite test pieces healed by use of tannin gum healing agent gave the highest recovered tensile strength of 69 MPa. It was also noted that the variation of healing agents was very significant in influencing recovered tensile strengths as seen from the very low P-Value [15].

Table 7 ANOVA for recovered compressive strength

ANOVA								
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*F crit*	***Decision***
Rows	148185.7	3	49395.24	1323.194	7.04E-61	2.737492	2.737492	Reject Ho
Columns	7314.125	23	318.0054	8.518692	1.88E-12	1.686897	1.686897	Reject Ho
Error	2575.792	69	37.33031					
Total	158075.6	95						

From comparison of calculated F_{ratio} and F_{ratio} table values at specified degrees of freedom and 5 % level of significance for the healing agents (rows), $F_{ratio\ (calculated)} = 1323.914$ and $F_{ratio\ (critical)} = 2.7375$ Therefore null hypothesis was rejected because $F_{ratio\ (calculated)} > F_{ratio\ (critical)}$. This implied that the rows (healing agents) influenced compressive strength of the composite.
Also calculated F_{ratio} and F_{ratio} table values at specified degrees of freedom and 5 % level of significance for the significant healing time (columns), $F_{ratio\ (calculated)} = 8.5187$ and $F_{ratio\ (critical)} = 1.6869$. Therefore null hypothesis was rejected because $F_{ratio\ (calculated)} > F_{ratio\ (critical)}$. This implied that the columns (significant healing time) influenced compressive strength of the composite.
For compressive strengths tests, composite test pieces healed by use of epoxy resin healing agent gave the highest recovered compressive strength of 151 MPa.

Percentage recovered mechanical strength
A comparison was done between pristine mechanical strengths and recovered mechanical strength after healing and retest. It was noted that the recovered mechanical strength was above 80 % in all cases concerning the specific tests and respective retests. This result was significant for decision making as to whether the healed rice husks fibre reinforced polypropylene composites had the potential of reuse after fracture and subsequent healing. Percentage recovered mechanical strength were as shown in table 8.

Table -8 Percentage recovered mechanical strengths after retest

Mechanical test	Pristine strength	Recovered strength	% strength recovery	Remarks
Impact	61 J/mm^2	60 J/mm^2	98.36	Test piece can be reused
Tensile	85 MPa	69 MPa	81	Test piece can be reused
Compressive	178 MPa	151 MPa	85	Test piece can be reused

Both the pristine and recovered tensile strengths were low. This could be attributed to low cellulose content of the rice husks fibres used to reinforce polypropylene. The high impact strength was attributable to stronger interface of the composite resulting from both fibre surface treatment as well as high silica content of rice husks.

CONCLUSION AND RECOMMENDATION

Surface modification of rice husks during composite constituents preparation aided in producing composite with strong interface. Variation of fibre content in composite modified resulting mechanical strength. This was also enhanced by longer cooling times before testing for the produced composites. However, % fibre weight fractions less or higher than 40 % did not produce composites with maximum mechanical strength. The mechanical strengths reduced significantly with reduction in % fibre weight fraction below 40 %, with a similar reduction observed in strength occurring with increase of % fibre weight fraction beyond 40 %.
Both healing agents and healing time before retesting caused variation in recovered mechanical strength. The highest recovered impact and compressive strength was obtained by use of epoxy resin healing agent with 75 minutes healing time and highest recovered tensile strength was obtained by use of tannin gum healing agent also with 75 minutes healing time. Beyond this healing time, the results were unstable possibly due to very small but significant environmental exposure including the effect of moisture ingress prior to pseudo equilibrium point. Healed test pieces from bending destructive test gave inconsistent results. This was attributable to very small displacement which may have occurred during prior bending tests before healing and retesting. The cure to this would require instrumented bending test machine for capturing the small displacements and then undertaking compression after bending test before healing the fractured test pieces and subsequent retesting.
Mechanical strength of pristine rice husks fibre reinforced polypropylene composites were sufficient for their use in light load structural applications. After healing and retesting, recovered mechanical strengths were high enough to conclude that the healed test pieces could be reused for their original light load structural functions.
Further research with similar plant based fibres for reinforcing polymers to form composite, destructive testing and repair is recommended to expand possibility of commercial sustainable production and reuse of the plant based reinforced polymer composite material after healing. This would go along way in reducing demand for timber thus saving the forests and mitigating potential environmental disasters associated with deforestation.

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