“Characterization and Optimization of Mechanical Performance of Natural Fiber Composites for Automobile Applications”

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By

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Title of the Thesis

"Characterization and Optimization of Mechanical Performance of Natural Fiber Composites for Automobile Applications"

Abstract

Since many years development of synthetic fibers has dominated but nowadays the rising interest in environmental awareness is rapidly springing up in terms of industrial applications. In today's developing era the concern for the prevention of non-biodegradable resources has attracted researchers to develop biodegradable materials based on green principles.

The fibers from agriculture waste give good advantages over conventional synthetic fibers such as low cost and density, non-toxicity, least environmental concern and waste disposal problems. In this work banana fibers and coir fibers have been used as the reinforcing agent with corn starch and glycerol as the matrix to increase the effectiveness of natural fibers.

Alkali treatment has been carried out to change the state of the materials from hydrophilic to hydrophobic. The composites have been fabricated by injection moulding method followed by high speed mixing and twin screw extrusion. In the present study, an effort has been made to fabricate a banana fiber and banana-coir fiber reinforced hybrid green composite with different combinations to enhance the mechanical properties. From the results, it has been observed that the composites having greater fiber content show evidence of superior properties.

As polymers matrix composites are being utilized in many applications, it is very important to enhance the mechanical properties of such composites by deriving the multiple response based different input parameter combination. The analysis of variance has been carried out to prove the homogeneity of the composite samples. Grey relational analysis has been proposed in decision making process to rank the mechanical properties with respect to different input variables. It shows how the input variable affects the different mechanical properties and gives best suitable combination of input variable. It has been observed that banana fiber is making the most influential effect on the mechanical properties.

Brief Description of the Research Topic

The history of composite materials prevails from the era of Mesopotamians and Egyptians to the present when different types of composites were developed and used for a wide variety of applications. The modern era of composites began when scientists developed plastics until natural resins derived from plants and animals were the only source of glues and binders. In 1868, American inventor John Wesley Hyatt with his brother Isaiah, patented the first plastic injection moulding machine in 1872. However, plastics alone could not provide enough strength for some structural applications. Reinforcement was needed to provide additional strength and rigidity. Though composite is a term which is used for a very long still a clear definition has not been evolved. In an extensive sense natural or artificial mixture of two or more phases is known as composite, whereas discontinuous phase is known as reinforcement and continuous phase is known as matrix. The prime goal of this material is to achieve a better balance of properties from the combination of materials.

Since many years development of synthetic fibers has dominated but nowadays the rising interest in environmental awareness is rapidly springing up in terms of industrial applications. Natural abundance, low density, low weight, high strength, very low cost and biodegradable nature make natural fiber striking as reinforcement than conventional synthetic fiber for engineering applications. Increasing environmental awareness and social concern has led to the need for green plastics as an alternative to traditional plastics. The realization of green composite is actually possible by combining a biopolymer with natural fibers. Nowadays this kind of composite are used in the packaging industries and other low strength applications.

GC has recently had a great interest for increased fuel efficiency in cars and cheaper building materials and growing public interest in environmental preservation. Due to significant weight saving and low cost of the raw materials, attractive alternative to glass and carbon fiber reinforced composites, the automobile sector needs to approach to overcome the problems and started to apply natural fiber reinforced composite in a variety of applications. The advantages of using natural fibers in composite for automobile applications can be summarized as follows: They are process friendly, having lower specific weight, do not wear out tooling and having good thermal as well as acoustic insulating properties.

However drawbacks such as the tendency to poor resistance to moisture greatly reduce the potential of natural fibers. Other than this limited maximum processing temperature, lower durability and fluctuation of prices can limit their industrial application.

Definition of the Problem

Problem defined in three different categories, (i) literature review, (ii) finding research gap and (iii) Problem definition.

A lot of research has been done on natural fiber based composites but research on fabrication of natural fiber reinforced green composites is very rare. Against this background, the present research work has been undertaken, with an intention to discover the potential of natural fiber and biopolymer based recyclable green composites for automobile applications.

Objectives and Scope of Work

The objectives of this investigation are to fabricate, characterize, optimize and achieve an improved understanding of the mechanical properties of green composite for automobile applications. The objectives of the research investigation are outlined below.

- To study the effect of alkali treatment on banana and coir fibers by scanning electron microscope.
- To fabricate the banana fiber reinforced and banana-coir fiber reinforced hybrid green composites with succession of different manufacturing processes.
- To evaluate the mechanical properties like tensile properties, flexural properties, impact strength and shore hardness of newly fabricated green composites.
- To optimize of mechanical properties and to find the best influential input parameter of green composites through multi variable optimization techniques.

Due to high strength, high toughness, high production rate and least environment concern thermoplastic is used over thermoset composites. In this work natural fibers are preferred over synthetic traditional fibers because it has very low cost, low density, low energy consumption and 100% biodegradability. Banana fibers and coir fibers have been selected as natural fiber corn starch and glycerol as matrix. As banana fibers are extracted from stem of the plant and coir fibers are from outer shell of the fruit both the fibers are waste product and no special harvesting is required while corn starch is having good Machinability and processability. Fiber content and matrix contents are restricted up to 10-30% and 70-90% respectively because injection moulding is not feasible for higher fiber content and work shows the poor mechanical properties for higher fiber content. To get higher production rate and sufficient strength injection moulding process has been selected over traditional hand layup method. In these work only physio-mechanical tests has been carried out as per ASTM standards. Application of newly developed green composites is restricted for automobile sector only.

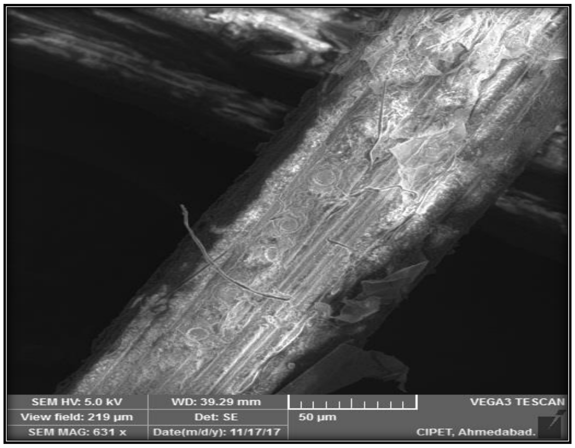
Original Contribution by the Thesis

Banana fiber is a bast natural fiber from musaceae family which is extracted from pseudo stem of banana tree. Banana fibers (Riddhi Enterprise, Ahmedabad) and Coir fiber (Maitri Enterprise, Mangrol) are used as a reinforcement material for green composite. Corn starch (Central Drug House (P) Ltd., New Delhi) and glycerol (Qualigens, Thermo Fisher Scientific, Mumbai) are used as a matrix material. Sodium Hydroxide (Qualigens, Thermo Fisher Scientific, Mumbai) is used for alkali treatment of banana fiber.

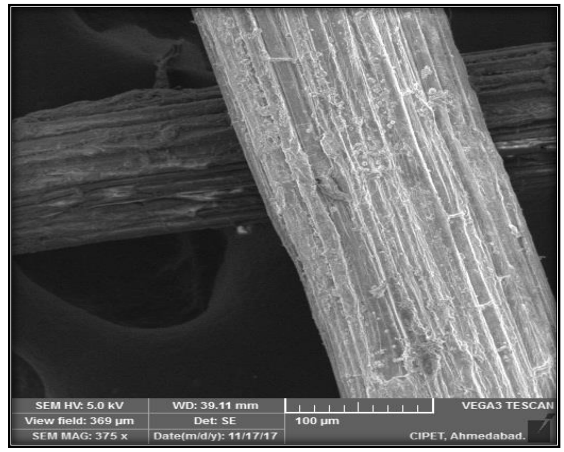
Alkali Treatment the cause the changes in the crystal structure of cellulose. Mercerization process changes the orientation of highly packed crystalline cellulose and forms an amorphous region by swelling the fiber cell wall. The fibers have been immersed in 4% NaOH at room temperature for 4-6 hrs which activates the –OH group of cellulose and lignin. The fibers have been washed with distilled water thoroughly to remove the excess of NaOH and finally dried in hot air oven at 70° for 2 hrs. NaOH increased the crystalline fraction of fiber due to removal of lignin. The dried fiber will be subsequently cut in to lengths of 3 to 4 mm.

SEM micrographs of non-treated and alkali treated banana and coir fibers are shown in Figure 1. This treatment enables improved reception to penetration by chemicals.

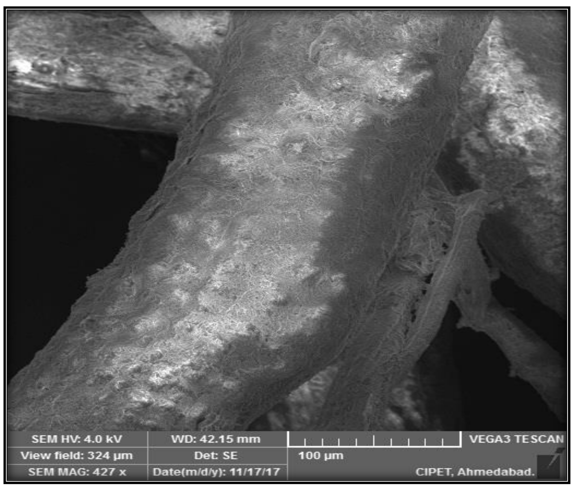
Biopolymer has been prepared by melt processing techniques. Corn starch and glycerol of 70:30 wt% ratio has been taken for high speed mixing (Maliksons High Speed Mixer, Model: HSM 5, Delta Machine Craft, Mumbai) to prepare a polymer matrix. Twin Screw Extruder (Model: High Torque ZV 20, Specifiq, Specific engineering and Automats, Vadodara) is used for compounding of both the materials. Alkali treated banana fiber, coir fiber and polymer matrix pallets have been mixed in the different wt % ratio as shown in Table 1. The mixer of fibers and matrix material is again processed in twin screw extruder. Extruded materials were air cooled and then pallets have been made. Injection moulding machine (40T Allplas, M/s Allied International, Agra) is used to make the specimens from the pallets.



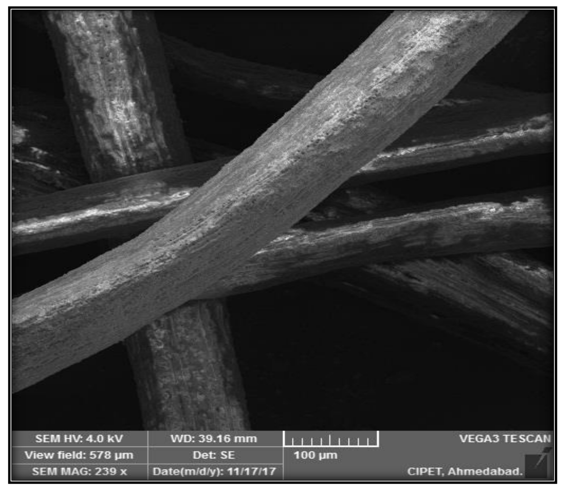
(a)



(b)



(c)



(d)

Figure 1 (a) Untreated Banana Fiber (b) NaOH treated Banana Fiber (c) Untreated Coir Fiber (d) NaOH treated Coir Fiber

Methodology of Research and Result

This technique is used when multiple cases are involved. It is a procedure for testing the difference among different groups of data for homogeneity. Two estimates of population variance (between samples and within samples variance) are required which are compared with F-test. Here ANOVA is carried out to find out that there is no level of significance in selecting the samples for different mechanical properties.

Table 1 Mechanical Properties of Green Composite Samples

Sr. No.	Sample Name	Tensile Strength (MPa)	Tensile Modulus (MPa)	Flexural strength (MPa)	Flexural Modulus (MPa)	Impact Strength (J / m)	Shore D Hardness
1	10-0-90	1.15	12.77	1.39	36.58	46.59	48
		1.02	11.81	1.42	36.37	46.88	49
		1.14	14.89	1.28	36.88	47.5	49
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		-----	-----	-----	-----	-----	49
2	20-0-80	1.20	24.55	2.41	77.47	66.33	55
		1.64	27.57	2.41	78.30	70.49	55
		1.60	34.44	2.46	71.06	76.57	55
		-----	-----	-----	-----	-----	56
		-----	-----	-----	-----	-----	57
3	30-0-70	3.95	44.02	2.63	64.14	58.45	56
		3.74	44.55	2.60	62.92	59.23	59
		3.60	40.69	2.93	61.67	60.93	60
		-----	-----	-----	-----	-----	61
		-----	-----	-----	-----	-----	64
4	5-5-90	1.96	20.25	1.75	47.74	80.35	54
		2.14	26.23	2.05	47.53	102.48	54
		2.29	23.39	2.08	47.57	127.24	58
		-----	-----	-----	-----	-----	58
		-----	-----	-----	-----	-----	59
5	10-10-80	2.58	14.07	1.52	34.50	124.57	52
		2.63	14.89	1.59	33.46	125.76	52
		2.57	14.29	1.62	33.54	145.44	52
		-----	-----	-----	-----	-----	53
		-----	-----	-----	-----	-----	53
6	15-15-70	2.38	46.32	1.51	27.68	180.58	48
		2.18	42.97	1.41	30.00	241.81	48
		2.34	34.22	1.56	30.32	272.86	49
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In the present study an attempt has been made to introduce GRA on mechanical properties of newly fabricated green composites to find the best optimum mechanical properties and most influential input parameter.

The normalized experimental results of the mechanical properties are introduced to calculate the coefficient and grade according to grey relational analysis. The experimentally obtained values of all the properties are presented in Table 1.

Table 2 Two way ANOVA without replication for Tensile Strength

	Source of Variation	SS	df	MS	F	P-value	F crit
Banana Fiber	Rows	0.001	2	0.001	**0.015**	0.985	**6.944**
	Columns	12.436	2	6.218	**130.016**	0.000	**6.944**
	Error	0.191	4	0.048			
	Total	12.629	8				

	Source of Variation	SS	df	MS	F	P-value	F crit
Banana-Coir Fiber	Rows	0.016	2	0.008	**0.511**	0.634	**6.944**
	Columns	0.330	2	0.165	**10.368**	0.026	**6.944**
	Error	0.064	4	0.016			
	Total	0.410	8				

Table 3 Two way ANOVA without replication for Tensile Modulus

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Banana Fiber	Rows	13.262	2	6.631	**0.511**	0.634	**6.944**
	Columns	1344.659	2	672.330	**51.823**	0.001	**6.944**
	Error	51.894	4	12.974			
	Total	1409.816	8				

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Banana-Coir Fiber	Rows	26.254	2	13.127	**0.751**	0.529	**6.944**
	Columns	1114.337	2	557.168	**31.867**	0.003	**6.944**
	Error	69.936	4	17.484			
	Total	1210.527	8				

Table 4 Two way ANOVA without replication for Flexural Strength

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Banana Fiber	Rows	0.012	2	0.006	**0.369**	0.713	**6.944**
	Columns	3.055	2	1.527	**91.970**	0.000	**6.944**
	Error	0.066	4	0.017			
	Total	3.134	8				

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	F crit
Banana-Coir Fiber	Rows	0.038	2	0.019	**1.711**	0.290	**6.944**
	Columns	0.375	2	0.187	**17.079**	0.011	**6.944**
	Error	0.044	4	0.011			
	Total	0.456	8				

Table 5 Two way ANOVA without replication for Flexural Modulus

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Banana Fiber	Rows	15.262	2	7.631	**1.582**	0.312	**6.944**
	Columns	2373.901	2	1186.951	**246.119**	0.000	**6.944**
	Error	19.291	4	4.823			
	Total	2408.453	8				

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Banana-Coir Fiber	Rows	0.403	2	0.201	**0.181**	0.841	**6.944**
	Columns	544.489	2	272.245	**244.664**	0.000	**6.944**
	Error	4.451	4	1.113			
	Total	549.343	8				

Table 6 Two way ANOVA without replication for Impact Strength

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Banana Fiber	Rows	31.521	2	15.761	**2.505**	0.197	**6.944**
	Columns	874.564	2	437.282	**69.491**	0.001	**6.944**
	Error	25.171	4	6.293			
	Total	931.255	8				

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Banana-Coir Fiber	Rows	4273.360	2	2136.680	**5.654**	0.068	**6.944**
	Columns	27266.266	2	13633.133	**36.079**	0.003	**6.944**
	Error	1511.491	4	377.873			
	Total	33051.118	8				

Table 7 Two way ANOVA without replication for Shore Hardness

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Banana Fiber	Rows	21.733	4.000	5.433	**2.672**	0.110	**3.838**
	Columns	318.400	2.000	159.200	**78.295**	0.000	**4.459**
	Error	16.267	8.000	2.033			
	Total	356.400	14.000				

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Banana-Coir Fiber	Rows	15.067	4.000	3.767	**2.861**	0.096	**3.838**
	Columns	160.133	2.000	80.067	**60.810**	0.000	**4.459**
	Error	10.533	8.000	1.317			
	Total	185.733	14.000				

Table 8 Calculation of S/N Ratio and Data Normalization by GRA

Exp. No.	S/N Ratio						Normalized Data					
	Ts	Tm	Fs	Fm	Is	Hs	Ts	Tm	Fs	Fm	Is	Hs
1	0.79	22.26	2.67	31.27	33.44	33.77	0.000	0.000	0.000	0.237	0.000	0.020
2	3.12	28.95	7.70	37.55	37.00	34.90	0.217	0.643	0.842	1.000	0.264	0.646
3	11.49	32.66	8.65	35.97	35.49	35.54	1.000	1.000	1.000	0.808	0.152	1.000
4	6.51	27.20	5.77	33.55	39.83	35.04	0.535	0.474	0.519	0.514	0.475	0.723
5	8.28	23.17	3.94	30.58	42.34	34.39	0.700	0.087	0.212	0.153	0.661	0.362
6	7.21	32.07	3.46	29.32	46.90	33.73	0.600	0.943	0.132	0.000	1.000	0.000

Table 9 Calculation of Deviation Sequence and Grey Relation Co-efficient

Exp. No.	Deviation Sequence						Grey Relation Co-efficient						GRG
	Ts	Tm	Fs	Fm	Is	Hs	Ts	Tm	Fs	Fm	Is	Hs	
1	1.000	1.000	1.000	0.763	1.000	0.980	0.500	0.500	0.500	0.567	0.500	0.505	0.512
2	0.783	0.357	0.158	0.000	0.736	0.354	0.561	0.737	0.863	1.000	0.576	0.739	0.746
3	0.000	0.000	0.000	0.192	0.848	0.000	1.000	1.000	1.000	0.839	0.541	1.000	0.897
4	0.465	0.526	0.481	0.486	0.525	0.277	0.682	0.656	0.675	0.673	0.656	0.783	0.687
5	0.300	0.913	0.788	0.847	0.339	0.638	0.769	0.523	0.559	0.542	0.747	0.610	0.625
6	0.400	0.057	0.868	1.000	0.000	1.000	0.714	0.946	0.535	0.500	1.000	0.500	0.699

Table 10 Response Table from Grey Relational Grade

Symbol	Input Factors	Grey Relational Grade				Rank
		Level-1	Level-2	Level-3	Max - Min	
B	Banana Fiber	0.350	0.660	0.794	0.444	1
B.C.	Banana-Coir Fiber	0.496	0.543	0.512	0.047	3
C.S.	Corn Starch	0.423	0.602	0.653	0.23	2

There are three results for each mechanical property per sample. Now data shown in Table 1 has to be transformed in to S/N ratio (See Table 8). Since all the mechanical properties has to be maximized so larger the better type of quality characteristics need to consider. The experimental results have been normalized for all the input parameter called grey relational generation (See Table 8). From the normalized data set, deviation sequence is calculated (See Table 9). The results of grey relational coefficient have been calculated with the help of quality loss which is absolute difference between normalized values (See Table 9). Grey relational grades have been found out using the results of grey relational coefficient which shows in Table 9. From the values of grey relational grade the effect of each input parameter can be observed.

The higher result of relational grade indicates stronger correlation to the reference series and good performance. Here higher value of grey relational grade gives maximum possible values of all mechanical properties. The optimal combination has been chosen based on higher grey relational grade result. Mean grey relational grade is presented in Table 10. The difference of maximum and minimum values of mean grey relational grade for all parameters has been obtained. The sequence of importance of input parameter on multi responses are shown by giving rank in Table 10.

Achievements with respect to objectives

Alkaline treatment has two effects on fibers: (1) Increases surface roughness resulting in better mechanical interlocking (2) Increases the amount of cellulose exposed on the fiber surface which increases number of possible reaction sites. It was observed the removal of wax, pectin, lignin, hemicelluloses on fibers surface.

In this experimental study, banana fiber and banana-coir fiber reinforced and corn starch based hybrid green composites have been developed by injection moulding process.

This analysis shows that maximum tensile strength and modulus is 3.76 MPa and 43.08 MPa has been achieved respectively when banana fibers added up to 30% by weight.

The maximum value of flexural strength and modulus of banana fiber reinforced composites reaches up to 2.72MPa and 75.61MPa for fiber loading of 30% and 20% respectively while in case of hybrid composites it reaches up to 1.96 MPa and 47.61 MPa for fiber loading of 5% banana and coir fiber each.

It has been conclude that maximum impact strength can be achieved up to 20% of fiber loading only. After that impact strength decreases slowly. It has been measured 70.4 J/m and 145 J/m for banana fiber and banana-coir fiber reinforced composites respectively.

For banana fiber and banana-coir fiber reinforced hybrid composites, experimental result shows that if fiber loading increases more than 20% and 10% respectively, the shore hardness values goes down. There is no significant difference observed when fiber loading increases more than 20%.

To validate the experimental results and to evaluate the accuracy of the analysis, confirmation tests have been performed. Results of ANOVA fall in to acceptance region. Hence, analysis supports the null hypothesis. There is no significance difference between the samples and is just a matter of chance. But there is a significant difference in mechanical properties with percentage mixture of fiber.

In grey relational analysis, higher grey relational grade represents that the corresponding experimental result is closer to the ideally normalized value. Sample 3 (30-0-70) has the best multiple performance characteristics among all samples because it has the highest grey relational grade. The results from the response table indicate that the wt% of Banana Fiber has the most influencing effect on mechanical properties.

Conclusions (Abridge) and Future Scope

- SEM analysis shows that cemented materials like wax, pectin, lignin, hemicelluloses is removed from the multi cellular fiber wall and individual cells became more prominent which lead to the improvement of the composite mechanical properties.
- Composite made by injection moulding gives good interferential bonding between reinforcement and matrix.
- For the same wt% hybrid composite gives better result than BFRC (up to 20%). Higher banana fiber content gives higher tensile modulus.
- Flexural properties decrease with the inclusion of coir fiber.
- Coir fiber increases the impact strength drastically as compared to BFRC.
- Same hardness can be achieved by hybrid composite with lower % of reinforcement.
- GRA shows that banana Fiber has the most dominating effect on mechanical properties than coir fiber and corn starch.
- GC is eco-friendly and economical materials & its application is possible in automotive industry.
- Grafting of Eco-nano-particles could be the best solution for material property improvement.
- Action should be undertaken in solving challenges related to moisture absorption rate and poor fiber matrix interaction.
- Apart from interior non-structural parts of automobile, structural parts with very high strength materials can be developed by green composite.

List of Publications

1. Pandya, V. J., & Rathod, P. P. (2017). Study of Biodegradable Matrix Materials for Green Composites : A Review. *INTERNATIONAL JOURNAL OF ADVANCE ENGINEERING AND RESEARCH*, 2–5.
   DOI: IJAERD 04 1046067 ***(UGC Approved)***
2. Pandya, V. J., & Rathod, P. P. (2018). Processing and Properties of Corn Starch based Thermoplastic Matrix for Green Composites : A Review. *JOURNAL OF POLYMER AND COMPOSITES*, *6*(1), 1–5.
   (UGC Approved, Web of Science Listed)
3. Pandya, V. J., & Rathod, P. P. (2019). Experimental Study of Banana Fiber Reinforced Green Composite. *INDIAN SCIENCE CRUIZER*.
   doi.org/10.24906/isc/2019/v33/i2/183891. ***(UGC Approved)***
4. Pandya, V. J., & Rathod, P. P. (2019). Fabrication and Mechanical Properties Evaluation of Banana and Coir Fiber Reinforced Green Composites. *A JOURNAL OF COMPOSITION THEORY*, *XII* (206), 206–215.
   DOI:19.18001.AJCT.2019.V12I7.19.10023 ***(UGC CARE 'A' Approved)***
5. Pandya, V. J., & Rathod, P. P. (2019). Optimization of mechanical properties of green composites by gray relational analysis. *MATERIALS TODAY: PROCEEDINGS*.
   doi.org/10.1016/j.matpr.2019.08.166 ***(Scopus & Web of Science Listed)***

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