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Optimization in Characteristics of Jute/Epoxy Composites for automotive applications Using Gray relation analysis

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Abstract

In Automotive sector, the evolution of new and improved composite material has triggered infinite product development prospects. Use of natural fibers is having great opportunity, in the development of automotive parts with polymer reinforced composites. Composite specimens were made with three different volume fractions (8.3%, 10% and 12.5%) of fibers and three different thicknesses (4 mm, 6 mm and 8 mm). The influences of fiber content and thickness on composite properties like tensile, compression, flexural, impact tests and water absorption, density were validated using analysis of variance (ANOVA). Grey relational analysis (GRA) is used for determine the optimal setting of process parameters for multi objective characteristics of jute fiber reinforced epoxy composites. Multi objective optimization using GRA shows the optimal combination of 10% volume fraction and 8 mm thickness of composites.

Further using optimal combination of jute fiber reinforced epoxy composites were developed for automotive application. The vehicle mudguard and mirror pocket were successfully fabricated with using simple hand layup method. As results suggest that jute fiber reinforced epoxy composites can be replaced synthetic fiber composites. Although these jute/epoxy composites may be used in other automotive applications such as door panel, seatbacks, dash board, car roof, door handle, door panels.

I INTRODUCTION

The use of natural fibers in composites is increasing due to its property advantages such as high availability, eco-friendly, relatively non- abrasive and potential for energy recovery Synthetic polymer composites have major issues such as waste disposal and recycling[2-4,6].

Due to this the application of natural fiber based composites is increasing rapidly[8]. The reuse of waste natural fiber has great advantages, major reasons of increasing growth of renewable materials use is the increased awareness about environment [3.] Natural fiber has been used in various fields of industry such as construction and building, transportation, packaging as well as storage devices, military applications, consumer products[12, 14]. Natural fibers can be used interior and exterior components of automotive applications. The interior components such as door cladding, seatbacks lining, seat bottoms, back cushions, head restraints, door trim, head-liners, and trunk-liners and exterior components such as dashboards, bumpers, exterior body panel[9, 14]. S.C.R.Furtado et al. investigated that dynamic characteristic of jute fiber composite for automotive applications. Jute fiber composites having a higher damping behavior as compared to glass fiber composites. S.V.Joshi et al. studied natural fiber composites are emerging as a realistic alternative to glass-reinforced composites in the field of automotive. Ayrilmils et al. studied coir fiber reinforced polypropylene (PP) composite panel developed for automotive interior applications. In the automotive sector use which leads to a lowering in fuel consumption, good recycling possibilities, reducing the waste disposal problem, reduction of greenhouse emissions, Competitive pricing ,Technical advantages ,Growth opportunity for agriculture , Social benefits[1,14].

The objective of this paper was to evaluate and multi optimize the mechanical and physical properties of jute fiber reinforced epoxy composites. Based on above measured properties and optimal process parameters developed automotive parts.

II SYSTEM ARCHITECTURE

In this study two natural fibers were taken, coir and jute fiber. These fibers mat were prepared in central institute of coir technology, Coir board, Bangalore (India). Epoxy resin of grade 505C and hardener EH 411 was supplied by Dobeckot.

Figure 1: Jute fiber mat and epoxy resin

Jute fiber reinforced epoxy composite (JFREC) composite materials were fabricated through the hand lay-up technique. The JFREC had fabricated with different volume fraction of fiber and different thickness of specimens. Composite sheets were made with 4 mm, 6 mm and 8 mm thickness and 8.3 % vol., 10 % vol. and 12.5 % vol. of fiber. Following table 1 shows detail of experimentation combinations,

Table 1: Process parameter and their levels

Level	Volume fraction of fiber (%)	Thickness (mm)
Low	8.3	4
Medium	10	6
High	12.5	8

The experiments were performed according to the trial condition as per L9 Orthogonal Array shown in Table 2,

I. Table 2: L9 Design matrix with actual values of level

Expt. No with designation	Vol. fraction of fiber (%)	Thickness(mm)
E 1	8.3	4
E 2	8.3	6
E 3	8.3	8
E 4	10	4
E 5	10	6
E 6	10	8
E 7	12.5	4
E 8	12.5	6
E 9	12.5	8

2.2 Composite Testing

The tensile and compressive tests were performed in the universal testing machine (UTM) Instron 1195. The ASTM standard test method for tensile and compression strength of fiber resin composites has the designation D 638 and D695 respectively. Flexural test was the three point bending test conducted as per ASTM D790 standard. The impact strength was conducted according to ASTM D256. The specimens were of rectangular shape having dimensions (64 × 13 mm). Water absorption was to determine the water absorption behavior of jute reinforced epoxy composites according to ASTM D598. The density measurement was performed by using direct method (weight/volume).

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III. PROPOSED SYSTEM

JFREC were fabricated as per the full factorial design (2 parameters and 3 levels in each parameters) 9 combinations. The results of tensile, compressive, flexural, impact test, water absorption and density are given in table 3.

Table 3: Mechanical and physical properties of JFREC

Experiment no.	Tensile strength (MPa)	Compressive Strength (MPa)	Flexural Strength (MPa)	Impact Strength (KJ/m^2)	Water Absorption %	Density (gm/cc)
01	26.44	52.4	40.91	2.84	2.15	1.02
02	27.96	57.33	44.60	2.13	2.85	1.08
03	27.26	53.88	44.32	3.46	2.97	1.02
04	28.55	60.10	46.84	2.98	3.02	1.01
05	28.65	59.85	48.78	3.21	3.46	1.03
06	32.10	62.80	46.98	4.98	3.46	0.94
07	20.11	41.3	34.95	6.23	3.13	0.87
08	23.78	50.56	40.54	5.45	4.25	0.95
09	31.56	57.65	45.7	7.79	5.79	0.934

3.1 Taguchi method

Taguchi method is widely used in optimization of process parameters. S/N ratios are calculated based on the smaller the better and the larger the better concepts, depending on the quality parameters[10,11,15]. In this study the S/N ratio is calculated using the larger the better concept for tensile, compressive, flexural and impact strengths and lower is better for water absorption, density. This is shown in Eq. (1 and 2),

1. Larger the better $\left(\frac{S}{N}\right)_{HB} = -10\ Log\ (MSD_{HB})$ (1)

Where, $MSD_{HB} = \frac{1}{R}\sum_{J=1}^{R} \left(\frac{1}{Y_J^2}\right)$

2. Lower the better $\left(\frac{S}{N}\right)_{LB} = -10\ Log\ (MSD_{LB})$ (2)

Where, $MSD_{LB} = \frac{1}{R}\sum_{J=1}^{R} \left(Y_J^2\right)$

Table 4: signal-to noise (S/N) ratios

Experiment no.	Tensile strength (MPa)	Compressive Strength (MPa)	Flexural Strength (MPa)	Impact Strength (KJ/m^2)	Water Absorption %	Density (gm/cc)
01	27.4452	34.3866	32.2366	9.0664	-6.6488	-0.1720
02	28.9307	35.1676	32.9867	6.5676	-9.0969	-0.6684

03	28.7105	34.6286	32.9320	10.7815	-9.4551	-0.1720
04	29.1121	35.5775	33.4123	9.4843	-9.6001	-0.0864
05	29.1425	35.5413	33.7648	10.1301	-10.7815	-0.2567
06	30.1301	35.9592	33.4383	13.9446	-10.7815	0.5374
07	24.0682	31.3190	29.8689	15.8898	-9.9109	1.2096
08	27.5242	34.0761	31.1577	14.0352	-11.0478	0.4455
09	29.9827	35.2024	33.1100	17.8107	-15.2536	0.5939

3.2 Multi-response optimization using GRA

In order to optimize the tensile strength, compressive strength, flexural strength, impact strength, water absorption and density grey relational analysis (GRA) has been utilized.

3.2.1: Normalization of S/N ratio

In the GRA data pre-processing is the initial step. It involves transforming an original sequence into a comparable sequence. A series of various units must be transformed to dimensionless quantities. Experimental results are thus normalized in a range of 0–1. Usually, each series is normalized by dividing the data in the original series by their average.

Table: 5 Sequence after data pre-processing

Expt. No.	Tensile strength	Compressive strength	Flexural strength	Impact strength	Water absorption	Density
1	0.5571	0.6611	0.3511	0.2223	0.0000	0.7356
2	0.8021	0.8294	0.8003	0.0000	0.2845	1.0000
3	0.7658	0.7132	0.7862	0.3748	0.3261	0.7356
4	0.8321	0.9177	0.9094	0.2594	0.3430	0.6901
5	0.8371	0.9099	1.0000	0.3169	0.4803	0.7808
6	1.0000	1.0000	0.9161	0.6561	0.4803	0.3579
7	0.0000	0.0000	0.0000	0.8291	0.3791	0.0000
8	0.2402	0.5942	0.2678	0.6642	0.5112	0.4068
9	0.9047	0.8154	0.8319	1.0000	1.0000	0.3278

3.2.2: Determination of deviation sequence

The deviation sequence $\Delta_{oi}(k)$ is the absolute difference between the reference sequence $x_i^0(k)$ and the comparability sequence $x_i^*(k)$ after normalization. It is determined using Eq.5 which is rewritten below for easy reference,

$$\Delta_{oi}(k) = |x_0^*(k) - x_i^*(k)| \qquad (5)$$

Table: 6 the deviation sequences

Deviation sequence	$\Delta_{01}(01)$	$\Delta_{01}(02)$	$\Delta_{01}(03)$	$\Delta_{01}(04)$	$\Delta_{01}(05)$	$\Delta_{01}(06)$

No.1,	i=1	0.4429	0.3389	0.6489	0.7777	1.0000	0.2644
No.2,	i=2	0.1979	0.1706	0.1997	1.0000	0.7155	0.0000
No.3,	i=3	0.2342	0.2868	0.2138	0.6252	0.6739	0.2644
No.4,	i=4	0.1679	0.0823	0.0906	0.7406	0.6570	0.3099
No.5,	i=5	0.1629	0.0901	0.0000	0.6831	0.5197	0.2192
No.6,	i=6	0.0000	0.0000	0.0839	0.3439	0.5197	0.6421
No.7,	i=7	1.0000	1.0000	1.0000	0.1709	0.6209	1.0000
No.8,	i=8	0.7598	0.4058	0.7322	0.3358	0.4888	0.5932
No.9,	i=9	0.0953	0.1846	0.1681	0.0000	0.0000	0.6722

3.2.3: Calculation of Grey Relational Coefficient (GRC) and Grey Relational Grade (GRG)

GRC for all the sequences expresses the relationship between the ideal (best) and actual normalized S/N ratio. If the two sequences agree at all points, then their Grey relational coefficient is 1. The Grey relational coefficient can be expressed by Eq.6 which reproduced as:

$$\gamma(x_0(k), x_i(k)) = \frac{\Delta_{min} + \zeta.\Delta_{max}}{\Delta_{0i}\ (k) + \zeta.\Delta_{max}} \qquad (6)$$

Where,k

$\Delta_{min} = min.min\ \Delta_{0,i}\ (k)$

$\Delta_{max} = max.max\ \Delta_{0,i}\ (k)$

$\Delta_{0i}\ (k)$ is the deviation sequence and

ζ = distinguishing coefficient, $\zeta \in (0,1)$ and for present study, ζ is set as 0.5.

The overall evaluation of the multiple performance characteristics is based on the Grey relational grade. The Grey relational grade is an average sum of the Grey relational coefficients, which can be calculated using Eq.7 and represented as:

$$\gamma(x_0, x_i) = \frac{1}{m}\sum_{i=1}^{m} \gamma(x_0(k), x_i(k)) \qquad (7)$$

Where,

$\gamma(x_0, x_{i)}$ is the Grey relational grade for the $j_{t\square}$ experiment and m is the number of performance characteristics.

Table: 7 Grey relational coefficients and grade values

No.	Tensile strength	Compressive strength	Flexural strength	Impact strength	Water absorption	Density	Grade value	Rank
1	0.5303	0.5960	0.4352	0.3913	0.3333	0.6541	0.4900	8
2	0.7165	0.7456	0.7146	0.3333	0.4114	1.0000	0.6536	5

3	0.6810	0.6355	0.7005	0.4444	0.4259	0.6541	0.5902	6
4	0.7486	0.8587	0.8466	0.4030	0.4321	0.6173	0.6511	4
5	0.7542	0.8474	1.0000	0.4226	0.4903	0.6952	0.7016	3
6	1.0000	1.0000	0.8563	0.5925	0.4903	0.4378	0.7295	2
7	0.3333	0.3333	0.3333	0.7453	0.4461	0.3333	0.4208	9
8	0.3969	0.5520	0.4058	0.5982	0.5057	0.4574	0.4860	7
9	0.8400	0.7303	0.7484	1.0000	1.0000	0.4266	0.7909	1

3.2.5: Analysis of Grey Relational Grade and Selection of Optimal Level of Parameters

Analysis of variance (ANOVA) of Grade values has been performed using statistical software, MINITAB on Grey relational grade values to evaluate the influence of process parameters on jute epoxy composites characteristics. ANOVA for grade values (Table 8) shows that parameters volume fraction (A) and Thickness (B) significantly affect the composite characteristics under 95% confidence levels. It is clearly observed from Table 7 the process parameter "setting of experiment no.9" has the highest Grey relational grade (0.7617) thus the 9th number experiment gives the best multiple performance characteristics among the 9 experiments. Using Taguchi method, response table has been generated to separate out the effect of each level of process parameters on Grey relational grade as shown in Table 8. Basically, larger the Grey relational grade, better the corresponding multiple composite characteristics. From the response table for Grey relational grade, the best combination of the process parameters is set with A3B3.

Table: 8 ANOVA for Grey Relational Grade

Parameter	**DOF**	**Seq. sum of square**	**Adj. Mean square**	**F**	**P**
Vol. fraction	2	0.03006	0.01503	1.35	0.357
Thickness	2	0.05018	0.02509	2.25	0.222
Error	4	0.04465	0.01166		
Total	8	0.12489			

Table: 9 Response Table for Grey Relational Grade (GRG)

Level	**Volume fraction**	**Thickness**
1	0.5780	0.5206
2	0.6941	0.6137
3	0.5659	0.7035
Max-min	0.1282	0.1829
Rank	2	1

Total mean value of GRG 0.6126

3.2.6: Prediction of Grey Relational Grade under optimum Parameters

After evaluating the optimal parameter settings, the next step is to predict and verify the improvement of quality characteristics using the optimal parametric combination.

The optimal Grey relational grade η_{opt} is predicted using same Eq.8 as below:

$$\eta_{opt} = \overline{T} + (\overline{A}_2 - \overline{T}) + (\overline{B}_2 - \overline{T}) \qquad (8)$$

Where

$\overline{T}$ = overall mean of the response

$\overline{A}_2, \overline{B}_2$ = average values of response at the second levels of parameters A and B respectively.

$\eta_{opt} = 0.7705$

The following table 10 shows the initial and optimum combination of jute fiber reinforced epoxy composites. The optimum combination is A2B3 (10% volume fraction of fiber and 8 mm thickness) gives Tensile strength 32.10 MPa ,compressive strength 62.80 MPa , flexural strength 46.98 MPa , impact strength 4.98 KJ/m^2, water absorption 3.46 % and density 0.94 gm/cc.

Table: 10 Initial and optimum values

Sr. No	**Composite characteristics** Optimal parameter	**Initial Combination** A3B3	**Optimum Combination** A2B3
1	Tensile strength	31.56	32.1
2	Compressive strength	57.56	62.8
3	Flexural strength	45.7	46.98
4	Impact strength	7.79	4.98
5	Water absorption	5.79	3.46
6	Density	0.934	0.94
	Grey Relational Grade	**0.7617**	**0.7705**

IV Applications

This research work found that JFREC has good mechanical and physical characterization which satisfies the minimum requirement of automotive interior and exterior component. It was found that range of tensile strength 19-32 MPa, compressive strength 45-

63 MPa, flexural strength 36-48 MPa, Impact strength 2-8 KJ/m^2, water absorption 2-6% and density 0.92-1.04 gm/cc.

The characteristics of JFREC were compared with minimum requirement of mudguard[7]. The result was shows that JFREC can be replaced existing material like glass fiber composites. Tables 11 indicate that JFREC obtained properties with minimum requirement of automotive non structural part.

Table: 11: Comparison of material requirement of automotive non structural parts with JFREC

Sr. no.	Material properties	Minimum requirement of automotive non structural parts	Properties JFREC
1	Density (Kg/m^3)	980-1100	940
2	Youngs modulus (GPa)	2-6	8
3	Tensile strength (MPa)	20-30	32.1

In this research study jute fiber reinforced with epoxy composites were used for fabricating automobile mudguard and mirror pocket successfully. The optimum parameter A2B3 (10% volume fraction and 8 mm thickness) were used. The simple hand layup method was used. Jute fiber mat layers were placed on a mold with epoxy resin applied to successive layers. A roller was used to remove entrapped air and control the thickness of product. The photographs of two wheeler mudguard, three wheeler mirror pocket and mudguard made from the jute fiber reinforced epoxy composites were shown in Figure 2 and 3.

Figure 2: mudguard used in two-wheeler vehicle.

Figure 3: mudguard and mirror pocket used in three-wheeler vehicle

V. CONCLUSION

This research work has discussed an application of the gray relation analysis (GRA) using analysis of variance (ANOVA) for investigating optimum combination of process parameter. This study leads following conclusion

- Jute fiber reinforced epoxy composites mechanical and physical properties greatly influenced by the fiber volume and thickness of composite. According to ANOVA of grade value, thickness is most significant parameters than volume fraction.
- Multi objective optimization using GRA shows that Initial combination (A3B3) grade i.e.,0.7617 increases by using new optimum combination (A2B3) grade up to 0.7705 Therefore, using present approach process parameters have been successfully optimized for better jute fiber reinforced epoxy composite characteristics.
- The results suggest that jute/epoxy composites were used for successfully fabricated motorcycle and three wheeler mudguard and mirror pocket. Although these composites may be used in other automotive applications such as door panel, seatbacks, dash board, car roof, door handle, door panels.

VI .ACKNOWLEDGEMENTS

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