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RESEARCH ARTICLE

Taguchi method for optimization of fabrication parameters with mechanical properties in fiber and particulate reinforced composites

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Abstract In this paper, the grey-based Taguchi method was used to optimize the fabrication parameters with mechanical properties (multiple performance characteristics) in roselle fiber with (5 % wt) Coconut shell powder (CSP) reinforced vinyl ester (RFRVE) composites. Composite plates were prepared based on the Taguchi's L_{27} orthogonal array using hand lay-up technique at room temperature. Fabrication parameters namely fiber length, fiber content, and fiber diameters were optimized based on the grey relational grade (GRG) as performance index obtained from the grey relational analysis to get the maximum level of multiple performance characteristics such as the tensile strength, the flexural strength, and the impact strength. The results show that the fiber content is the most significant fabrication parameter which greatly affects the mechanical properties of RFRVE composite compared to the fiber length and the fiber diameter. It was proved that the multiple performance characteristics of the plant based natural fiber and particle reinforced polymer composites can be effectively improved by this method.

Keywords Coconut shell powder (CSP) · Fiber · Polymer · Grey-based Taguchi

Introduction

Recently, the material engineers, scientists and researchers are focusing their interest in using lignocellulosic natural fibers such as jute, coir, sisal, pineapple,

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ramie, bamboo, and banana as reinforcement in polymers matrix [1–6]. These fibers are excellent raw materials for production of wide range of composites for different applications such as structural and automotive etc. and also now considered as serious alternative to synthetic fibers such as glass, for use in polymer composites as reinforcement [7]. Polymer composites reinforced with natural fibers are also claimed to offer environmental advantages such as reduced dependence on non-renewable energy/material sources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery, and end of life biodegradability of components. In recent years, many researchers have studied the mechanical behaviour of the plant based natural fiber reinforced polymer (NFRP) composites. Mostly, researchers have studied the mechanical behaviour of NFRP composites without and with modification of fiber and matrix materials. The effect of coupling agent and compatibilizer on the behavior of NFRP composites was also studied by some researchers. The main aim of the material engineers, scientist, and researchers was to obtain the better results (maximum response) for various combinations of fabrication parameters in NFRP composites. In the case of fiber reinforced polymer composites, the better results or response can be obtained by using the better combination (optimum) of fabrication parameters with cost effective manner. Very few research attempts have been done to optimize mechanical properties of the plant based natural fiber-polymer composites.

Generally, optimization problems are solved by conventional and non-conventional optimization methods. Conventional method is statistical design of experiment which includes Taguchi technique and response surface methodology. Non-conventional techniques include genetic algorithm, simulated annealing, and Tabu search etc. All the techniques are mostly used for solve the single objective problems. But in real time most of the engineering problems are multi-response in nature. To solve multi-objective problems, it is convenient to convert all the objectives into an equivalent single objective problem. A grey-based Taguchi technique can be used to solve the multi-objective problems. The integrated grey based Taguchi technique combines advantages of both grey relational analysis and Taguchi technique. In the grey relational analysis, the grey relational co-efficient can express the relationship between the desired and actual experimental results. Then a grey relational grade is obtained to evaluate the multi- response. Complicated multi-response problems are converted into a single response problems based on the grey relational grade. Grey based Taguchi technique was successfully applied to optimize the multi-response of complicated problems in various manufacturing areas [8–15]. The present study reports the application of grey-based Taguchi method in optimization of mechanical properties of RFRVE composites. Composite specimens were fabricated by hand lay-up method at room temperature and characterized based on mechanical properties such as tensile strength, flexural strength and impact strength. The result data are generalized and analyzed by the grey based-Taguchi method. A statistical analysis of variance (ANOVA) is performed to reveal the level of significance of influence of fabrication parameters on the mechanical properties of RFRVE composite. Confirmation tests are carried out to verify the optimal fabrication parameters combination.

Experimental procedure

Plan of experiments

An experiment is a process that results in the collection of data. In an experiment, we deliberately change one or more process variables in order to observe the effect the changes have on one or more response variables. The design of experiments (DOE) is an efficient procedure for planning experiments so that the data obtained can be analyzed to yield valid and objective conclusions. Taguchi method of design of experiment [16, 17] is a relatively simple and powerful tool for systematic modeling, analysis and optimization of the process parameters which includes selection of parameters, experimental design, conducting an experiment, data analysis, determining the optimal combination, and verification. Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a number of experiments, where the experimental results are transformed into signal-to-noise (S/N) ratio as the measure of the quality characteristic. Depending on the criterion for the quality characteristic to be optimized, the S/N ratio characteristics can be divided into three stages: smaller-the-better (for making the system response as small as possible), larger-the better (for making the system response as large as possible), and nominal-the-better (for reducing variability around a target). Regardless of the category of the performance characteristic, the larger Signal-to-noise ratio corresponds to the better performance characteristic. Therefore, the optimal level of the parameter is the level with the highest S/N ratio. Finally a confirmation experiment is carried out to verify the optimal combination of the parameter settings. Table 1 gives the fabrication parameters (control factors) used in preparation of composite specimens and their levels. During the mechanical testing of RFRVE composites, tensile strength, flexural strength, and impact strength have been considered as larger-the-better type in the present study. Hence, the *S*/*N* ratios SN_L of the quality characteristics (larger-the-better type) are expressed as:

$SN_L = -10$ Log [mean of sum of squares of reciprocal of measured data] i.e.,

$$SN_L = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (1)$$

where n is the number of replications; y_i is the observed response value, and $i = 1, 2, \ldots, n$.

Table 1 Fabrication parameters and their levels

Fabrication parameters	Level I	Level II	Level III
A: Fiber length (mm)	3	8	13
B: Fiber content (wt%)	18.88	36.01	51.79
C: Fiber diameter (mm)	0.24	0.82	1.45

Materials

Roselle fibers (*Hibiscus sabdariffa L.*) was used as reinforcement filler and purchased from nearby village (Mills Krishnapuram, Rajapalayam, Tamilnadu, India). Vinyl ester resin was used as a matrix material and purchased from GVR Chemicals, Trade name-Satyen Polymer (Satyen Polymers Pvt. Ltd., Bangalore), Madurai, Tamilnadu, India. Methyl ethyl ketone peroxide (MEKP), Cobalt napthenate (CoNap) and N, N-dimethylaniline were used as accelerator, catalyst and promoter respectively and purchased from GVR Chemicals.

Preparation of composite specimens

Composite specimens were manufactured by simple hand lay-up method developed in our laboratory at room temperature. Prior to processing, to ensure the easy removal of cured composite plate from the mould box, release agent (zinc stearate) and parting compound (poly vinyl acetate) was applied to the surfaces of the mould box. Before the impregnating the roselle fibers in resin matrix, vinyl ester resin, accelerator, catalyst, and promoter were mixed carefully in the ratio of 100: 2: 1.5: 2 by using a mechanical stirrer and then roselle fibers were pre-impregnated with the resin matrix. The impregnated roselle fibers and resin materials were poured in the mould box of size 150 × 150 × 3 mm. After pouring, the mould box is closed and allowed to cure at laboratory temperature for 24 h. Twenty seven composite plates with different combinations of fiber length (A), fiber content (B), and fiber diameter (C) were prepared based on the experimental design of Taguchi's L_{27} orthogonal array.

Taguchi method with grey relational analysis

Optimization of multiple performance characteristics (MPC) is not easy and much more attentions are required compared to single performance characteristics. Generally, Taguchi method solve only single response optimization problem. But in real time most of the engineering application problems are multi response in nature. To solve the multi-response problems (MRPs), it is convenient to convert all the objectives into an equivalent single objective. To solve the MRPs, Taguchi method is coupled with grey relational analysis (GRA). GRA is a measurement of the absolute value of the data difference between sequences, and is also used to measure an approximate correlation between sequences. This GRA based Taguchi method has been widely used in different fields of engineering to solve MRPs. In the present study, the problem has three performance characteristics such as tensile strength, flexural strength, and impact strength that need to be maximizing by choosing appropriate fabrication parameters (fiber length, fiber content, and fiber diameter). After the correct sequencing and analyzing, the fabrication parameters corresponding to the highest weighted GRG gave maximum values of the tensile strength, flexural strength, and impact strength. In this manner, the multi-response problem was converted into single response problem using GRA method. The steps followed in GRA based Taguchi method is shown in Fig. 1.

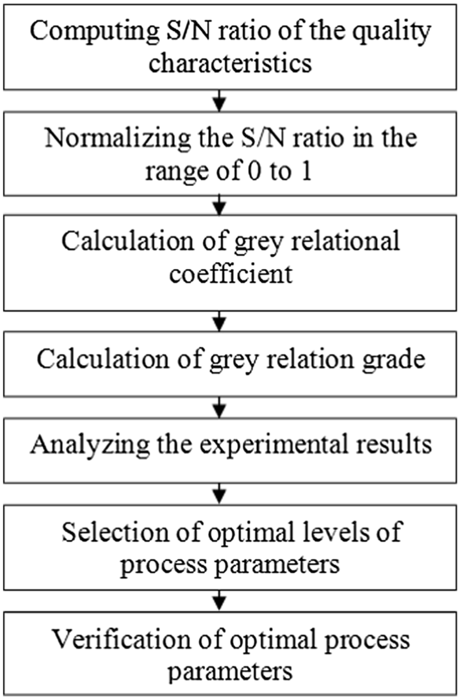

Fig. 1 Flow chart showing the various steps followed in grey –based Taguchi method

The desired quality characteristics of RFRVE composites should follow the larger – the better criterion (Eq. (1)). These quality characteristics are normalized between 0 to 1 using the following equation:

$$x_i^*(k) = \frac{x_i^{(0)}(k) - \min x_i^{(0)}(k)}{\max x_i^{(0)}(k) - \min x_i^{(0)}(k)} \tag{2}$$

where $x_i^{(0)}(k)$ is the original sequence; $x_i^*(k)$ is the sequence after the normalizing; max $x_i^{(0)}(k)$ is the largest value of $x_i^{(0)}(k)$ and min $x_i^{(0)}(k)$ is the smallest value of $x_i^{(0)}(k)$. Normalizing process can be used to reduce the variability between the data because one data may differ from others. After normalizing process, the GRC and GRG are calculated. The data sequences used in the GRA is called as GRC. They are used to express the relationship between the best and the actual experimental results. The equation for the GRC is denoted as

$$\zeta\left(x_0^*(k), x_i^0(k)\right) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{0i}(k) + \zeta\Delta_{\max}} \tag{3}$$

where $x_0^*(k)$ is reference sequence, $x_i^0(k)$ is the sequence to be compared. $\Delta_{\min}$ is the smallest value of $\Delta_{0i}(k)$, $\Delta_{\max}$ is the largest value of $\Delta_{0i}(k)$. $\Delta_{0i}(k)$ is the absolute value of the difference between $x_0^*(k)$ and $x_i^0(k)$, which is called deviation sequence, $\Delta_{0i}(k) = \|x_0^*(k) - x_i^0(k)\|$ and ζ is the coefficient of reorganization, $\zeta \in [0,1]$. After the determination of GRC, the average value of the grey relational coefficient is taken as the GRG. It shows the correlation between the reference data sequences and the comparability data sequences. The GRG is determined using the following equation:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \zeta_i(k) \tag{4}$$

where n is the number of process responses. The higher value of the grey relational grade represents the stronger relational degree between the reference sequence $x_0^*(k)$ and the given sequence $x_i^0(k)$. Therefore, the higher GRG means that the corresponding parameter combination is closer to the optimal one.

Characterization of composite

Composites were characterized for tensile, flexural and impact strength according ASTM standards. Tensile test was carried out on the specimen size of 150 mm × 20 mm × 3 mm according to ASTM D638-10. Tensile tests were performed on FIE universal testing machine with cross head speed of 2 mm/min and also with gauge length of 50 mm. Flexural tests were also carried out on same machine with same conditions according to ASTM D 790-10. Un-notched Izod impact tests were conducted on composite specimens according to ISO 180. All tests were carried out at a temperature of 27 °C and at the relative humidity of 50 %. Five composite specimens were tested for each combination and their average values were recorded. Table 2 shows the average values of tensile strength, flexural strength, and impact strength of composites prepared as per L_{27} orthogonal array.

Results and discussion

The static mechanical properties such as tensile, flexural and impact properties at maximum level provide the better strength of composite materials. Thus, data sequences of responses have the lager - the - better criterion and are used to calculate the S/N ratio. These values are normalized by using Eq. (2). The maximum tensile strength, flexural strength, and impact strength are set as a reference sequence $x_i^{(0)}(k)$, and the results of all experiments have the comparability sequences $x_i^*(k)$. After normalization, $x_0^*(k)$ is denoted as reference sequence and $x_i^0(k)$ is denoted as comparability sequence. Then, the absolute value of the difference between data sequences $(\Delta_{0i}(k)^)$ is calculated. The normalized values and the absolute values of the difference between reference and comparability sequence are given in Table 3.

After data processing of deviation sequence, the grey relational coefficient is determined using the Eq. (3). The value of ζ is taken as 0.5 because all the fabrication parameters influence the responses almost equally and substituted in Eq. (3). Then, the weighted GRG is calculated using the Eq. (4). The grey relational coefficient and weighted grey relational grade for each test is listed in Table 4. It is observed from the Table 4 that the test number 22 has the highest weighted GRG. Therefore, it may be considered as a best test sequence for obtaining the better combination of mechanical properties in RFRVE composite. Then, the mean of the grey relational grade for each

Table 2 The average values of tensile, flexural and impact strength of RFRVE composite

Test no.	Fiber length (mm)	Fiber content (wt%)	Fiber diameter (mm)	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (KJ/m^2)
1	3	18.88	0.24	28.5	35.9	0.97
2	3	18.88	0.82	30.7	34.7	1.11
3	3	18.88	1.45	28.3	32.3	0.89
4	3	36.01	0.24	35.8	40.8	1.82
5	3	36.01	0.82	39.5	37.1	1.8
6	3	36.01	1.45	33.9	36.2	1.91
7	3	51.79	0.24	31.9	35.3	1.96
8	3	51.79	0.82	33.5	34.2	1.85
9	3	51.79	1.45	32.7	33.7	1.83
10	8	18.88	0.24	34.2	40.5	1.23
11	8	18.88	0.82	33.4	40.4	1.28
12	8	18.88	1.45	31.1	39.6	1.21
13	8	36.01	0.24	38.7	46.1	2.32
14	8	36.01	0.82	37.8	46.9	2.22
15	8	36.01	1.45	35.5	45.8	2.31
16	8	51.79	0.24	36.9	39.3	2.11
17	8	51.79	0.82	35.9	39.4	1.99
18	8	51.79	1.45	33.1	38.1	1.98
19	13	18.88	0.24	37.7	48.4	1.27
20	13	18.88	0.82	36.6	48.7	1.25
21	13	18.88	1.45	36.2	47.6	1.27
22	13	36.01	0.24	41.3	52.3	2.36
23	13	36.01	0.82	40.5	52.1	2.39
24	13	36.01	1.45	38.8	51.3	2.33
25	13	51.79	0.24	37.8	43.1	2.24
26	13	51.79	0.82	36.3	43.7	2.19
27	13	51.79	1.45	35.9	42.3	2.25

level of different fabrication parameters and the total mean of the grey relational grade is determined and listed in Table 5. It was observed that the optimal parametric combination is the fiber length at level 3 (13 mm), fiber content at level 2 (36.01 wt%), and fiber diameter at level 1 (0.24 mm).

Effect of fabrication parameters on grey relational grade

Mechanical properties of natural fiber polymer composite depends generally on fiber length, fiber orientation, fiber dispersion, fiber concentration, fiber- matrix adhesion which includes adsorption and wetting, interdiffusion, electrostatic attraction, chemical bonding, and mechanical adhesion etc. The fiber length is a critical factor in preparation of fiber reinforced polymer composites. If the fiber length is too long, they entangle

Table 3 S/N ratio of tensile, flexural, and impact strength values

Test no.	S/N ratio of experimental results		
	Tensile strength	Flexural strength	Impact strength
1	43.41	45.42	14.05
2	44.06	45.12	15.22
3	43.35	44.50	13.30
4	45.39	46.53	19.52
5	46.25	45.70	19.42
6	44.92	45.49	19.93
7	44.39	45.27	20.16
8	44.81	44.99	19.66
9	44.60	44.87	19.56
10	44.99	46.46	16.11
11	44.79	46.44	16.46
12	44.17	46.27	15.97
13	46.07	47.59	21.62
14	45.86	47.74	21.24
15	45.32	47.53	21.59
16	45.65	46.20	20.80
17	45.42	46.22	20.29
18	44.71	45.93	20.25
19	45.84	48.01	16.39
20	45.58	48.06	16.25
21	45.49	47.87	16.39
22	46.63	48.68	21.77
23	46.46	48.65	21.88
24	46.09	48.52	21.66
25	45.86	47.00	21.32
26	45.51	47.12	21.12
27	45.42	46.84	21.36

with each other and causing problems in dispersion. But if the fiber length is very small, they do not offer sufficient stress transfer from the matrix to the fiber. The fiber breakage in a fiber reinforced polymer composites mainly depends on the type and its initial aspect ratio. The effects and its importance of fiber length on the properties of the fiber reinforced polymer composites were studied by several researchers [18–21]. In this study, increase in fiber length from 3 mm to 8 mm and 13 mm increases mechanical properties of RFRVE composites. Composites having fiber length of 8 mm show the better mechanical properties compared to composites having fiber length of 3 mm. Therefore, mechanical properties increased by increasing the fiber content from 3 mm to 13 mm, which can be seen in Fig. 2a.

Table 4 Data processing of each response (deviation sequence)

Test no.	Tensile strength ($\Delta_{0i}(1)$)	Flexural strength ($\Delta_{0i}(2)$)	Impact strength ($\Delta_{0i}(3)$)
1	0.018630	0.219265	0.087135
2	0.215346	0.148719	0.223616
3	0	0	0
4	0.621919	0.484749	0.724186
5	0.882112	0.287489	0.712999
6	0.477653	0.236532	0.773047
7	0.316783	0.184292	0.799207
8	0.44625	0.118603	0.740736
9	0.382309	0.088043	0.729733
10	0.500962	0.469436	0.327541
11	0.438343	0.464306	0.367872
12	0.249592	0.422805	0.310939
13	0.827982	0.738170	0.969908
14	0.765732	0.773869	0.925305
15	0.599657	0.724623	0.965535
16	0.701982	0.407025	0.873859
17	0.629299	0.412298	0.814584
18	0.414474	0.342679	0.809484
19	0.758724	0.839195	0.359932
20	0.680386	0.852017	0.343863
21	0.651314	0.804611	0.359932
22	1	1	0.987213
23	0.948253	0.992049	1
24	0.834809	0.959942	0.974262
25	0.765732	0.598544	0.934384
26	0.658612	0.627231	0.911531
27	0.629299	0.559670	4.039404

Fiber content in the matrix plays a major role in determining the mechanical performance of the fiber reinforced polymer composites. As the fiber content is increased to the highest level the properties gradually improve to give strength higher than that of the matrix. The fiber content beyond which the properties of the composite improve above the matrix strength is known as optimum fiber content. The lower fiber content gives lower mechanical properties. In the present study, composite having 36.01 wt% fiber content shows the better mechanical properties compared to 25.67 and 55.55 wt% composite. It may be an optimum fiber content for RFRVE composite. Thus, all mechanical properties are higher and reflect in the higher value of the weighted GRG (Fig. 2b) at 36.01 wt% fiber content.

Generally the properties of natural fiber reinforced polymer composites were improved by utilization of fibers with less diameter or higher fineness. The reasons for

Table 5 Determined GRC and their mean weighted GRG for 27 sequences

Test no.	Grey relational coefficient			Weighted GRG
	Tensile strength	Flexural strength	Impact strength	
1	0.337525	0.390400	0.353890	0.360605
2	0.389209	0.370019	0.391731	0.383653
3	0.333333	0.333333	0.333333	0.333333
4	0.569424	0.492489	0.644484	0.568799
5	0.809208	0.412367	0.635323	0.618966
6	0.489070	0.395736	0.687802	0.524203
7	0.422577	0.380023	0.713477	0.505352
8	0.474497	0.361952	0.658532	0.498327
9	0.447351	0.354115	0.649125	0.483531
10	0.500481	0.485171	0.426451	0.470701
11	0.470962	0.482768	0.441646	0.465125
12	0.399869	0.464168	0.420499	0.428179
13	0.744027	0.656314	0.943231	0.781191
14	0.680950	0.688581	0.870026	0.746519
15	0.555344	0.644847	0.935514	0.711901
16	0.626552	0.457467	0.798542	0.627520
17	0.57425	0.459684	0.729484	0.587806
18	0.460606	0.432032	0.724096	0.538911
19	0.674512	0.756653	0.438570	0.623245
20	0.610043	0.771625	0.432474	0.604714
21	0.589146	0.719022	0.438570	0.582246
22	1	1	0.975062	0.99168
23	0.906211	0.984348	1	0.96352
24	0.751663	0.925824	0.951043	0.876177
25	0.680950	0.554658	0.883991	0.706533
26	0.594256	0.572889	0.849662	0.672269
27	0.57425	0.531726	−0.196896	0.303026

improved properties of composites by less fiber diameter or high fiber fineness are: (i) better embedment and (ii) improved ratio between surface and volume which leads to increased contact surface between fiber and polymer matrix. The fiber diameter is also important because increase in fiber diameter beyond a certain value results in decreased strength of composites [22, 23]. Therefore, the polymer composites reinforced by fibers with more diameters will result in lower strength. Flax fibers show a less diameter or higher fineness compared to hemp fibers and kenaf fibers. Strength of flax fiber reinforced polypropylene composite is greater than hemp fiber-polypropylene composite and kenaf fiber-polypropylene composite [24]. It can be seen from the Fig. 2c that the effects of fiber length and fiber content have great influence on mechanical properties of RFRVE composite compared to fiber diameter.

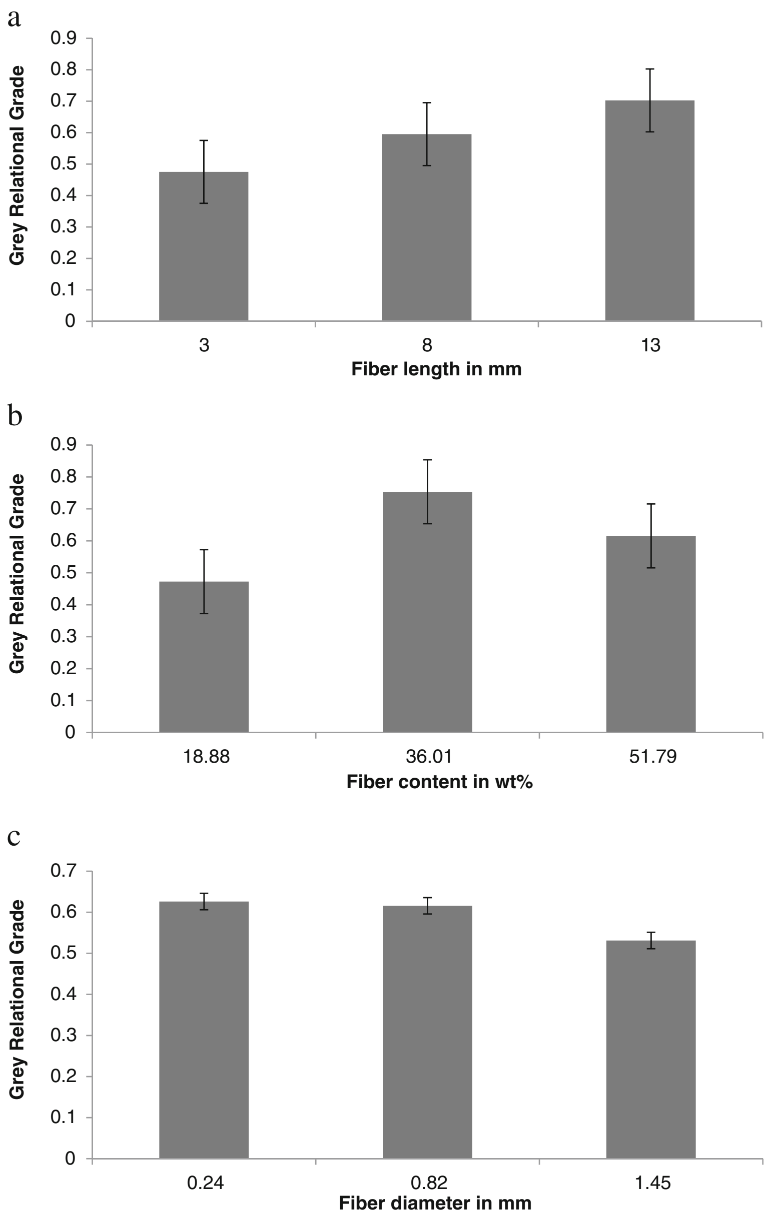

Fig. 2 Mechanical properties of RFRVE composites such as **a** the tensile strength, **b** the flexural strength, and **c** the impact strength, on GRG

ANOVA for GRG

Analysis of variance (ANOVA) is used to analysis the GRG of responses and also investigates which parameter significantly affects the responses. ANOVA is performed for identifying the significant parameters at a level of significance

Table 6 Mean response table for the overall GRG

Fabrication parameters	GRG		
	Level 1	Level 2	Level 3
A	0.475198	0.595318	0.702602
B	0.472423	0.753663	0.547032
C	0.626183	0.615656	0.531279

of 0.05. It establishes the relative significance of parameters. The calculated total sum of square values represented in third column is used to measure the relative influence of the parameters. The results of ANOVA (Table 6) show that the fiber content, parameter B ($p = 0.001$) and the fiber length, parameter A ($p = 0.018$) have great influence on mechanical properties of RFRVE composites compared to the fiber diameter, parameter C ($p = 0.478$). In addition to the p values, the F values can also be used to determine which parameter has a significant effect on the responses. It is also observed that the fiber content (the parameter B) has a significant effect on the mechanical properties of RFRVE composites because the F value is large (10.56). It was followed by the fiber length (the parameter A) because the F value is 4.79.

Confirmation tests

Once the optimum parameter levels are identified, the performance characteristics of RFRVE composite are predicted using the optimum parameter levels. The following equation is used to predict the weighted GRG using these optimal parameters [25]:

$$\gamma_{i(\text{Predicted})} = \gamma_m + \sum_{i=1}^{P} (\gamma_0 - \gamma_m) \tag{5}$$

where γ_0 is the mean grey relational grade at optimal level; γ_m is the total mean value of the grey relational grade and P is the number of fabrication parameters that affect the responses. The results of the confirmation test using the optimal fabrication parameters is given in Table 7. It was observed from the results of Table 7 that the tensile strength

Table 7 Results of ANOVA for GRG

Fabrication parameter	Degree of freedom	Sum of squares	Mean squares	F value	p value	% of contribution
A	2	0.233	0.1165	4.79	0.018	28.54
B	2	0.3821	0.191	10.56	0.001	46.8
C	2	0.0487	0.0244	0.76	0.478	5.97
Error	20	0.15263	0.00763			18.69
Total	26	0.81643				100

Table 8 Comparison between mechanical properties of RFRVE composite using initial and optimal fabrication parameters

Fabrication parameter	Initial fabrication parameter	Optimal fabrication parameter	
		Predicted	Experimental
Preparing level	$A_1B_1C_1$	$A_3B_2C_1$	$A_3B_2C_1$
Tensile strength (MPa)	28.5		41.3
Flexural strength (MPa)	35.9		52.3
Impact strength (KJ/m^2)	0.97		2.36
Grey relational grade	0.36	0.86	0.99

increased from 28.5 MPa to 41.3 MPa, the flexural strength increased from 35.9 MPa to 52.3 MPa, and the impact strength also increased from 0.97 KJ/m^2 to 2.36 KJ/m^2. The value of predicted weighted GRG was also increased from 0.86 to 0.99 which confirms the improvement in mechanical properties of RFRVE composites when using the optimal fabrication parameters i.e., an improvement of 15.11 % is observed in the weighted GRG (Table 8).

Conclusion

The optimization of fabrication parameters with mechanical properties of RFRVE composite was performed by using grey based-Taguchi method. The term GRG was used to identify the optimal fabrication parameters such as the fiber length, the fiber content and the fiber diameter. The final results recommend the following levels of fabrication parameters as optimal parameters for maximizing mechanical properties of RFRVE composite. They are the fiber length (A) at level 3 (13 mm), the fiber content (B) at level 2 (36.01 wt%), and the fiber diameter at level 1 (0.24 mm). Among these fabrication parameters, the fiber content shows the most significant effect on mechanical properties of RFRVE composite followed by the fiber length and the fiber diameter. The result of the confirmation test shows an improvement of 15.11 % in weighted GRG, which ensures the usefulness of this approach in optimization of mechanical properties of RFRVE composite. Finally it may conclude that the multiple performance characteristics of natural fiber reinforced polymer composites can greatly improved using this approach.

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