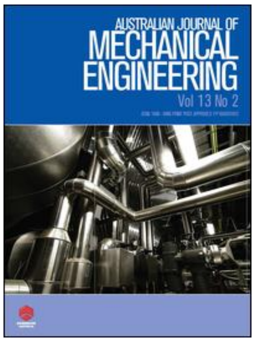

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Taguchi method for optimization of fabrication parameters with mechanical properties in sisal fibre–vinyl ester composites

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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 (MPC) in sisal fibre-reinforced vinyl ester (SFRVE) 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 fibre length, fibre content and fibre diameters were optimized based on the grey relational grade as performance index obtained from the grey relational analysis to get the maximum level of MPC such as the tensile strength, the flexural strength and the impact strength. The results show that the fibre content is the most significant fabrication parameter which greatly affects the mechanical properties of SFRVE composite compared to the fibre length and the fibre diameter. It was proved that the MPC of the plant-based natural fibre-reinforced polymer composites can be effectively improved by this method.

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Composites; fibre; polymer; grey-based Taguchi

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1. Introduction

Recently, the material engineers, scientists and researchers are focusing their interest in using lignocellulosic natural fibres such as jute, coir, sisal, pineapple, ramie, bamboo and banana as reinforcement in polymers matrix (Varghese, Kuriakose, and Thomas 1994; Mi, Chen, and Guo 1997; Acharya and Mishra 2007; Mishra 2009; Gupta et al. 2011; Mishra and Mishra 2011). These fibres are excellent raw materials for the production of wide range of composites for different applications such as structural and automotive and also now considered as serious alternative to synthetic fibres such as glass, for use in polymer composites as reinforcement (Joseph et al. 2002). Polymer composites reinforced with natural fibres 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 fibre-reinforced polymer (NFRP) composites. Mostly, researchers have studied the mechanical behaviour of NFRP composites without and with modification of fibre and matrix materials. The effect of coupling agent and compatibilizer on the behaviour 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 fibre-reinforced polymer composites, the better results or response can be obtained 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 fibre–polymer composites.

Generally, optimization problems are solved by conventional and non-conventional optimization methods. Conventional method is a statistical design of experiment which includes Taguchi technique and response surface methodology. Non-conventional techniques include genetic algorithm, simulated annealing and Tabu search. All the techniques are mostly used to 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 (GRA) and Taguchi technique. In the GRA, the grey relational co-efficient can express the relationship between the desired and actual experimental results. Then, a GRG is obtained to evaluate the

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Table 1. Fabrication parameters and their levels.

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

multi-response. Complicated multi-response problems (MRPs) are converted into a single response problems based on the GRG. Grey-based Taguchi technique was successfully applied to optimize the multi-response of complicated problems in various manufacturing areas(Lin 2004; Chiang and Chang 2006; Tosun 2006; Kopac and Krajnik 2007; Lua et al. 2009; Mathew and Rajendrakumar 2011; Pawade and Joshi 2011; Ilo, Just, and Xhiku 2012). This study reports the application of grey-based Taguchi method in optimization of mechanical properties of sisal fibre-reinforced vinyl ester (SFRVE) 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 analysed 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 SFRVE composite. Confirmation tests are carried out to verify the optimal fabrication parameters combination.

2. Experimental procedure

2.1. 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 analysed to yield valid and objective conclusions. Taguchi method of design of experiment (Ross 1996; Montgomery 1997) is a relatively simple and powerful tool for systematic modelling, analysis and optimization of the process parameters which include 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 SFRVE composites, tensile strength, flexural strength and impact strength have been considered as larger the better type in this 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.

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

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

2.2. Materials

Sisal fibre (*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.

2.3. 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) were applied to the surfaces of the mould box. Before the impregnating, the sisal fibres in resin matrix, vinyl ester resin, accelerator, catalyst and promoter were mixed carefully in the ratio of 100:2:1.5:2 using a mechanical stirrer and then sisal fibres were pre-impregnated with the resin matrix. The impregnated sisal fibres and resin materials were poured in the mould box of size 150 × 150 × 3 mm. After pouring, the mould

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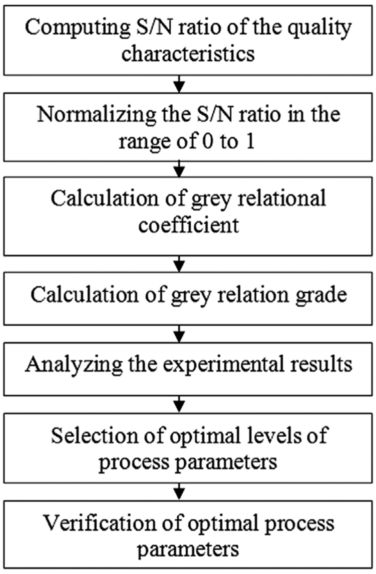

Figure 1. Flow chart showing the various steps followed in grey-based Taguchi method.

box is closed and allowed to cure at laboratory temperature for 24 h. Twenty-seven composite plates with different combinations of fibre length (A), fibre content (B) and fibre diameter (C) were prepared based on the experimental design of Taguchi's L_{27} orthogonal array.

2.4. Taguchi method with GRA

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 MRPs, it is convenient to convert all the objectives into an equivalent single objective. To solve the MRPs, Taguchi method is coupled with 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 this 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 (fibre length, fibre content and fibre diameter). After the correct sequencing and analysing, 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 are shown in Figure 1.

The desired quality characteristics of SFRVE composites should follow the larger the better criterion (Equation (1)). These quality characteristics are normalized between 0 and 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 are 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:

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

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 GRC 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 GRG 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.

2.5. Characterization of composite

Composites were characterized for tensile, flexural and impact strength according American Society for Testing and Materials (ASTM) standards. Tensile test was carried out on the specimen (Figure 2) size of 150 × 20 × 3 mm according to ASTM D638-10. Tensile tests were performed on fuel instruments and engineers 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

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Figure 2. Digital image of the composite specimen.

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 (Table 3).

3. 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 using Equation (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 4.

After data processing of deviation sequence, the grey relational coefficient GRC is determined using the Equation (3). The value of ζ is taken as 0.5 because all the fabrication parameters influence the responses almost equally and substituted in Equation (3). Then, the weighted GRG is calculated using the Equation (4). The grey relational coefficient GRC and weighted GRG for each test is listed in Table 5. It is observed from the Table 5 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 SFRVE composite. Then, the mean of the GRG for each level of different fabrication parameters and the total mean of the GRG is determined and listed in Table 6. It was observed that the optimal parametric combination is the fibre length at level 3 (13 mm), fibre content at level 2 (36.01 wt%) and fibre diameter at level 1 (0.24 mm).

3.1. Effect of fabrication parameters on GRG

Mechanical properties of natural fibre–polymer composite depend generally on fibre length, fibre orientation, fibre dispersion, fibre concentration, fibre-matrix adhesion which includes adsorption and wetting, interdiffusion, electrostatic attraction, chemical bonding and mechanical adhesion. The fibre length is a critical factor in preparation of fibre-reinforced polymer composites. If the fibre length is too long, they entangle with each other and causing problems in dispersion. But if the fibre length is very small, they do not offer sufficient stress transfer from the matrix to the fibre. The fibre breakage in a fibre-reinforced polymer composites mainly depends on the type and its initial aspect ratio. The effects and its importance of fibre length on the properties of the fibre-reinforced polymer composites were studied by several researchers (Rashed, Islam, Rizvi 2006; Basiji et al. 2010; Sumaila, Amber, Bawa 2013; Vinod, Sudev 2013). In this study, increase in fibre length from 3 to 8 mm and 13 mm increases mechanical properties of SFRVE composites. Composites having fibre length of 8 mm show the better mechanical properties compared to composites having fibre length of 3 mm. Therefore, mechanical properties increased by increasing the fibre content from 3 to 13 mm, which can be seen in Figure 3(a).

Fibre content in the matrix plays a major role in determining the mechanical performance of the fibre-reinforced polymer composites. As the fibre content is increased to the highest level, the properties gradually improve to give strength higher than that of the matrix. The fibre content beyond which the properties of the composite improve above the matrix strength is known as optimum fibre content. The lower fibre content gives lower mechanical properties. In this study,

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

Test no.	Fibre length (mm)	Fibre content (wt%)	Fibre 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

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

	S/N ratio of experimental results		
Test no.	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (kJ/m^2)
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

composite having 36.01 wt% fibre content shows the better mechanical properties compared to 25.67 and 55.55 wt% composite. It may be an optimum fibre content for SFRVE composite. Thus, all mechanical properties are higher and reflect in the higher value of the weighted GRG (Figure 3(b)) at 36.01 wt% fibre content.

Generally, the properties of NFRP composites were improved by utilization of fibres with less diameter or higher fineness. The reasons for improved properties of composites by less fibre diameter or high fibre fineness are (i) better embedment and (ii) improved ratio between surface and volume which leads to increased contact surface between fibre and polymer matrix. The fibre diameter is also important because increase in fibre diameter beyond a certain value results in decreased strength of composites (Pavithran et al. 1987; Sergio, Kestur, and Felipe 2010). Therefore, the polymer composites reinforced by fibres with

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Table 4. Data processing of each response (deviation sequence).

Test no.	Tensile strength ($\Delta_{0i}(1)$) (MPa)	Flexural strength ($\Delta_{0i}(2)$) (MPa)	Impact strength ($\Delta_{0i}(3)$) (kJ/m^2)
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

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

	Grey relational coefficient			
Test no.	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (kJ/m^2)	Weighted GRG
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

Table 6. Mean response table for the overall GRG.

	GRG		
Fabrication parameters	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

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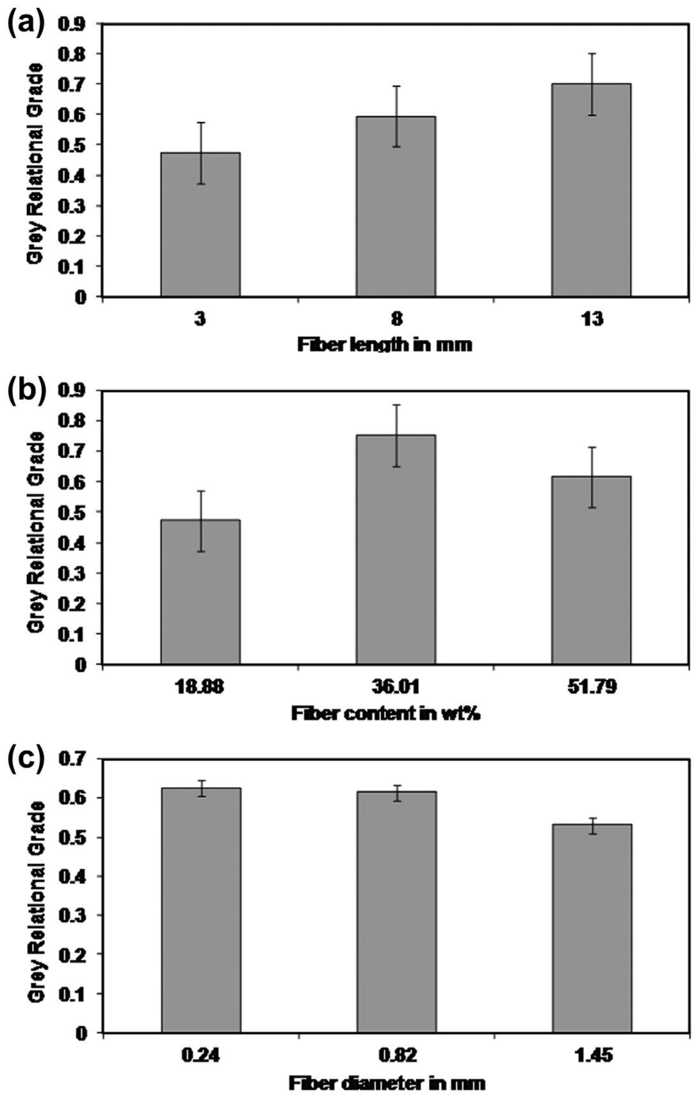

Figure 3. Mechanical properties of SFRVE composites such as (a) the tensile strength, (b) the flexural strength and (c) the impact strength, on GRG.

more diameters will result in lower strength. Flax fibres show a less diameter or higher fineness compared to hemp fibres and kenaf fibres. Strength of flax fibre-reinforced polypropylene composite is greater than hemp fibre–polypropylene composite and kenaf fibre–polypropylene composite(Mueller 2005). It can be seen from the Figure 3(c) that the effects of fibre length and fibre content have great influence on mechanical properties of SFRVE composite compared to fibre diameter. SEM image of fractured surfaces of composites is shown in Figure 4(a) before tensile test (b) after tensile test

3.2. ANOVA for GRG

ANOVA is used to analyse the GRG of responses and also investigate which parameter significantly affects the responses. ANOVA is performed for identifying the significant parameters at a level of significance 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 7) show that the fibre content, parameter B, ($p = 0.001$) and the fibre length, parameter A ($p = 0.018$), have great influence on mechanical properties of SFRVE composites compared to the fibre 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 fibre content (the parameter B) has a significant effect on the mechanical properties of SFRVE composites because the F value is large (10.56). It was followed by the fibre length (the parameter A) because the F value is 4.79.

3.3. Confirmation tests

Once the optimum parameter levels are identified, the performance characteristics of SFRVE composite are predicted using the optimum parameter levels. The

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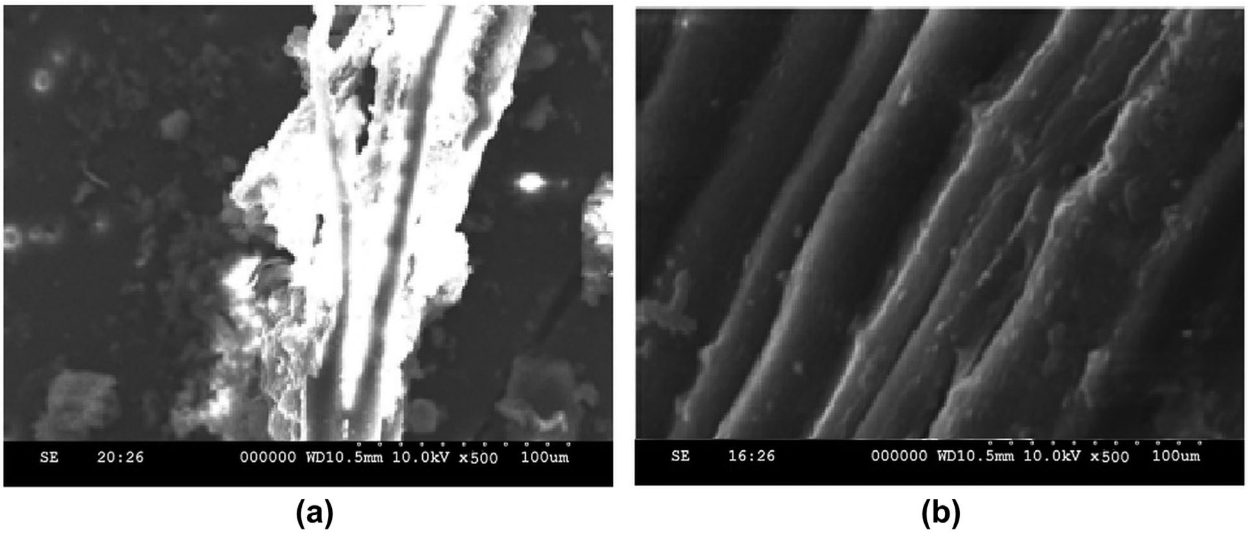

Figure 4. SEM image (x500) of fractured surfaces of composites (a) before tensile test (b) after tensile test.

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 SFRVE 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

following equation is used to predict the weighted GRG using these optimal parameters (Yang 2011):

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

where γ_0 is the mean GRG at optimal level, γ_m is the total mean value of the GRG and P is the number of fabrication parameters that affect the responses. The results of the confirmation test using the optimal fabrication parameters are given in Table 8. It was observed from the results of Table 7 that the tensile strength increased from 28.5 to 41.3 MPa, the flexural strength increased from 35.9 to 52.3 MPa and the impact strength also increased from 0.97 to 2.36 kJ/m^2. The value of predicted weight of GRG was also increased from 0.86 to 0.99 which confirms the improvement in mechanical properties of SFRVE composites when using the optimal fabrication parameters, i.e. an improvement of 15.11% is observed in the weighted GRG.

4. Conclusion

The optimization of fabrication parameters with mechanical properties of SFRVE composite was performed using grey-based Taguchi method. The term GRG was used to identify the optimal fabrication parameters such as the fibre length, the fibre content and the fibre diameter. The final results recommend the following levels of fabrication parameters as optimal parameters for maximizing mechanical properties of SFRVE composite. They are the fibre length (A) at level 3 (13 mm), the fibre content (B) at level 2 (36.01 wt%) and the fibre diameter at level 1 (0.24 mm). Among these fabrication parameters, the fibre content shows the most significant effect on mechanical properties of SFRVE composite followed by the fibre length and the fibre 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 SFRVE composite. Finally, it may conclude that the MPC of NFRP composites can be greatly improved using this approach.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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