OPTIMIZATION OF MECHANICAL PROPERTIES OF E-GLASS WOVEN FABRIC COMPOSITE

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ABSTRACT

Manufacturing of composite material has been an extensive area of research as they have high strength-to-weight ratio that are equivalent or superior to many metallic materials. This paper describes the preparation of E-Glass (woven fabric) Fiber Reinforced Polymer Composite (GFRP) with different fiber mat material, orientation and resin. The purpose of this paper is to investigate the influence of the process parameters on the mechanical properties of GFRP composite using Taguchi experimental design in combination with Grey Relational Analysis (GRA). The conclusion revealed that fiber orientation and resin were the most influential factor on the mechanical properties, respectively. It is observed that the optimum properties were obtained at 400 fabric mat, polyester resin, 45°/–45° orientation.

Keywords: E-glass composite; Grey–Taguchi method; ANOVA; scanning electron microscopy.

OPTIMISATION DES PROPRIÉTÉS MÉCANIQUES D'UN COMPOSITE DE TISSU DE FIBRE DE VERRE-E

RÉSUMÉ

La fabrication de matériaux composites est depuis longtemps un vaste domaine de recherche, en ce qu'ils ont un rapport élevé de résistance/poids qui est équivalent ou supérieur à beaucoup de matériaux métalliques. Le présent article décrit la préparation du tissu de fibre de verre-E (tissu tissé) de polymères renforcés de fibre de verre (PRFV) avec différents matériaux plats fibreux. Le but de cette recherche est l'étude de l'influence des paramètres de procédé sur les propriétés mécaniques du composite PRFV en utilisant la méthode Taguchi en combinaison avec l'analyse rationnelle gris (GRA). La conclusion révèle que l'orientation de la fibre et la résine étaient respectivement les facteurs qui avaient le plus d'influence sur les propriétés mécaniques. On a observé que les propriétés optimales étaient obtenues pour des matériaux plats fibreux de 400, de résine de polyester, et d'une orientation de 45°/–45°.

Mots-clés : composite de fibre de verre-E; méthode Grey–Taguchi; ANOVA; microscope optique à balayage.

1. INTRODUCTION

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. In disparity to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. The two constituents are reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part, Vignesh et al. [1] investigated the optimization condition of the mechanical behaviors on the composite material properties namely tensile, compressive, flexural and impact strength using Grey–Taguchi analysis. Mat Kandar and Akil [2], studied the effect of optimizing the hot press forming process parameters using Response Surface Methodology (RSM) developed a model to expand the mechanical properties of the woven composites. Mahesh and Senthilkumar [3] investigated the tensile and flexural behavior of glass fiber reinforced aluminum laminates (Glare) with different orientation and concluded that the most significant factor of flexural strength respectively. In [4] Raif Sakin et al. used samples produced by the RTM (Resin Transfer Molding)method to investigate bending fatigue performances for glass-fiber composite material. The property of the GFRP (Glass Fiber Reinforced Plastic) material is dominant on the fatigue strength which has been evidently observed from the experiments. Gunasegaran et al. [5], studied the four process parameters and their subsequent study on the effects of the mechanical properties of filament wound Glass Reinforced Plastic (GRP) pipes was conducted. In [6], mechanical properties for glass fiber composites were evaluated by Kumar Tanwer. Composites were prepared with longitudinal and cross Bidirectional glass fiber reinforced with epoxy based polymer. Unidirectional oriented glass fiber epoxy composites have large values of all the properties, such as ultimate force, yield force, compressive strength, tensile strength, elongation, etc., in tensile as well as in compression tests. It means that unidirectional oriented glass fiber composites are stronger than bidirectional glass fiber composites. Yadav Eagala et al. [7] studied the physical and abrasive wear behaviour of the compositesusing Taguchi's experimental design. Bhanu Kiran et al. [8] improved the mechanical properties of green composites by optimizing the hot press forming process parameters using Taguchi's analysis. Process parameters such as temperature, pressure, heating time, cooling system and recrystallization soak time were chosen for evaluation by Taguchi's method. It is evident that the establishment of optimal combination of hot press forming parameters is very beneficial to the manufacturing of green composites with better tensile, flexural and impact strength [9]. In this study, fabrication parameters, namely red mud percentage, fiber treatment, length of fiber, and weight fraction of fiber, are optimized with consideration of multi response such as impact strength, flexural strength, and tensile strength. A grey relational grade is obtained from the grey analysis. Optimum level of parameters has been identified and significant parameters are determined by analysis of variance (ANOVA). In [10], the multi characteristics optimization and identification are carried out. To find the influence of parameter using design of experiment techniques, Vignesh et al. [11] investigated the optimization of the process parameters to enhance the mechanical properties of bone powder impregnated coir fiber reinforced polyester composites using Taguchi's method in combination with Grey relational analysis. The recommended parameter levels are 0.5 mm coir fiber diameter, 80 mm coir fiber length, 20% weight of BP content and 120 m BP size which is taken from the response table and graph. It gives the maximum the tensile strength, flexural strength, compressive strength and impact energy. Kumar Vankanti and Ganta [12] optimized the process parameters, namely cutting speed, feed, point angle and chisel edge width in drilling of glass fiber reinforced polymer (GFRP) composites. The results indicate that at a speed of 500 rpm, a feed rate of 0.06 mm/rev, a point angle at 950 and a chisel edge width of 1.6 mm are found to be optimal [13].

This article presents a method for optimizing the deep cryogenic treatment (DCT) process parameters for 100Cr6 bearing steel using Taguchi's method with Grey's relational analysis. The DCT parameters considered for the optimization included the cooling rate, soaking temperature, soaking time, and tempering

Table 1. Parameter and their levels.

Parameter	Symbols	Units	Levels		
			1	2	3
Mat	M	GSM	200	400	600
Resin	R	–	E	P	I
Orientation	O	Degree	0°/90°	30°/60°	45°/–45°

temperature. The concluded that the Grey–Taguchi method showed a 13.77% improvement in dimensional stability, a 49.02% improvement in wear resistance, and a 19.35% improvement in the hardness compared to 100Cr6 bearing steel samples without cryogenic treatment [14]. E-glass fiber reinforced epoxy composites were fabricated by hand lay-up method and investigating the tribology behaviors. The Taguchi method was employed. It can be concluded that the applied load (82.60%) had the highest influence on the wear rate of E-glass fiber reinforced epoxy composites. According to the analysis of variance for coefficient of friction, the sliding speed (50.45%) is the most significant factor [15]. A series of vinyl ester and polyurethane interpenetrating polymer networks were prepared by changing the component ratios of VER (Vinyl Ester) and PU (Polyurethane) and the polymerization process was confirmed with Fourier Transform infrared spectroscopy. The mechanical properties of the E-glass and carbon fiber specimens were compared from tests including tensile, compressive, flexural, ILSS (Inter Laminar Shear Strength), impact and Head Deflection Test (HDT). El-Kady et al. [16] investigated several AA7075 wrought aluminum alloy feedstock, produced using the Cooling Slope (CS) casting technique at different fabrication conditions. The optimum values of pouring temperature, cooling length and tilt angle were found to be 650°C, 350 mm and 45°C, respectively.

2. EXPERIMENTAL DESIGN TECHNIQUE

The design of experiments is a great tool for modeling and analyzing the direction of control factors on performance output. The most important stage in the design of experiments is the selection of the control factors. An, exhaustive literature review on mechanical performance of polymer composites exposes that parameters such as, tensile, compressive, flexural and impact largely influence the mechanical properties of polymer composites. The effect of these four parameters is studied using L9 orthogonal design. Here, only the main effects of the factors are of interest, and their relations are excepted from data analysis. The processing conditions under which E-Glass composites are fabricated are given in Table 2. All the three parameters have three levels. In a full factorial experiment design, it would require combination of runs to study three parameters each at three levels, whereas Taguchi's factorial experiment approach reduces it to only 9 runs, offering a great advantage in terms of experimental cost and time. The experimental observations are further transformed into a signal-to-noise (S/N) ratios. Based on the type of performance characteristics, one has to select the suitable S/N ratio. In this study, "higher is better" is considered to maximize tensile, compressive, flexural and impact strength of the E-Glass woven fabric composites. For this case, S/N ratio is calculated as a logarithmic transformation of loss function as shown below.

The designed experiments are shown in Table 1. Each column represents a process parameter, whereas a row stands for processing condition, which is nothing but a combination of parameter levels. The mechanical tests were carried out on these experiments and simulated three times. The levels of the factors are assigned to the L9 orthogonal array and there are obtained in Table 2.

Table 2. L9 orthogonal array.

Runs	Levels of parameter – A	Levels of parameter – B	Levels of parameter – C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

3. GREY RELATIONAL ANALYSIS

The Grey relational analysis (GRA) based on Grey's system idea can be used to solve complicated interrelationships among the multiple responses. GRA is actually a measurement of the absolute value of the data difference between sequences, and it can be used to measure the near correlation between sequences. The multiresponse process based on GRA is combined with the Taguchi method to determine the optimal combination of the factor levels and optimize the mechanical properties of the E-glass fiber with the objective of maximizing the tensile, compressive, flexural and impact. The overall approximation of the S/N ratio is necessary for optimization of the multiple performance characteristics. In GRA, the experimental data of the quality characteristics are first normalized to a range from zero to one, known as the Grey relation generation. The next step is determination of the Grey relation coefficient, which is based on the normalized experimental data to represent the relationship between the desired and actual experimental data. The Grey relation grade is calculated by averaging the Grey relational coefficient corresponding to the selected responses. The overall performance characteristic of the multiple response process also depends on the calculated Grey relational grade. The optimization problem results in changing the multiple response process into the optimization of a single response by utilizing the function of the Grey relation grade. The optimal levelof the process parameter is the level at which the maximum overall Grey relational grade can be achieved. In addition, analysis of variance (ANOVA) was used to identify the effect of the individual mechanical properties. The final step is to verify the improvement and the optimal level of the mechanical properties by conducting a confirmation experiment using the results obtained from the analysis.

4. EXPERIMENTATION

4.1. Tensile Test

The tensile testis one of the most widely used of the mechanical test. The commonly used specimen for tensile test as per ASTM (D638) is the dog-bone type. During the test a uniaxial load is applied both the ends of the specimen. Typical points of interest when testing a material include: ultimate tensile strength (UTS) or peak stress; counterweigh yield strength (CYS) which represents a point just beyond the beginning of permanent deformation; and the rupture (R) or fracture point. The tensile test is usually carried out with help of a universal testing machine (UTM), three different types of specimens are prepared based on the orientation, and the schematic diagram of tensile test specimen is shown in Fig. 1.

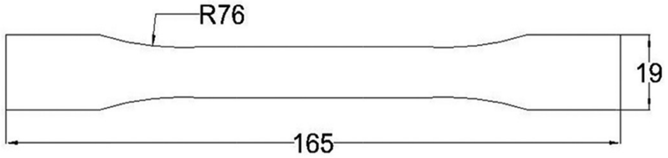

Fig. 1. Tensile test specimen.

4.2. Compressive Test

The compression specimen is prepared as per the ASTM (D695) standard. A compression test involves mounting the specimen in a machine and subjecting it to the compression. The compression process involves placing the test specimen in the testing machine and applying compress to it until it fractures. The compressed force is recorded as a function of displacement. During the application of compression, the elongation of the gauge section is recorded against the applied force. The schematic diagram of compressive test specimen is shown in Fig. 2.

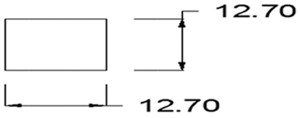

Fig. 2. Compressive test specimen.

4.3. Flexural Test

The flexural specimens are prepared as per the ASTM (D790) standard. The schematic diagram of flexural test specimens is shown in Fig. 3. Flexural strength, also known as modulus of rupture, bend strength, or fracture strength a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. In which a rod specimen having either a circular or rectangular cross-section is bent until fracture using a three point flexural test technique.

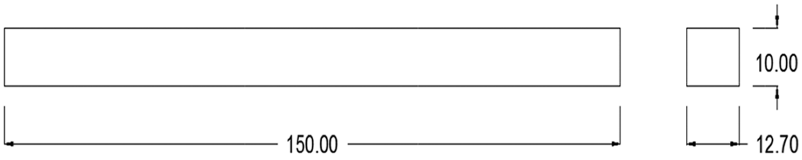

Fig. 3. Flexural test specimen.

4.4. Impact Test

The impact test is performed to study the behavior of materials under dynamic load (i.e. suddenly applied load). Specimens are prepared according to the ASTM (D256) standard. The specimens are subjected to an impact blow by the pendulum till it fractures and the consistent energy absorbed by the material is obtained.This test gives maximum energy that a material can absorb in breaking the specimen can be measured. The schematic diagram of impact test specimen is shown in Fig. 4.

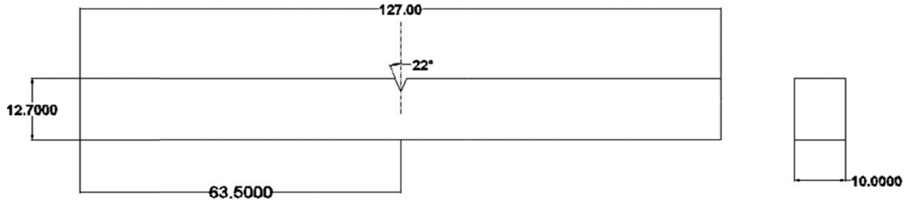

Fig. 4. Impact test specimen.

Table 3. List of ingredients to prepare a composite laminate.

Description	Parameter
Type of resin	Epoxy, polyester, iso-phthalic
Type of fiber	E-Glass (200, 400, 600 woven fabric)
Hardener used	HY 951
No. plies per laminate	10
Nature of laminate	Symmetric type
Method of preparation	Compression moulding method

5. GREY RELATIONAL ANALYSIS FOR THE EXPERIMENTAL RESULTS

The ingredients of composite laminate for E-glass fiber and its standard specification are shown in Table 3. The results obtained from the E-Glass fiber samples with respect to Orthogonal array for tensile, compressive, flexural and impact test are shown in table 4.three replications were performed for all the factor level settings per the Taguchi orthogonal array. Y1, Y2, and Y3 refer to the replications.

5.1. Signal-to-Noise Ratio

The response values from the three replicates were transformed into an S/N ratio. The equation for calculating the S/N ratio is based on “the lower the better”, “the higher the better” or “the more nominal the better”.

1. *The lower the better*: this characteristic is a non-negative measurable characteristic that has an ideal state value of zero.

   $$\text{S/N ratio} = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_{ij}^2\right) \tag{1}$$

   This should be applied to the problem when the minimization of the quality characteristics is intended.

2. *The higher the better*: the characteristic is a nonnegative measurable that has an ideal state value of infinity:

   $$\text{S/N ratio} = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_{ij}^2}\right) \tag{2}$$

   This should be applied to the problem when the maximization of the quality characteristic is intended.

3. *The more nominal the better*: this is a measurable characteristic with a specific user-defined target value. The value may be positive or negative:

   $$\text{S/N ratio} = -1 - \log_{10}\left(\frac{\mu^2}{\sigma^2}\right) \tag{3}$$

Table 4. Response for the experiment set.

S1 No.	Tensile Strength (MPa)			Compressive Strength (MPa)			Flexural Strength (MPa)			Impact Energy (kJ/m^2)		
	Y1	Y2	Y3	Y1	Y2	Y3	Y1	Y2	Y3	Y1	Y2	Y3
1	75.87	24.22	40.34	28.42	3.23	2.43	27.43	179.22	326.143	3.50	4.85	5.20
2	34.69	28.90	39.22	31.61	28.01	30.56	72.98	59.43	62.79	14	12	13
3	39.49	17.89	18.43	24.78	28.90	7.32	234.67	219.56	569.43	3.56	2.98	3.10
4	11.507	14.578	2.874	18.001	21.445	46.509	321.676	472.012	108.520	3.50	4.00	3.75
5	124.48	132.51	112.44	54.38	54.43	50.59	200.87	198.25	176.25	19.1	20.5	17.9
6	134.89	114.68	120.39	30.45	29.43	24.12	110.32	278.94	183.42	12	15	11
7	11.50	14.57	2.87	18.00	21.44	46.50	321.67	472.01	108.52	3.50	4.00	3.75
8	41.27	43.58	55.23	45.29	46.84	44.83	114.05	137.74	165.36	17	21	23
9	28.68	22.69	30.78	28.91	19.49	24.68	59.62	39.90	45.98	11	15	12

where

$$\mu = \frac{y_1 + y_2 + y_3 + \cdots, y_n}{n}$$

$$\sigma^2 = \frac{(\sum_{i=1}^{n} y_{ij}^2)}{n-1}$$

where n is the number of replications and y_{ij} is the observed response value where $i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, k$; k is the number of experiments. This should be applied to a problem when one wants to minimize the mean squared error around a specific target value.

5.2. Normalized S/N Ratios

Normalization is a transformation performed on a single data input to allocate the data evenly and scale it into a suitable range for further analysis. y_{ij} is normalized as Z_{ij} ($0 \leq Z_{ij} \leq 1$) by Eqs. (4–6) to set right the effect of adopting different units and to reduce the variability.

$$Z_{ij} = \frac{y_{ij} - \min(y_{ij}, i = 1, 2, \ldots, n)}{\max(y_{ij}, i = 1, 2, \ldots, n) - \min(y_{ij} = 1, 2, \ldots, n)} \tag{4}$$

Equation (4) should be used for S/N ratios with a “the higher the better” characteristic.

$$Z_{ij} = \frac{\max(y_{ij}, i = 1, 2 \ldots, n) - y_i}{\max(y_{ij}, i = 1, 2, \ldots, n) - \min(y_{ij} = 1, 2, \ldots, n)} \tag{5}$$

Equation (5) should be used for an S/N ratio with a “the lower the better” characteristic.

$$Z_{ij} = \frac{(y_{ij} - \text{Target}) - \min(|y - \text{Target}|, i = 1, 2, \ldots, n)}{\max(y_{ij}, i = 1, 2, \ldots, n) - \min(y_{ij} = 1, 2, \ldots, n)}. \tag{6}$$

Equation (6) should be used for an S/N ratio with “the more nominal the better” characteristic.

The S/N ratio is intended to be used as the measure of the effect of noise factors on the target characteristics. In general, there are three categories of the performance characteristics in the investigation of the S/N ratio: lower-the-better, higher-the-better and nominal-the better. Three replications (y_1, y_2 and y_3) are executed for all the three-level settings, as per the Taguchi orthogonal array. Here, the S/N ratio is calculated based on “the higher the better” principle. S/N ratio values are tabulated in Table 5. This characteristic is a non-negative computable characteristic that has an extreme state value of infinity. Normalization is a

Table 5. S/N Ratio and Normalized S/N Ratio

Run	S/N Ratio				Normalized S/N Ratio			
	Tensile Strength (MPa)	Compressive Strength (MPa)	Flexural Strength (MPa)	Impact Energy (kJ/m^2)	Tensile Strength (MPa)	Compressive Strength (MPa)	Flexural Strength (MPa)	Impact Energy (kJ/m^2)
1	30.80	10.52	33.41	12.70	0.612	0	0.002	0.166
2	30.49	29.53	36.17	22.23	0.601	0.793	0.185	0.766
3	26.50	21.45	48.54	10.07	0.459	0.456	1	0
4	13.54	27.20	44.81	11.44	0	0.696	0.754	0.086
5	41.75	34.49	45.61	25.61	0.999	1	0.807	0.999
6	41.76	28.80	43.61	21.84	1	0.763	0.688	0.741
7	13.04	31.74	40.42	21.18	0.656	0.885	0.465	0.699
8	33.18	33.18	42.57	25.95	0.696	0.945	0.607	1
9	28.52	27.39	33.37	21.84	0.531	0.704	0	0.741

Table 6. Grey relational co-efficient and grey relational grade values.

Sl. No.	Grey Relational Co-efficient				Grey Relational Grade
	Tensile Strength (MPa)	Compressive Strength (MPa)	Flexural Strength (MPa)	Impact Energy (kJ/m^2)	
1	0.563	0.333	0.334	0.345	0.391
2	0.556	0.707	0.380	0.681	0.581
3	0.480	0.479	1	0.333	0.573
4	0.333	0.622	0.670	0.354	0.495
5	0.998	1	0.722	0.96	0.920
6	1	0.678	0.616	0.659	0.738
7	0.592	0.813	0.483	0.624	0.628
8	0.622	0.901	0.560	1	0.771
9	0.515	0.628	0.333	0.659	0.534

transformation execution on a single data input to share out the data evenly and scale it into a suitable range for further analysis. It should be used for S/N ratios with “the higher the better”. The quality characteristics arechosen in this study integrated with flexural strength (“the higher the better”), tensile strength (“the higher the better”), compressive strength (“the higher the better”), impact strength (“the higher the better”) that is, the better the performance of all parameters. These characteristics are adopted for both S/N ratios and normalized S/N ratios.

5.3. Grey Relational Coefficients and Grey Relations Grade

The Grey relational coefficient and grade is calculated using the normalized S/N ratio values in Table 6.

6. RESULTS AND DISCUSSION

To examine the E-Glass fabric woven mat to identify the optimum parameters for Mechanical properties, prediction of the Taguchi technique and Grey relation analysis was used. Grey relation analysis and ANOVA provide the optimum parameter settings and the most influential factor in mechanical properties. In order to determine the average Grey relation grade for each factor level, the response table of the Taguchi method was employed. First, the Grey relation grades were grouped by the factor level for each column in the orthogonal array and then averaged. For example, to find the Grey relation grade of the fiber mat, the response value of level 1 in the first column of the OA should be averaged (i.e., experiments 1–3), then the response value of

Table 7. Response table for the Grey relational grade.

Levels	Mat (A)	Resin (B)	Orientation (C)
L1	0.515	0.505	0.633
L2	0.718	0.757	0.537
L3	0.644	0.615	0.707

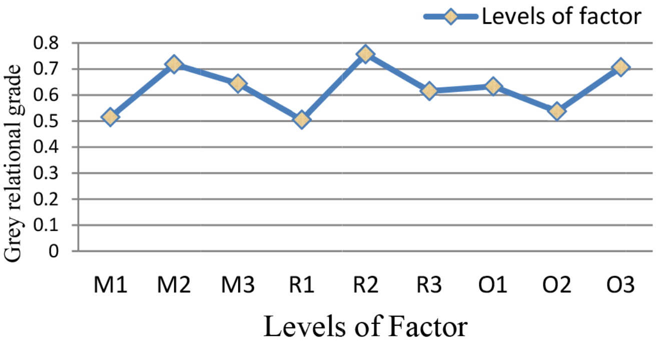

Fig. 5. Response graph of overall grey relational grade.

level 2 in the first column of the OA should be averaged (i.e., experiments 4–6), and the response value of level 3 in the first column of the OA should be averaged (i.e., experiments 6–9). Similarly, it is calculated for the particular levels for the resin, and orientation. This is shown in Table 7.

From the Grey relation analysis it is clear that the optimal parameter combination for mechanical parameter of the E-glass fabric woven mat is the highest average response combination in Table 7. Therefore, levels A2, B2, and C3 have the highest Grey relational grade value for the factors fiber mat, resin and orientation correspondingly. Based on the above study, the optimal values of the E-glass fabric woven fiber were a 400 mat, polyester resin, and 45° orientations. It is noted that the improvement was high for the other types of mat, resin and orientation. The response data of the Grey relation grade at various levels of the E-glassparameters are plotted in Fig. 5. The figure shows the optimal process parameter level yielded by the highest Grey relation grade.

6.1. Analysis of Variance

ANOVA was formulated from the average Grey relational grade value in Table 6. The idea of the ANOVA is to investigate which E-glass fiber parameters significantly affect the performance characteristics, among the factors fiber mat, resin, and orientation for the multiresponse values of tensile strength, compressive strength, flexural strength and impact strength. This is accomplished by separating the total variability of the Grey relational grades, which is measured by the sum of the squared deviations from the total mean of the Grey relational grade, into the contributions by each E-glass fiber parameter and the error. Using ANOVA, the influence of the E-glass fiber parameters on the quality targets can be examined. The percentage contribution by each E-glass fiber parameter to the total sum of the squared deviations can be used to evaluate the importance of the E-glass fiber parameter change on the performance characteristics. The contribution of each process parameter is given in the ANOVA table, exposed in Table 8.

From the ANOVA table, it can be seen that the fiber mat has a 31.27% contribution, resin 47.20%, and orientation 21.53%, on the multiple performance characteristics. It was found that among the three factors, resin made the major contribution and had a significant effect on the multiple performance characteristics. This suggests that the resin is more important than the manufacturing of composite laminate.

Table 8. Results of the ANOVA for the grey relational grade.

Factors	Parameter	Degree of freedom	Sum of squares	Variance	% Contribution
A	Mat	2	0.0211	0.0105	31.27
B	Resin	2	0.0319	0.016	47.20
C	Orientation	2	0.0145	0.0073	21.53
Error	–	0	0	0	0
Total	–	6	0.0675	0.0339	100

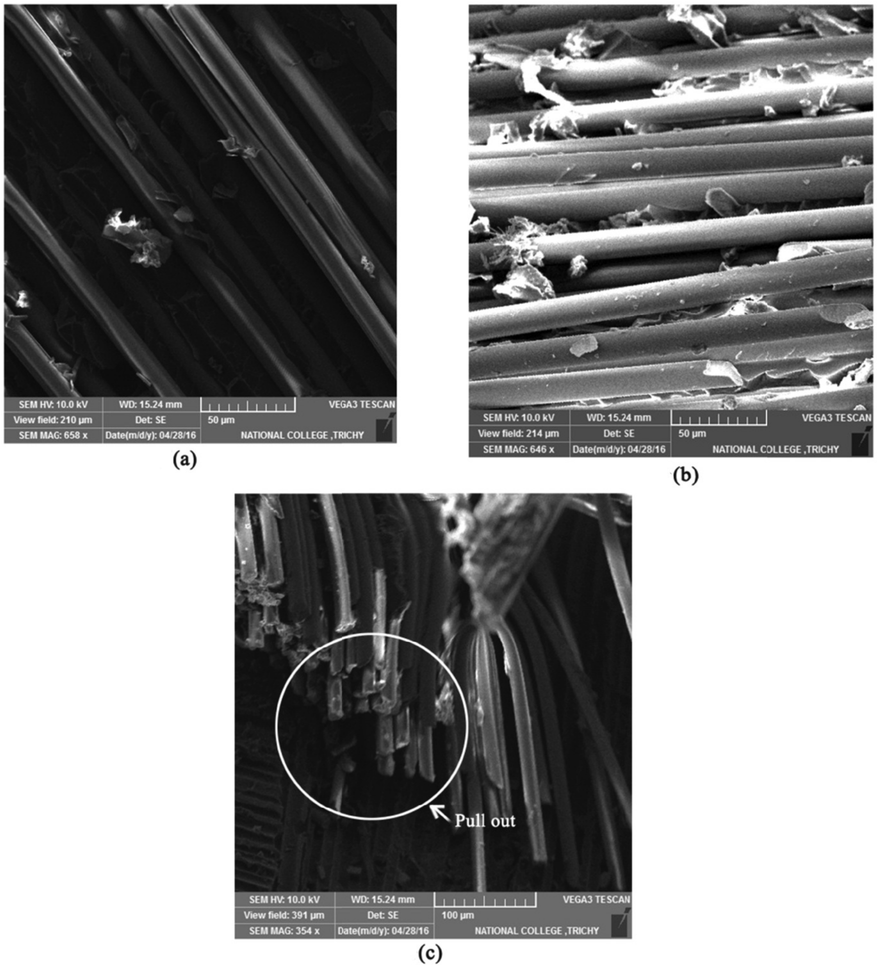

Fig. 6. SEM Image (a) unevenness fiber; (b) arrangement of fiber; (c) fiber pull out.

6.2. Morphological Analysis

Scanning Electron Microscopy examination was carried out to identify the possible improvement the mechanical properties of E-Glass fiber, fractured composite samples were investigated using SEM,the samples were coated with a thin layer of gold to reduce charging during analysis. From the microscopy of the fractured surface of the E-glass fiber specimen (Fig 6a), it is observed that the surface is flexible in nature. There is smoothness in the fractured surface with very little unevenness.

Figure 6b shows the arrangement of glass fibers in the woven fiber mat. The fibers are fractured due to the sudden impact and no trace of fatigue failure is observed. Moreover, due to the woven nature of the glass fiber, it is clear that there is an unchanging distribution in the matrix and interfacial adhesion is also present to a decent level.

Figure 6c shows that the glass fiber surface is smooth. Bundles of glass fiber pullout and deboning can be observed. This is due to the lacking of interfacial adhesion between the glass fiber and epoxy matrix.

7. CONCLUSION

In the current study, the detailed approach of Taguchi optimization technique coupled with Grey relational analysis has been adopted and applied for evaluating optimal parametric combination.

The recommended parameter levels are E-glass 400 Fabric mat, polyester resin, 45°/–45° orientation which is taken from the response table and graph. It gives the maximum the tensile strength, flexural strength, compressive and impact strength. The most significant factor for the performance improvement is identified by the ANOVA as the Polyester resin content as 47.20%. It is concluded that the composite makes the main contribution and has a significant effect on the multiple performance characteristics.

The microstructural analysis exposed that the uniform precipitation of resin bonding and fiber orientation of the E-glass fiber enhanced the hardness and dimensional stability of E-glass woven fabric mat fiber.

REFERENCES

1. Vignesh, K., Natarajan, U., Srinivasan, C. and Ramasivam, G., “Optimization on mechanical behavior of filler added fiber reinforced polyester composites using Grey–Taguchi method”, *Journal of Applied sciences Research*, Vol. 11, No. 14, pp. 127–132, 2015.
2. Mat Kandara, M.I. and Akil, H.M., “Application of design of experiment (DoE) for parameter optimization in compression molding for flax reinforced bio composites”, *Procedia Chemistry*, Vol. 19, pp. 433–440, 2016.
3. Mahesh, M. and Senthilkumar, A., “Comparison of mechanical properties for aluminum metal laminates (GLARE) of three different orientations such as CSM, woven roving and 450 stitched mat”, *IOSR Journal of Mechanical and civil Engineering*, pp. 09–13.
4. Sakin, R., Irfan, A.Y. and Ramazan Yaman, “An investigation of bending fatigue behavior for glass-fiber reinforced polyester composite materials”, *Materials and Design*, Vol. 29, pp. 212–217, 2008.
5. Gunasegaran, V., Prashanth, R. and Nararyanan, M., “Experimental investigation and finite element analysis of filament wound GRP pipes for underground applications”, *Procedia Engineering*, Vol. 64, pp. 1293–1301, 2013.
6. Kumar Tanwer, A., “Mechanical properties testing of uni-directional and bi-directional glass fibre reinforced epoxy based composites”, *International Journal of Research in Advent Technology*, Vol. 2, No. 11, 2014.
7. Yadav Eagala, R., Gopichand, A., Raghavendra, G. and Ali, S., “Abrasive wear behavior of bamboo-glass fiber reinforced epoxy composites using taguchi approach”, *International Journal of Advances in Engineering and Technology*, Vol. 5, No. 1, pp. 339–405, 2012.
8. Bhanu Kiran, K.N.S., Suman, N., Mohan Rao, R. and Maheswara Rao, U., “A study on the influence of hot press forming process parameters on mechanical properties of green composites using Taguchi experimental design”, *International Journal of Engineering, Science and Technology*, Vol. 3, No. 4, pp. 253–263, 2011.
9. Arumuga Prabu, V., Uthayakumar, M. and Manikandan, V., “Investigation of the mechanical properties on red mud filled polyester banana composites using Grey relational technique”, *Material Physics and Mechanics*, Vol. 14, pp. 57–63, 2012.
10. Hansda, S. and Banerjee, S., “Optimizing multi characteristics in drilling of GFRP composite using utility concept with Taguchi’s approach”, *Procedia Materials Science*, Vol. 6, pp. 1476–1488, 2014.
11. Vignesh, K., Ramasivam, G., Natarajan, U. and Srinivasan, C., “Optimization of process parameters to enhance the mechanical properties of bone powder and coir fiber reinforced polyester composites by Taguchi method”, *APRN Journal of Engineering and Applied Sciences*, Vol. 11, No. 2, 2016.
12. Kumar Vankanti, V. and Ganta, V., “Optimization of process parameters in drilling of GFRP composite using Taguchi method”, *Journal of Material Research and Technology*, Vol. 3, No. 1, pp. 35–41, 2014.
13. Sri Siva, R., Mohan Lal D. and Arockia Jaswin, M., “Optimization of deep cryogenic treatment process for 100Cr6 bearing steel using the Grey–Taguchi method”, *Tribology Transactions*, Vol. 55, pp. 854–862, 2012.

14. Ozsoy, N., Ozsoy, M. and Mimaroglu, A., “Influence of parameters on tribological behaviour of E-glass fiber reinforced epoxy composites”, *Acta Physica Polonica A*, Vol. 128, 2015.
15. Suresh, G. and Jayakumari, L.S., “Evaluating the mechanical properties of E-Glass fiber/carbon fiber reinforced interpenetrating polymer networks”, *Polímeros*, Vol. 25, No. 1, pp. 49–57, 2015.
16. El-Kady, E.Y., El-Mahallawi, I.S., Mahmoud, T.S., Attial, A., Mohammed, S.S. and Monir, A., “Optimization of the cooling slope casting parameters for producing AA7075 wrought aluminum alloy thixotropic feedstock”, *MSAIJ*, Vol. 14, No. 8, pp. 279–287, 2016.