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TOWARDS THE OPTIMIZATION OF PROCESS PARAMETERS FOR IMPACT STRENGTH OF NATURAL FIBER REINFORCED COMPOSITES: TAGUCHI METHOD

ABSTRACT

This paper presents an investigation of impact strength of sponge gourd, coir, and jute fibers reinforced epoxy resin-based composites. Impact strength of specimens, made of composites with various proportions of wt% ratio of resin and hardener, wt% of resin and hardener, wt% ratio of sponge gourd and jute, wt% ratio of sponge gourd and coir, was measured. Design of experiment was done by Taguchi method using four control factors with three levels. Effect of the above control factors on impact strength was examined and the best combinations of control factors are advised. Confirmation test was performed by using this combination and the percentage of contribution of the above factors on impact strength was investigated by Analysis of Variance (ANOVA). Contour and interaction plots provide helpfully examines to explore the combined influences of different control factors on output characteristics. The regression equation represents a mathematical model that relates control factors with impact strength.

Keywords: Natural fiber-reinforced composites; impact strength; Taguchi analysis; ANOVA analysis; regression analysis

INTRODUCTION

Natural fibers neither synthetic nor manmade and are extracted from various plant and natural sources. Fiber-reinforced composites got considerable priority in science and technological applications due to the exceptional properties and comparative advantages of natural fiber over synthetic fibers such as lightweight, high weight to strength ratio, low cost, excellent mechanical properties, high durability, and corrosive resistance, processing flexibility, biodegradable, and minimal health and environment hazards [1]. At present, researchers put forward their concentrations on natural fiber-reinforced hybrid composites all over the world. The main focus areas were to incorporate natural fibers which are extracts from the plant as reinforcement in hybrid composites. In recent times, Natural fiber composites (NFC) are in major focusing for various applications from the deep sea to space. Different factors such as fiber size, environmental impact of the fibers and fiber treatments have a significant influence on the NFC

properties. That's why various natural fibers extraction from the plant and characterization methods were developed over the decades. Chemical treatments of *Agave Americana* fiber for composite material reinforcement was investigated by Madhu et al. [2]. They found *Agave Americana* fiber suitable for lightweight composite during the observation of mechanical, Physico-chemical, thermal and morphological properties. In another study, *Aristida adscensionis* fibers extraction and characterization were done for the first time to use as a novel reinforcement in composite material [3]. Natural fiber extraction, preparation, and characterization methods also discussed in the following study for composite material reinforcement [4-7]. NFC is going to be a new alternative of engineering materials for its available extraction, processing methods, unique property, a wide range of composition formation and range of variability which could substitute the use of synthetic fiber composites in very near future [8].

The mechanical and morphological properties of bio-based high-density polyethylene (HDPE) and sponge gourd composites were studied by Escocio et al. [9]. Sponge scrap and HDPE were mixed by blending process at various proportions of 10, 20, 30, and 40% wt/wt. The impact strength was found for different compositions of composites is 25.5-34.7 J/m². A comparison of short jute fiber (2-3 mm) based polypropylene composites and short E-glass fiber were done by Khan et al. [10]. Compression molding was used for composite fabrication with 20wt% of fiber. Impact strength of the composites was found 18 kJ/m² and short jute fiber-based composites showed excellent mechanical property over the short E-glass fiber-based composites. Bidirectional jute fiber mate-based epoxy composites were fabricated by hand lay-up method and analyzed by Mishra et al. [11]. Maximum impact strength 4.875J was found at 48wt% fiber loading. They concluded that impact strength is increased as the fiber loading increases. A novel treating method was introduced for jute fiber mat treat using sodium hydroxide (NaOH) and Maleic anhydride-grafted polypropylene (MPP) emulsion by Liu and Dai [12]. Jute polypropylene-based composites were prepared by film stacking method and maximum impact strength found 65.0 Jm⁻¹.

Bhagat et al. [13] investigated the physical and mechanical performance of luffa-coir based hybrid composites. The highest impact strength 31.74 kJ/m² is found at 15wt% of coir and 10wt% of luffa with 35 mm fiber length. In another study, luffa-coir hybrid composites were fabricated and analyzed by Krishnudu et al. [14]. They used epoxy and hardener at 10:1 ratio and found the impact strength 68 kJ/m². Jute-coir fiber-based hybrid composites were fabricated and Physico-mechanical properties were tested by Siddika et al. [15]. Different fiber loading was used with jute and coir fibers at a ratio of (1:1) during composite fabrication. The authors found that mechanical properties were increased with the increase of fiber loading except for tensile strength and 20wt% of fiber loading provides the best mechanical properties. Rafiquzzaman et al. [16] manufactured woven jute and coir-based composite using hand lay-up technique. They found the highest impact strength of 202.18 J/m² at 40 wt% fiber loading. In another study, Rafiquzzaman et al. [17] prepared composites using hand lay-up process and investigated the mechanical property of glass-jute fiber polymer composites. Maximum impact strength 265.87 J/m² was found for composite with 10% jute and 30% glass fiber by weight. Coir and jute-based hybrid composite were fabricated by Ahmed et al. [18] and Physico-mechanical properties were investigated. The results of their analysis showed an increase in impact strength with an increase in fiber loading.

From the best of the author's knowledge, there is no natural composite had been made yet by using sponge gourd, coir, and jute fiber. On the other hand, by using Taguchi method optimum process parameter selection for impact strength of natural reinforced composite is rare. The

objective of this research work is to fabricate epoxy resin-based sponge gourd, coir and jute fiber reinforced natural composites. Besides, the investigation of impact strength of these composites with different compositions has been performed. To understand the effect of different parameters on output characteristics and find out the optimum experimental condition of this composites by utilizing the Taguchi method is another important objective of this research. Impact strength optimization parameters for the fabricated composites were predicted using Taguchi experimental design and Analysis of variance (ANOVA). Finally, determine the optimum combination of this composite and validate the values of different impact strength by Regression Analysis has done.

MATERIALS AND METHODS

Materials collection

In this study, sponge gourd, coconut coir, and jute fiber were used for reinforcement in the composite. Sponge gourd, coconut coir, and jute fiber were collected from the local market of Bangladesh. Sponge gourd is collected as a ripen and dried one. Coconut coir and jute fiber were collected as peeled coir and dismantled jute fiber. For matrix material, Epoxy resin (ADR 246 TX) was used. To enhance the interfacial adhesion and improve the strength of composites, Hardener ADH 160 and Methyl Ethyl Ketone Peroxide (MEPOXE) were used.

Anatomical section of fibers

Sponge gourd

Sponge gourd, the fruit of *Luffa cylindrica*, are widely used throughout the world. The fruit resembles a cucumber in shape and size [19]. Sponge gourd has a reticulated fibro-vascular structure that forms an open network of random small-scale lattices. High porosity (79-93%) and high specific volume of pore (21-29 cm³/g) is found in these small-scale lattices [20-21].

Fig. 1. (a) Sponge gourd, (b) macro/microstructures of high-density sponge gourd, (c) macro/microstructures of low-density sponge gourd [26]

Based on the structures of sponge gourd, it has four parts namely outer surface, inner surface, middle layer and inter layer [22]. Fiber bundles are circumferential directions on the outer surface, whereas on the inner surface fiber bundles with longitudinal directions. The middle layer consists of radial directions of fiber bundles and this layer is connected with the fiber bundles using hoop stress [23]. Between the inner and outer surface, inter layer part is found where fiber bundles grow in three directions. Nowadays, fully ripened sponge gourd fibers are used in different natural or hybrid composites fabrication [9, 24-25]. Fig. 1 shows the anatomical representation of sponge gourd.

Coconut coir

Coir fiber comes from the husk of the coconut fruit (*Cocos nucifera*). A large number of lumens is found in coir fiber with thin walls which makes it porous and the cross-section of the fiber is rather circular. SEM images of elementary fiber are representing in Fig. 2a.

Fig. 2. SEM images of elementary fibers: (a) lumens and cell walls, (b) primary and secondary cell walls microfibrils, (c) Schematic presentation of the orthogonal slice of single coir fiber [28]

The lumens are found inside the elementary fiber with discontinuous alignment. Elementary fiber consists of two layers of cell walls containing microfibrils and elementary fibers are held together by middle lamella. The cell structure of coir fiber is as same the cell structure is found in wood and plant fibers. The difference is coir fiber microfibrillar angle is much larger than wood and plant fibers. The microfibrils in the primary and secondary wall seem to be aligned with around 45° and close to 90° respectively and the primary wall is less thick than the secondary wall which is observed in Fig. 2b. Fig. 2c shows the schematic representation of an orthogonal slice of coir fiber with the arrangement of elementary fiber. Coir fiber can be reinforced with both thermoset and thermoplastic resins [27].

Jute fiber

Jute fiber is derived primarily from plants of the genus *Corchorus*, once known as Tiliaceae, and currently as Malvaceae. Among the fiber category, it includes in the group of bast fiber. Two types of jutes are cultivated in Bangladesh namely white jute (*Corchorus capsularis*) and tossa jute (*Corchorus olitorius*). White jute is used in this study. Cellulose (45.0-71.5 wt.%), hemicellulose (13.6-21.0 wt.%), and lignin (12.0-26.0 wt.%) are the main constituents in jute fiber [29]. Jute fiber is collected from the outer part of the stem after retting it. Jute fiber composed of two layers of cell walls containing hemicellulose bundles and lignin together. Microfibrils are found on the elementary layer of jute. Elementary fibril consists of larger amount of cellulose. Fig. 3 shows the microstructure of jute fiber.

Fig. 3. Jute fiber macro/microstructures [30]

Fiber preparation

As earlier mentioned, we collected the sponge gourd as a dried one, coir and jute picked as peeled coir and dismantled jute fiber. That's why no fiber extraction method is involved here. After cleaning properly, a shredder machine was used to cut sponge gourd, coir, and jute fibers into small pieces. The size of short fibers is within 3-5 mm. A solution of 5% concentration

NaOH by volume, was used for chemical treatment of these short fibers for 24 hours and then fibers were dried at sunlight. Chemically treated dried fibers were then stored properly. Fig. 4 shows the fibers used to fabricate the composite.

Fig. 4. (a) Sponge gourd, (b) coconut coir, and (c) jute fiber

Composite fabrication procedure

There are a large number of composites fabrication techniques available namely resin transfer molding, compression molding, vacuum molding etc. In this study, hand lay-up method is used for composite fabrication. The main reason for using hand lay-up technique is to not only reduce fabrication time and cost but also to fabricate large and complicated part. The dimension of the mold was measured $27.5 \times 15.5 \times 0.5 \text{ cm}^3$ which was made from mild steel plate. Parachute cloth was applied to the mold surface for easy removal of composite. The Charpy impact test specimens were made by using a Jig saw machine according to the ASTM A370 standard in which the dimension is $55 \times 10 \times 10 \text{ mm}$. Fig. 5 shows the geometry of impact strength test specimen.

Fig. 5. Specimen geometry for impact strength test

Taguchi method

To optimize the process parameters, Taguchi method is a useful and effective tool which is a combined application of statistical and mathematical methods. Signal-to-noise (S/N) ratio and orthogonal arrays are the main two approaches applied in Taguchi method [31]. S/N ratio is applied in experimental results to aid in the selection of the best process or product design [32]. As the maximization of impact strength is our research objective so, the larger the S/N ratio is

better and this principle is considered in this study. Equation (1) is used to calculate the characteristics of S/N ratio.

$$\eta(dB) = -10 \log_{10} \frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \quad (1)$$

Where, y_i is the i^{th} value of the response variable. The minimum number of experiments to be conducted is to be fixed and calculated using Equation (2).

$$N \text{ Taguchi} = 1 + NV (L - 1) \quad (2)$$

Where, N Taguchi is the Number of experiments to be conducted, NV is the Number of parameters and L is the number of levels. The main target of Taguchi design is to achieve an optimized result with minimum number of experiments. In this work considering cost and time factor, four parameters are expected to be optimized (so NV=4) and in this case, it is possible to select level values 2, 3, 4 or 5. If the level value of 2 is selected, it may be less accurate as it provides only linear relation (only two points makes a simple linear line) for any parameter. So, the level value of 3 (L=3) is selected to have a more accurate result. A level value higher than 3 requires a large number of experiments for four parameters that will incur huge costs and extra time. In this work, we have chosen NV = 4 and L = 3 hence, according to Equation (2) the value of N Taguchi is 9. N Taguchi design of experiments suggests L9 orthogonal array, where 9 experiments are sufficient to optimize the parameters. The influence of four factors was studied using L9 (3^4) orthogonal design. Table 1 shows the operating conditions under which tests were performed.

Table 1. Levels of the variables used in the experiment

Control factors	Levels		
	1	2	3
wt% ratio of resin and hardener, A	1.50	1.25	1.00
wt% of resin and hardener, B	91	88	85
wt% ratio of sponge gourd and jute, C	0.33	1.00	3.00
wt% ratio of sponge gourd and coir, D	0.33	1.00	3.00

RESULTS AND DISCUSSION

Table 2 shows the design of experiment by using Taguchi L9 orthogonal array with impact strength values of natural composites. Experiment no. 6 gives the maximum impact strength value (89.361 MJ/m²). This value is found when wt% ratio of resin and hardener is 1.25; wt% of resin and hardener is 85; wt% ratio of sponge gourd and jute is 0.33; and wt% ratio of sponge gourd and coir is 1.00. On the other hand, experiment no. 9 reveals the minimum impact strength value (34.820 MJ/m²), where wt% ratio of resin and hardener, wt% of resin and hardener in composite, wt% ratio of sponge gourd and jute, and wt% ratio of sponge gourd and coir are 1.00,

85, 1.00 and 0.33 respectively. From Table 2, it is visualized to choose the factors to impact strength values of the natural composites.

Table 2. Taguchi Experimental design using L9 orthogonal array with responses of natural composite

Experiment No.	wt% ratio of resin and hardener	wt% of resin and hardener	wt% ratio of sponge gourd and jute	wt% ratio of sponge gourd and coir	Impact Strength (MJ/m ²)	S/N Ratio (dB)
1	1.50	91	0.33	0.33	41.120	32.281
2	1.50	88	1.00	1.00	65.352	36.305
3	1.50	85	3.00	3.00	74.137	37.401
4	1.25	91	1.00	3.00	45.640	33.187
5	1.25	88	3.00	0.33	80.762	38.144
6	1.25	85	0.33	1.00	89.361	39.023
7	1.00	91	3.00	1.00	54.550	34.736
8	1.00	88	0.33	3.00	37.580	31.499
9	1.00	85	1.00	0.33	34.820	30.836

Taguchi Analysis

The decision factor “larger is better” is used for choosing S/N ratio. Table 3 shows the response of S/N for impact strength of the natural composites. From Table 3 and Fig. 6, it is seen that variations are small for the factor wt% of resin and hardener in composite, very low response in case of 91 level value. High variation comes from wt% ratio of resin and hardener. So at a first glance, it may be predicted that wt% ratio of resin and hardener would be the main cause of improvement of impact strength. High response from 1.25 wt% ratio of resin and hardener in the natural composite that was somewhat desired for high impact strength. Very poor results are obtained in the case of 1.00 wt% ratio of resin and hardener. wt% of resin and hardener is another much better option for the improvement of impact strength. But, it should be kept in mind that, 91 wt% of resin and hardener should be avoided. As the ratio decreases, that is, a relative reduction of resin compared to hardener in the composite, much better results can be obtained. The result is higher incremental for 85 wt% of resin and hardener. wt% ratio of sponge gourd and jute is another option that affects the impact strength of the composites. From Fig. 6, wt% ratio of sponge gourd and jute should be maintained close to 3.00. Similarly, the wt% ratio of sponge gourd and coir must be maintained very close to 1.00 for higher impact strength of the natural composite.

Table 3. Response table for signal to noise ratio of impact strength at various levels of input parameters

Level	wt% ratio of resin and hardener, A	wt% of resin and hardener, B	wt% ratio of sponge gourd and jute, C	wt % ratio of sponge gourd and coir, D
1	32.36	35.75	34.27	33.75
2	36.78	35.32	33.44	36.69
3	35.33	33.40	36.76	34.03
Delta	4.43	2.35	3.32	2.93
Rank	1	4	2	3

Fig. 6. Main effect plots for SN ratio values of impact strength

Confirmation experiment

To verify the experimental results, confirmation test is an important test and strongly recommended by Taguchi. Taguchi's experimental design has provided the optimal parameter combination. The optimal control factor combination for maximum impact strength is A(1.25), B(85), C(3.00), D(1.00). Thus, the predicted S/N ratio for maximum impact strength is given by the equation:

$$\begin{aligned} \text{Impact Strength (Predicted)} &= \eta_{A(1.25)} + \eta_{B(85)} + \eta_{C(3.00)} + \eta_{D(1.00)} - 3\eta_m \\ &= 36.78 + 35.75 + 36.76 + 36.69 - 3(34.82) = 41.52 \end{aligned}$$

Where A_i , B_i , C_i , and D_i are the values of S/N ratio at their i^{th} levels respectively, and η_m is the overall mean. The optimal control factor combination did not correspond to any experiment number in L9 orthogonal array showed in Table 2. So, a new experiment was performed to verify the predicted value of impact strength on three samples. The predicted and experimental values of S/N ratio for impact strength are 41.52 and 39.57 respectively where the percentage of error is only 4.69%.

ANOVA analysis

F Statistic that is mainly used for ANOVA analysis based on the F probabilistic distribution. To accept or reject null hypothesis, F statistic is used. F test result consists of F value and F critical value. The value that is calculated from experimental data is termed as F value and the value that is obtained from the F distribution table is known as F critical. Generally, the null hypothesis is rejected when the calculated F value is larger than the F critical value. During the F test result, p-value is an important consideration and it is determined by the F statistic. The value of p indicates the probability that the results could have happened by chance.

The degree of freedom (DF) is a term that explains the amount of information uses in an experiment. The total DF is determined by the number of observations carried out in the designed experiment. Variation of different components of the model is measured by Adjusted sums of squares (Adj SS) and how much varied a component is determined by Adjusted mean squares (Adj MS). This variation determination considers all other terms present in the model and no matter what order they were entered. Between the Adj SS and Adj MS, Adj MS only considers the DF. Minitab separates the sums of squares in ANOVA analysis result into different components that describe the variation due to different sources.

The percentage of contribution shows how much a source contributes to total variation. From this one-way ANOVA analysis shown in Table 4, the maximum percentage of contribution was found 27.62 for wt% of resin and hardener. The F value should always be used along with the p-value in deciding whether the results are significant enough to reject the null hypothesis. No relation between the term and the response is indicated by the null hypothesis. Usually, a significance level is denoted by as α and in this study significance level of 0.05 has been used due to the value 0.05 works well. From F-distribution table [33], for numerator 1 (as DF=1 for wt% of resin & hardener) and denominator 4 (as DF=4 for error), critical value $F_{critical}=7.71$. The F statistic just compares the joint effect of all the variables together. To put it simply, reject the null hypothesis only if the significance level is larger than the p-value. In this study, calculated F-value corresponding to maximum percentage of contribution is 1.29 which is smaller than critical F-value. So, p-value is 0.319 or 31.9% which is larger than significance level of 0.05 that indicates the assumption is acceptable. Similarly, the minimum percentage of contribution was found 2.19 for wt% ratio of sponge gourd and coir. Here, calculated F-value is 0.10 which is less than 7.71. So, p-value is 0.765 or 76.5% which is greater than significance level of 0.05 that indicates the high probability of accepting the null hypothesis. In this analysis, combinational effects of factors that are not considered, contribute 21.4% as error.

Table 4. ANOVA Analysis for impact strength at 95% confidence level

Source	DF	Adj SS	Adj MS	F-Value	p-Value	Percentage of contribution
wt% ratio of resin and hardener	1	479.88	479.88	1.14	0.345	24.47
wt% of resin and hardener	1	541.65	541.65	1.29	0.319	27.62
wt% ratio of sponge gourd and jute	1	476.70	476.70	1.14	0.347	24.32
wt% ratio of sponge gourd and coir	1	42.88	42.88	0.10	0.765	2.19
Error	4	1678.66	419.66			21.40
Total	8	3219.78				100

Contour plot analysis

Fig. 7 depicts the contour plots of impact strength of the natural composite. wt% of resin and hardener below 87.5 with the wt% ratio of resin and hardener higher than 1.4, shows the contour surface of better result, impact strength higher than 70 MJ/m². But decrease in wt% ratio of resin and hardener indicates the lower impact strength contour. Higher wt% ratio of sponge gourd and jute with higher wt% ratio of resin and hardener is effective for achieving higher impact strength.

Fig. 7. Contour plots of impact strength

A decrease in wt% ratio of resin and hardener value with the decrease of wt% ratio of sponge gourd and jute shows the lower impact strength contour surfaces. The better contour surface for wt% ratio of sponge gourd and coir and wt% ratio of resin and hardener is mainly depended on the value of wt% ratio of resin and hardener. Higher wt% ratio of sponge gourd and jute with lower wt% of resin and hardener shows the higher impact strength contour surface. If the values are reversed then the impact strength contour surface is lower. The better contour surface for wt% ratio of sponge gourd and coir along with wt% of resin and hardener is mainly depended on the value of wt% of resin and hardener. Similarly, the better contour surface for wt% ratio of sponge gourd and coir along with wt% ratio of sponge gourd and jute in mainly depended on the value of wt% ratio of sponge gourd and jute.

Interaction plots results

The interaction plot for impact strength of the natural fiber-reinforced composite is shown in Fig. 8. When wt% ratio of resin and hardener interacts with wt% of resin and hardener, level value of 1.25 for wt% ratio of resin and hardener is the most influential to improve impact strength. It provides improved results relative to two other level values of wt% ratio of resin and

hardener. Level value of 1.25 for this factor results in maximum impact strength with 85 level value of wt% of resin and hardener. With the decrease of level value for wt% of resin and hardener, it may be possible to improve impact strength. 1.50 level value of wt% ratio of resin and hardener behaves alike when it interacts with wt% ratio of resin and hardener. Generally, response pattern is alike but different in values. For the level value of 1.50 of wt% ratio of resin and hardener, 85 level value of wt% of resin and hardener provides better response than other two, 88%, and 91%. It can be said that the smaller wt% of resin and hardener, the higher impact strength considering the combinational effect with wt% ratio of resin and hardener. For these two factors, level value of 1.00 of wt% ratio of resin and hardener provides the worst result. But in this case, the pattern is reversed, with the increase of wt% of resin and hardener impact strength improves although improvement is in very little scale.

Fig. 8. Interaction plots of impact strength

When wt% ratio of resin and hardener interacts with wt% ratio of sponge gourd and jute, maximum response is from 1.25 level value of wt% ratio of resin and hardener and 0.33 level value of wt% ratio of sponge gourd and jute is desirable in this case. It is a specific point sensitive. Level value of 1 for wt% ratio of sponge gourd and jute may not be effective as it lowers the response on very large scale, but then increasing level value of this factor results in improving the response, specifically for level value of 3.00 although less than for the level value of 0.33. But it is an indication or sign that there is a scope to improve impact strength by increasing level value higher than 3.00. 1.50 level value of wt% ratio of resin and hardener shows linear relation with other factor values of wt% ratio of sponge gourd and jute. With increasing level value after 3.00, it also may be a good option to improve response. In this case, also level value of 1.00 for wt% ratio of resin and hardener provides the worst result. It should be avoided.

Here for interaction between wt% ratio of resin and hardener and wt% ratio of sponge gourd and coir, level value of 1.25 of wt% ratio of resin and hardener is more effective. Level value of 1.00 for wt% ratio of sponge gourd and coir maximizes the response but increasing the level value after 1.00 seems to be not efficient. Level value of 1.50 for wt% ratio of resin and hardener shows a linear pattern of impact strength improvement with the level values of wt% ratio of sponge gourd and coir. Level value of 1.00 for wt% ratio of resin and hardener is specific point sensitive.

When factors, wt% of resin and hardener and wt% ratio of sponge gourd and jute, are considered level value of 85 for wt% of resin and hardener provides a maximum response, but specific point sensitive. 0.33 level value of wt% of sponge gourd and jute shows high impact strength, but when it is increased to level value of 1.00, it shows very low output. Both 88 and 91 level value shows a linear relation with respect to wt% ratio of sponge gourd and jute, but different in slope.

88 level value of wt% of resin and hardener is in linear increasing relation with wt% of sponge gourd and coir. But 85 level value of wt% of resin and hardener represents the highest response, not having linear relation to maximize output value. 91 level value of wt% of resin and hardener is not recommended as it produces impact strength below average in this case for every level value of wt% of sponge gourd and coir.

When it is necessary to interpret two factors, namely wt% ratio of sponge gourd and jute and wt% ratio of sponge g. and coir, level value of 0.33 of wt% ratio of sponge gourd and jute combined with level value of 1.00 of wt% ratio of sponge gourd and coir is more important as it is sensitive to a specific point and helps to maximize response. Other two-level values of wt% ratio of sponge gourd and coir should be avoided. Level value of 3.00 for wt% ratio of sponge gourd and jute may be a good option to improve impact strength, but level value of 1.00 of wt% ratio of sponge gourd and coir with it, should not be selected. Level value of 3.00 of wt% ratio of sponge gourd and jute is not satisfactory in this case to improve strength.

Regression analysis

The regression analysis is a numerical means method for analyzing the relationship among various parameters. In this study, the optimal mechanical properties for polymer composite are obtained employing regression analysis using MINITAB 18. By providing input and output parameters in the Taguchi L9 orthogonal array in DOE, the main feature form of regression equation is obtained. The equations are formed based on the value of four factors in case of composite polymer. The regression equation of impact strength for the natural composite is as follows:

$$\text{Impact strength (MJ/m}^2\text{)} = 286 + 35.8A - 3.17B + 6.42C - 1.92D$$

In this equation, 286 is added as constant, whereas factor A and factor C indicate a positive response. The coefficient of factor A is the largest, so it is a clear indication that increasing the value of A, it may maximize the impact strength at a rate higher than other factor values. Factor C can also improve the impact strength but rate is lower than factor A as its coefficient is smaller. Similarly, factor B and factor D can lower the impact strength with the increase of values as they have negative coefficient.

Fig. 9 shows a comparison between experimental and predicted impact strength values. The figure reveals the nature of the two graphs practically almost similar. The experimental impact strength values for the experiment no. 2, 4, 7 and 8 almost matches with the predicted value. So, the authors would like to highly recommend the regression equation of impact strength of the natural composite.

Fig. 9. Comparison between experimental and predicted impact strength values

CONCLUSIONS

Fabrication and impact tests of sponge gourd, jute, and coir fiber-reinforced composite were performed successfully. From result and discussion, the following conclusion can be drawn:

- The combination of wt% ratio of resin and hardener is 1.25, wt% of resin and hardener 85, wt% ratio of sponge gourd and jute is 3.00, and wt% ratio of sponge gourd and coir is 1.00 were found as the optimum setting for obtaining maximum impact strength.
- Confirmation experiments were carried out with the optimum settings on three different samples. The average experimental S/N ratio for impact strength in that optimum combination was 39.57 which was very close to the predicted value with only 4.69% error.
- From the ANOVA table, maximum and minimum contribution on the impact strength was found for wt% of resin and hardener and wt% ratio of sponge gourd and coir.
- Contour and interaction plots reveal the collective influences of different control factors on the impact strength behavior of these composites.
- The regression equation showed a very close resemblance between predicted and experimental values.

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