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Optimization of Design Parameters for Achieving Highest Impact Strength of Rice straw Based Polymer Composite Using Taguchi Method

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ABSTRACT

The main objectives of this research are optimization of design parameters and to find out the best design from a set of design parameters for achieving highest impact strength for the composite fabricated by rice straw. Taguchi method has been applied for determining the most desirable design for the composites. In this study L9 orthogonal array and signal-to-noise (S/N) Ratio is employed to optimize control factors affecting the impact strength of the composite. To calculate the signal to noise ratio "larger is better" approach has been followed as this research seeking the highest impact strength. It has been found that this fiber weight (%) is the most effective parameter other than resin (%) and number of layers. The highest impact strength are found 185.90 KJ/m2 for the combinations of 40 fiber weight (%), 80 resin (%), 3 number of layers. The interaction among the design parameters has also the significant effects on achieving highest impact strength.

Keywords: *Optimization, Design parameters, Impact strength, Rice straw based polymer composite, Taguchi method*

Introduction & Literature Review

Now-a-days a big portion of material science has been conquered by composite materials. Composites are one of the most widely used materials because of their adaptability to different situations and the relative ease of combination with other materials. Then can serve specific purposes and exhibit desirable properties. This is a very important issue in many engineering works.

A composite material can be defined as a combination of two or more materials. It results in better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. By combining materials different properties of the materials can be enhanced to a desired limit. The two constituents are known as reinforcement and matrix. The main advantages of composite materials are their high strength and stiffness. They also have the property of low density, when compared with bulk materials, allowing for a weight reduction in the finished part.

In the recent years there is a vast growth in natural fiber based polymer composites due to its various attractive features likes biodegradability, no abrasiveness, flexibility, availability, low cost, light weight etc. Different researchers have performed various experiments to enhance the mechanical properties of natural fiber based polymer composites.

Particulate composites tend to be much weaker and less stiff than continuous fiber composites, but they are usually much less expensive. Particulate reinforced composites usually contain less reinforcement (up to 40 to 50 volume percent) due to processing difficulties and brittleness Tuttle (2012). Biswas, kindo & Patnaik (2011) studied the effect of length on mechanical behavior of coir fiber reinforced epoxy composites and observed that the hardness is decreasing with the increase in fiber length up to 20 mm.

A study on pulp fiber reinforced thermoplastic composite shows that while the stiffness is increased by a factor of 5.2, the strength of the composite is increased by a factor of 2.3 relative to the virgin polymer Lundquist, Marque, Hagstrand, Leterrier, & Manson (2003). Reinforcement is provided, layer by layer in different directions Tiwari (2014).

1. Laminate: Here, the constituent material in all layers is the same.
2. Hybrid laminates: These have more than one constituent material in the composite structure.

Gowda, Naidu, & Chhaya (1999) investigated the mechanical behavior of jute fabric-reinforced polyester composites and found that jute fiber based composites shows better strengths than those of wood based composites. The mechanical properties of coir fiber/polyester composites were evaluated and the effect of the molding pressure on the flexural strength of the composites is studied. The results obtained for flexural strength allowed comparison of the technical performance of the composites with other conventional materials. Monteiro, Terrones, & D'almeida (2008); Luo & Netravali (1999) studied the tensile and flexural properties of polymer composites with different pineapple fiber content and compared them with the virgin resin. The tensile and flexural strengths of "green" composites are significantly higher in the longitudinal direction while they are lower in the transverse direction. Amash & Zugenmaier (2000) reported the effectiveness of cellulose fiber in improving the stiffness and reducing the damping in polypropylene cellulose composites. Dynamic mechanical behavior of natural fibers like sisal, pineapple leaf fiber, oil palm empty fruit bunch fiber etc. in various matrices has been studied by Joseph et al, 1992 & George et al (1996). A great deal of work has been done on various aspects of polymer composites reinforced with banana fibers. Mechanical properties, failure, aging characteristics and comparative analysis of banana fibers are performed with other reinforcement Joseph et al., 2002; Pothan et al., 2002 & Corbière-Nicollier et al. (2001).

Chawla & Bastos (1979) investigated the effect of fiber volume fraction on Young's modulus, tensile strength and impact strength of untreated jute fibers in unsaturated polyester resin. Schneider & Karmaker (1996) studied the mechanical behavior of jute and kenaf fiber based polypropylene composites and reported that jute fiber provides better mechanical properties than kenaf fiber. A systematic study on the properties of henequen fiber and pointed out that these fibers have mechanical properties suitable for reinforcement in thermoplastic resins by Cazaurang et al. (1991).

Shibata et al. (2005) have studied the effects of the volume fraction and length on flexural properties of kenaf and bagasse fibers based composites. Above 60% fiber volume fraction kenaf and 66% bagasse, the flexural modulus decreased due to insufficient resin. Hepworth et al. (2000) has studied the mechanical behavior of unidirectional hemp fiber reinforced epoxy composites. He has found that the pinning-decortication treatment resulted in stronger, stiffer, composites. Lack of retting did not significantly change the reinforcing capabilities of hemp fiber. Sapuan, Leenie et al. (2006) investigated the tensile and flexural behavior of musaceae/epoxy composites. It was found that that the maximum value of stress in *x*-direction is 14.14 MN/m^2, meanwhile the maximum value of stress in *y*-direction is 3.398 MN/m^2. For the Young's modulus, the value of 0.976 GN/m^2 in *x*-direction and 0.863 GN/m^2 in *y*-direction were computed. Pavithran, Mukherjee et al. (1987) studied the fracture energies for sisal, pineapple, banana and coconut fiber reinforced polyester composites and reported that, except for the coconut fiber, increasing fiber toughness was accompanied by increasing fracture energy of the composites.

Bos, Mussig et al. (2006) investigated the mechanical properties of flax/polypropylene composites. Flax fibres are quite effective in improving strength and stiffness of a compound and effective compatibilisation of the fiber/matrix interphase can be easily reached. Tobias (1993) analyzed the influence of fiber length and fiber content in banana fiber reinforced epoxy composites and reported that the impact strength increased with higher fiber content and lower fiber length. Santulli (2001) investigated the post impact behavior of plain-woven jute/polyester composites subjected to low velocity impact and reported that the impact performance of these composites is poor.

Taguchi method analyzes the influence of parameter variation on response characteristics. Thereby, and an optimal result can be obtained from the sensitivity analysis respect to parameter variation. However, Taguchi method has shown some defects in dealing with the problems of multiple performance characteristics Bement (1989); Roy (2001); Berginc, Kampus & Sustarsic (2006). Sumaiya Shahria et al. (2017) researched to reduce aluminum casting defects by optimizing proportion of water and bentonite using Taguchi method and the research has found optimum level of composition for casting Al with the result of 90% sand, 5% bentonite, and 5% water.

The main objectives of this research are optimization of design parameters and to find out the best design from a set of design parameters using Taguchi method. The rest of the papers are organized as the materials and method, experimentation and interpretation, results & discussion and conclusion.

Materials and Methods

Study on Rice Straw Fiber

Rice straw is a rice by-product produced when harvesting paddy. Each kg of milled rice produced results in roughly 0.7–1.4 kg of rice straw depending on varieties, cutting-height of the stubbles, and moisture content during harvest. Rice straw is separated from the grains after the plants are threshed either manually, using stationary threshers or, more recently, by using combine harvesters.

Rice straw, as a lignocellulose biomass, is comprised of three components: lignin, cellulose, and hemicelluloses. These could be fractionated through pretreatment as shown in Figure1. Cellulose and hemicelluloses are fiber organics, whereas lignin is the cell wall.

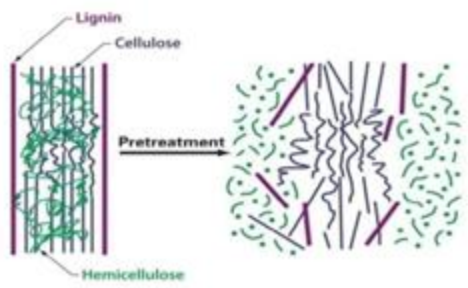

Figure1. *Major components of lignocellulose biomass*

Table1. *Detailed list of physical and mechanical properties of Rice straw fiber*

Properties	Rice Straw fiber
Length (mm)	25-80
Density (g/mm^3)	0.00095
Young modulus (GPa)	65
Specific Gravity (gm/cc)	2.2
Poisson's ratio	0.2
Tensile strength(MPa)	1.2
Opacity (%)	85.6
Porosity(s)	20
Breaking elongation (%)	2.2-3.5
Moisture regain (%)	7.9-8.9

Table2. *Mechanical properties of epoxy resin*

Mechanical Properties	Ratings
Glass transition temperature (Tg)	120 - 130 °C
Tensile strength	85 N/mm^2
Tensile Modulus	10,500 N/mm^2
Elongation at break	0.8%
Flexural strength	112 N/mm^2
Flexural Modulus	10,000 N/mm^2
Compressive Strength	190 N/mm^2
Coefficient of linear thermal expansion	34 10-6
Water absorption - 24 hours at 23°C	5-10 mg (0.06-0.068%) ISO 62 (1980)

Study on Epoxy Resin

Epoxy resins are low molecular weight pre-polymers or higher molecular weight polymers which normally contain at least two epoxide groups. The epoxide group is also sometimes referred to as a glycidyl or oxirane group.

The molecular structure of epoxy is complex. The structure of the cured epoxy glue is given below by Figure.2 and the Mechanical properties of epoxy resin is given in following Table2.

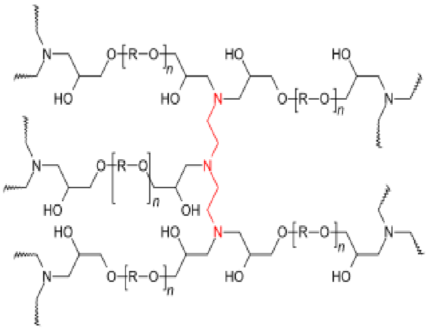

Figure2. *Structure of cured Epoxy*

Study on Taguchi Method

Taguchi technique is a powerful tool for the design of high quality systems and it employs a special design of orthogonal array to investigate the effects of the entire control parameters through the small number of experiments. By applying the Taguchi technique, the time required for experimental investigations can be significantly reduced, as it is effective in the investigation of the effects of multiple factors on performance as well as to study the influence of individual factors to determine which factor has more influence.

In this paper, the cutting parameter design by the Taguchi method is adopted to obtain optimal impact strength of Rice straw composite.

Nominal is the best: $\frac{S}{N_T} = 10\log(\bar{y}\,/s_y^2)$

Larger is the better(maximize): $\frac{S}{N_L} =$

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

Smaller is the better(minimize): $\frac{S}{N_S} =$

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

Where, $\bar{y}$ is the average of observed data, s_y^2 is the variance of y, n is the number of observations and y is the observed data. Notice that these *S/N* ratios are expressed on a decibel scale.

The goal of this research was to produce composite with higher impact strength. Larger impact strength values represents stronger composite. Therefore, a larger-the-better quality characteristic was implemented and introduced in this study.

Experimentation & Interpretation

Initiating Taguchi method

The main purpose of the project is to optimize the design parameters of rice straw composite to obtain maximum impact strength. For this purpose L9 orthogonal array of the design parameters are given below:

Table3. *Design parameters*

Level	Epoxy (%)	Fiber weight (%)	Number of layers
1	60	40	2
2	70	30	3
3	80	20	4

Table4. *L9 orthogonal array of the design parameters*

Experiment Number	Epoxy (%)	Fiber Weight (%)	Number of layers
1	60	20	2
2	60	30	3
3	60	40	4
4	70	20	3
5	70	30	4
6	70	40	2
7	80	20	4
8	80	30	2
9	80	40	3

Fabrication Procedure

In this study, Rice straw fiber is used as reinforcement and the epoxy resin (ADR 246 TX) used as the matrix as shown in the Figure3. The rice straw having an average length of 150 mm, width of 20 mm and thickness of 9 mm. A resin and hardener mixture of 3:2 is used to obtain optimum matrix composition. In this study, the composites are manufactured by the hand lay-up process. The complete sequential fabrication process is shown in figure4.

Figure3. *Epoxy resin and rice straw fiber*

Figure4. *complete sequential process for fabrications (a) Fibers (b) Forming the mold (c) Mixing resin and fiber in appropiate proportion (d) Pouring mixer into the mold (e) Pressed to force the air gap to remove any excess air present and kept for 72 hours (f) Fabricated composite*

Impact Test (Izod Test)

Impact testing of the specimen is carried out on Tinius Olsen machine as per procedure mentioned in ASTM D256. The fabricated composites are cut using a grinding machine to obtain the specimen for mechanical testing as per the ASTM D3039 standards.

Composite specimens are placed in vertical position (Izod Test), hammer is then released to make impact on specimen, and CRT reader gives the reading of impact strength.

Figure5. *Impact Tester*

Results & Discussions

The impact strength and S/N ratio are calculated with respect to the various combination of the design parameters. To obtain optimal design for best impact strength the larger the better performance characteristics has been taken. The results of Impact strength and S/N Ratio are shown in the following Table 5.1.

Table5. *Calculation of Impact strength and S/N Ratio*

Experiment Number	Resin (%)	Fiber Weight (%)	Number of Layers	Impact strength (kJ/m^2)	S/N Ratio
1	60	20	2	126.23	41.4401
2	60	30	3	147.33	43.7166
3	60	40	4	178.34	44.5458
4	70	20	3	140.29	42.7817
5	70	30	4	148.33	43.7977
6	70	40	2	175.32	44.5372
7	80	20	4	150.29	43.6776
8	80	30	2	149.28	43.7271
9	80	40	3	185.90	45.4851

The response table for this experiment is given below by Table6.

Table6. *Response table for S/N Ratio*

Response Table for Signal to Noise Ratios Larger is better			
Level	**Resin (%)**	**Fiber weight (%)**	**Number of Layers**
1	43.23	42.63	43.23
2	43.71	43.75	43.99
3	44.30	44.86	44.01
Delta(Max-Min)	1.06	2.22	0.77
Rank	2	1	3

The control factors are sorted in relation to the differences in values. The S/N ratios response of the impact strength for test specimens is presented in Table6. This experimental study has shown that the most effective influence on impact strength rate appears due to be variations on the fiber weight (%) used for the composite specimens.

That is, the varying rates of fiber weight (%) into the main structure caused the resulting composite material to exhibit different level of impact strength. It has been found that this fiber weight (%) is the most effective parameter other than resin (%) and no. of layers. The resin (%) in the rice straw composite is the second most influential factors. The highest impact strength are found 185.90 KJ/m^2 for the combinations of

40 fiber weight (%), 80 resin (%), 3 number of layers. This combinations are the optimum design parameters. The interaction among the design parameters has also the significant effects.

GRAPHICAL REPRESENTATION OF THE RESULTS

The graphical analysis has been performed for the confirmation test of the results obtain from the Taguchi method. The main effect & interaction effect plot for both for S/N ratio and maximum load (N) are drawn by using MINITAB 17 which indicates the same results obtained from the Taguchi.

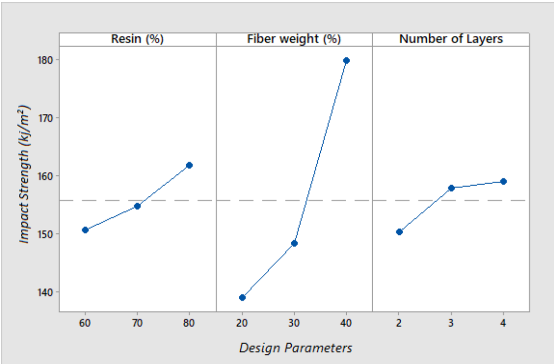

Figure6. *Main effects plot for impact strength (kJ/m2)*

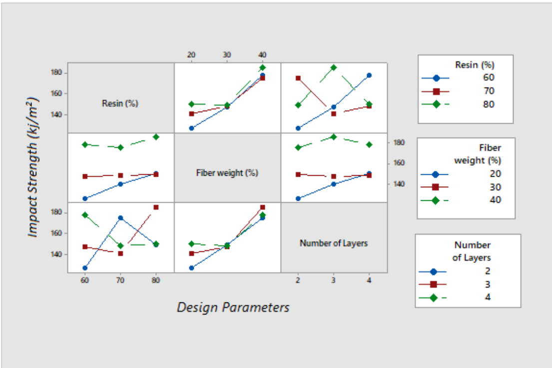

Figure7. *Interaction plot for impact strength (kJ/m2)*

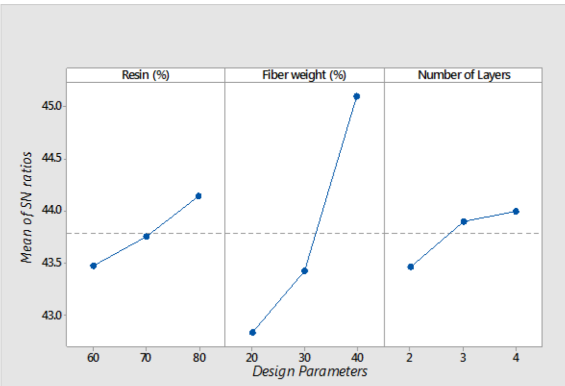

Figure8. *Main effects plot for S/N Ratio*

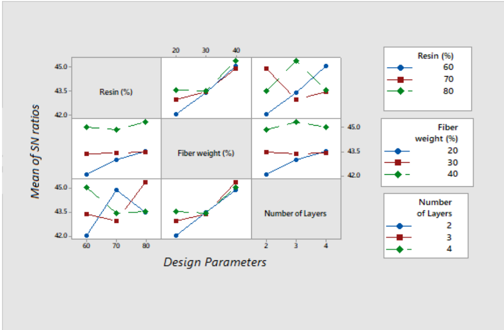

Figure9. *Interaction plot for S/N Ratio*

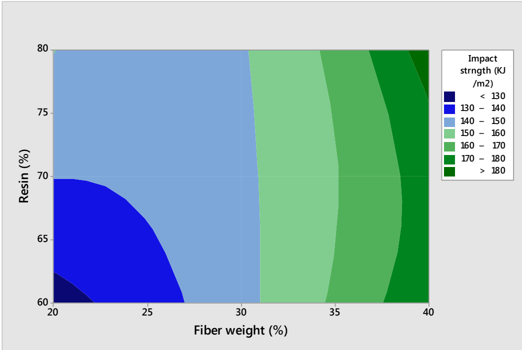

Figure10. *Contour plot for impact strength: Epoxy resin (%) vs. Fiber weight (%)*

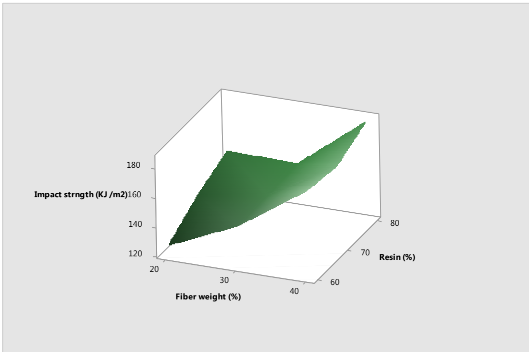

Figure11. *Surface plot for impact strength vs. Epoxy resin (%), Fiber weight (%)*

By analyzing Figure6. To Figure11. It gives the clear indications that the impact strength is proportional to the fiber weight (%), resin (%) and number of layers to be fabricated. This increase rate is significantly higher for the fiber weight (%) then for the resin (%) and number of layers to be fabricated respectively. The interaction among the design parameters is also conspicuous. Finally the effects of two most influential design parameters against impact strength has been depicted through the contour & surface plot.

CONCLUSION

Different natural fibers are being combined with synthetic fibers to give better mechanical and physical properties. But while using natural fibers researchers also have to face some difficulties. The optimum use of design parameters is being very important both for the quality fabrications and cost minimization. The volume percentage of fibers and resin have to maintain properly because the properties of composite are largely dependent on it. In addition to that, to make better quality composite with higher strength, higher flexibility and durability of the design parameters of the composites also have to be optimized. In this research work it is found that the impact strength is increased with the increase of fiber weight (%), resin (%) and number of layers to be fabricated. This increase rate is significantly higher for the fiber weight (%) then for the resin (%) and no. of layer to be fabricated respectively. The optimum design parameters for the fabrication is found 40 fiber weight (%), 80 resin (%), 3 number of layers. There is a huge scope for future work and applications in this research field of optimization of design parameters of rice straw composite.

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