Utilization of grey Taguchi method to optimize the mechanical properties of hemp and coconut shell powder hybrid composites under liquid nitrogen conditions

G Velmurugan*, K Babu2, L Immaculyne Flavia3, C Stories Stephy4, M Hariharan5

1, 3,4&5 Department of Mechanical Engineering, Jeppiaar Engineering College, Chennai, Tamilnadu, India-600119.
2Department of Mechanical Engineering, SSN College of Engineering, Chennai, Tamilnadu, India-603110.

*Email: velresearch032@gmail.com

Abstract Through this work an attempt was made to improve the mechanical properties of composite materials by using a process called Gray-Taguchi. Hand lay-up approach has been adopted for manufacturing. Here, Woven Hemp fiber diameter, Number of hemp layer, coconut shell powder content and cryogenic temperature ranges at different levels were incorporated as result parameter. ASTM specifications were set for the manufactured laminates to perform the mechanical tests. Hemp and coconut shell powder material are exposed to 5 percent NaOH treatment to create the matrix-fiber interface exchange. To optimize composite, the Taguchi method is combined with the Gray relational analysis. The quality targets are set for mechanical properties that include compressive strength, tensile strength, impact strength and flexural strength. This study involved nine experiments on the orthogonal array of the L9 (3^4) Taguchi method. A combination of the composite, Gray relational analysis was applied to obtain the optimal parameter. The results of optimum parameters were verified using Conformation test. The maximum prescribed parameters are 0.7 mm woven hemp diameter, two hemp layers, 10 percent CSP content weight, and -130°C cryogenic temperature range provides the maximum energy of impact, tensile strength and flexural strength.

1. Introduction
Natural fibers can be widely used for a variety of uses. It evolved over the past few years from an ecological awareness. Present ecological procedures have stressed the engineering sector such as the automobile, wrapping and manufacturing industries to search for new products that can in effect be used as an alternative to traditional composite materials. Such materials consist of plastic matrix and inorganic filler reinforcement material which has an adverse environmental effect. Glass fiber filled thermoplastic composites already use distinct inorganic fillers such as aramid and carbon fibres. There are also limitations on the use of inert fibers as they have issues such as non-biodegradability, health concerns such as skin problems due to inadequate handling and processing. They generate abrasions in the dispensing equipment [1]. The key advantage over traditional artificial fillers is that they are lower in density, less abrasive, cost-effective, reusable and environmentally friendly [2]. Similar to fiber
glass, the fiber board obtained from the hemp based composites has greater strength but lighter than other wood composites.

Cellulose is a significant constituent of the fabric, which is the reason for its fabric strength, resilience, and stiffness. The concentration of cellulose in hemp is 70.2-70.4%, which is higher than in other bast fibers [3]. The hybrid composite material is commonly used in low-cost engineering; strength-to - weight ratio, and ease of manufacture [4]. Such hybrid composites provide an alternative for securing property mixtures such as stiffness, ductility and strength, which cannot be consumed by composites reinforced with single fibre. Hybrid composites have increased fatigue life, greater crack resistance and less sensitivity compared to single fiber composites. [5]. Coir fiber is naturally found in plants. Composites made from coconut shell filler particles and epoxy resin, which show the increased flexural and tensile properties of the composites together with the increased content of filler particles [6]. Wear resistance increases during the addition of coir fiber and coconut shell strength to the polyester composite while coir fiber and coconut shell powder is used as reinforcing material [7].

Good compatibility and bonding are very essential for the fiber and matrix in order to obtain optimum properties of the composites. Some modifications on the surface of the fibers were performed on the basis of chemicals used in the treatment. Among the various chemical treatments, NaOH treatment is the successful way to extract oil and wax from the surface of the fibre, and it is the preliminary treatment for expanding the rough surface, as pore structure and WAXS help to evaluate the crystalline shape, density and crystallite thickness. [8-11]. Cryogenic treatments can further enhance the mechanical properties of fibre-reinforced composites. For example, the materials used for aircraft frames can preserve their mechanical properties at extreme temperatures up to -200 °C [12]. Cryogenically treated plastics and composites are stronger, longer lasting and have improved durability and wear resistance [13]. Therefore, cryogenic composite treatment has become an important part of ongoing research and development to enhance the performance of materials in natural compounds.

The main objective of the work is to assess the potential properties of the hemp fibers when hybridized in a thermoplastic composite with coconut shell powder. To achieve this goal, coconut shell powder and hemp fiber based hybrid epoxy compounds were manufactured using simple hand-lay technique. In NaOH solution, natural fibers such as coconut shell powder and hemp fibers were treated to strengthen their adhesion and reduce the absorption of moisture. The composites were subsequently treated with liquid nitrogen for various temperature ranges and their mechanical properties were measured experimentally and compared to optimum processing parameters such as Woven Hemp fiber diameter, number of hemp layer, coconut shell powder content and cryogenic temperature ranges. The Taguchi methods based on Grey have been used for various multi-response routing difficulties and their constraints have been configured effectively [14, 15].

2. Experimental Methods
2.1 Materials
In the southern region of Tamilnadu, India, coconut shell powder and hemp required for the present research study was collected from natural fiber industry. All fires were sun-dried for 2 days, and afterwards long fibers were removed by hand sorting. To obtain better properties, the hemp fiber is straightened and compressed by mechanical rolling. The fiber is then graded into different lengths and thicknesses. All specimens are added uniformly with hemp of about 4 grams. Coconut shell powder (CSP) typically contains few moisture content. So, to reduce dampness, CSP is stored at an ambient temperature. Then CSP packs in pockets as percentage and size of weight required. Specific composite materials are produced using the hand-lay technique.

2.2 Fiber Treatment
The raw hemp and coconut shell powder is washed at a temperature of 70°C for about 1 hour with 2 per cent detergent solution, then washed in distilled water and finally dedicated in a vacuum oven at around 70 ° C. The dehydrated fibre was chosen as raw fibre. For surface treatments the organic jute fibers are exposed to Alkali. Initially, the untreated fibers were dewaxed by immersing batches of
untreated fibers in ethanol and benzene at a ratio of 1:2 for around 72 hours at 50°C. The dewaxed fibers are submerged for 24hrs in 5 percent NaOH at 30°C followed by assiduous washing in distilled water and air drying secures 5 percent of alkali treated fibers.

2.3 Fabrication of Bio Composites
Composite fabrication is done using a stainless steel mold of 300 x 300 x 3 mm. After the molds are cleaned and dehydrated, the epoxy is added. The wax is the releasing agent which is used here. Using hand lay-up technique, the coconut shell powder treated along with the woven hemp fibers were taken for composite manufacture. Coconut shell powder of different contents was first dispersed by intense stirring into the prepared epoxy resin. This combination of matrixes was drizzled onto the layers of fibers in the mouth. When the fiber mats are fully moist by matrix combinations, the mold was bolted at usual hotness and dried. The hybrid composite samples produced were placed in the desiccators to ensure no further moisture absorption. The manufactured samples were then immersed in liquid nitrogen for cryogenic treatment according to the design for different temperature range. The composites were taken out and kept at room temperature after the cryogenic procedure. In accordance with Taguchi design, L9 orthogonal array was selected for 4 parameters each with 3 levels and 9 composite plates were subsequently manufactured for further investigation. Tables 1 and 2 show the parameters and their levels and the L9 orthogonal array (OA).

Table 1. Specification and their stages used for experimentation

| Specifications       | Symbol | Levels    |
|----------------------|--------|-----------|
| Woven hemp Dia (mm)  | A      | 0.3 0.5 0.7 |
| Number of hemp layer (no) | B      | 1 2 3 |
| CSP content (%)      | C      | 10 12 15 |
| Cryogenic Temp Range (°C) | D      | -100 -130 -160 |

Table 2. L9 Orthogonal Array

| Runs | Stages of A | Stages of B | Stages of C | Stages of D |
|------|-------------|-------------|-------------|-------------|
| 1    | 1           | 1           | 1           | 1           |
| 2    | 1           | 2           | 2           | 2           |
| 3    | 1           | 3           | 3           | 3           |
| 4    | 2           | 1           | 2           | 3           |
| 5    | 2           | 2           | 3           | 1           |
| 6    | 2           | 3           | 1           | 2           |
| 7    | 3           | 1           | 3           | 2           |
| 8    | 3           | 2           | 1           | 3           |
| 9    | 3           | 3           | 2           | 1           |

3. Mechanical Testing
Upon fabrication, the research specimens are applied according to ASTM specifications through variety mechanical checks. The tension test is performed using standardized test method, ASTM D638. Universal testing machine KALPAK performs flexural, tensile and Impact tests. The flexural tests are performed in three-point bending test. The flexural check is conducted in compliance with ASTM standards D790. Flexural force values are calculated using equation (1).

\[ \text{Flexural strength} = \frac{3PL}{2bd^2} \]  \hspace{1cm} (1)
Where, P is applied burden at the purpose of crack, L is the help range length, b is the example width, d is the example thickness. Izod impact testing machine as per ASTM D 256 is used to perform the impact tests. Impact strength (I.S) is calculated using Equation (2).

\[ \text{I.S} = \text{Observed Energy} / \text{Cross sectional Area} \]  

(2)

The responses for the experiment sets are tabulated, as shown in Table 3

| Run | Tensile (MPa) | Flexural (MPa) | Impact (KJ/m^2) |
|-----|--------------|---------------|-----------------|
| 1   | 20.19        | 21.54         | 46.36           |
| 2   | 30.19        | 39.47         | 51.31           |
| 3   | 23.43        | 25.49         | 56.66           |
| 4   | 21.12        | 39.87         | 56.04           |
| 5   | 20.17        | 39.95         | 51.92           |
| 6   | 25.19        | 42.98         | 53.31           |
| 7   | 29.73        | 36.04         | 56.24           |
| 8   | 22.72        | 50.28         | 56.29           |
| 9   | 21.92        | 26.72         | 62.83           |

3.1 Investigation of Experimental outcomes by grey relational method

Taguchi experiment design method is an effective tool for systematic demonstration, investigation and optimization of various process constraints such as constraint selection, study plan, testing direction, data analysis, optimum arrangement description and confirmation. Using this method, the results of the analysis are converted into the signal-to-noise ratio (S/N) for deciding the prominent characteristic. Based on the definitive factor to be improved for the prominent feature, the S / N ratio features were divided into the following phases (i) larger-better, (ii) nominal-better, and (iii) smaller-better.

3.1.1 Signal to Noise Ratio

The high S/N ratio represents the enhanced performance characteristic, despite the performance feature criteria. The stage with the greatest S / N ratio is thus an optimal parameter level. In the end, a verification check is conducted to verify the optimal permutation of the restriction sites. Impact, flexural and tensile strength were measured throughout the mechanical testing of natural fiber composites through the larger phase is better. Subsequently, signal to noise fractions of the eminence features (larger is better) are explicit as

\[ \text{S/N Ratio} = -10 \log_{10} \left( \frac{1}{k} \sum_{a=1}^{k} \frac{1}{X_{a}} \right) \]  

(3)

Where k is the repetitions number, \( X_{ab} \) is the experiential reaction and a = 1, 2, ..., k b= 1, 2... k

3.1.2 Standardized Signal to Noise Ratio

Standardization is an achievement in altering an individual record response to segment the response equally, and measures it into an adequate series for further investigation. \( X_{ab} \) is standardized as \( Y_{ij} \)
(0 ≤ \( Y_{ij} \) ≤ 1) by the underlying equation to determine the correct outcome of embracing multiple elements and reduce the inconsistency. For this investigation integrated with Tensile (Larger is good), Flexural (Larger is good), and Impact capabilities (Larger is good), the eminence features are chosen, and these are the enhanced recital of all constraints. Table 4 describes the integration of S/N ratios and uniform S/N ratios for rising eminence feature.

\[
Y_{ij} = \frac{x_{ab} - \min(x_{ab=1,2,\ldots,k})}{\max(x_{ab=1,2,\ldots,k}) - \min(x_{ab=1,2,\ldots,k})}
\]

(4)

3.1.3 Coefficient of Grey Relation

The Gray Relational Coefficient was calculated using the standard S / N ratio values. The Grey coefficient of relation is represented as follows:

\[
\gamma (x_a(y), x_b(y)) = \frac{\Delta \min + \zeta \Delta \max}{\Delta \min(y) + \zeta \Delta \max}
\]

(5)

Where \( b = 1, 2, \ldots; y = 1, 2, \ldots, m \); \( y \) is the investigational statistical numbers and \( m \) is the quantity of retorts; \( x_a(y) \) is the orientation series \((x_a(y) = 1, y = 1, 2, \ldots, m)\); \( x_b(y) \) is the exact relationship series; \( ab = \{\Delta x_a(y) \} \) is the entire difference values between \( x_a(y) \) and \( x_b(y) \); \( \Delta \min = \min \{x_a(y) - x_b(y)\} \) is the least value of \( x_b(y) \); \( \Delta \max = \max \{x_a(y) - x_b(y)\} \) is the maximum value of \( x_b(y) \); and \( \zeta \) is the incriminate constant set in between the range of zero to one. In the current research, the process constraints have an equivalent weight and discriminate constant was fixed by 0.5.

3.1.4 Grey Relational Grades

With the help of equation (6), each Grey relation coefficients feedback is converted to the Grey relationship grade. Any ideal stage of controllable factor is calculated from the grades of the relationship of the gray. The results are outlined in Table 5. In which \( \bar{Y}_j \) is the \( J^{th} \) experiment grades of grey relation and \( k \) is performance characteristics numeral. Subsequently, the grades and coefficient of Grey relationship were performed for all \( L_9 \) (3⁴) orthogonal experiments; By means of Grey analyzes and Taguchi relationship techniques, the multi-response problem on optimization was changed to a single-response objective function. Grey-based Taguchi approach has been used to
achieve the overall grades of Gray Relationship and that it is just the output features. By searching for
a parameter setting, you can achieve the highest comprehensive grey relational grade.

\[
y_j = \frac{1}{k} \sum_{i=1}^{m} y_{ij}
\]

(6)

| Run | Grey Relational Co efficient | Grey relational Grades |
|-----|------------------------------|------------------------|
|     | Tensile | Flexural | Impact |                     |
| 1   | 0.336   | 0.333    | 0.366  | 0.259                |
| 2   | 1.006   | 0.636    | 0.472  | 0.529                |
| 3   | 0.446   | 0.384    | 0.333  | 0.291                |
| 4   | 0.363   | 0.646    | 0.684  | 0.423                |
| 5   | 0.335   | 0.648    | 0.64   | 0.406                |
| 6   | 0.529   | 0.729    | 0.546  | 0.451                |
| 7   | 0.932   | 0.56     | 0.631  | 0.531                |
| 8   | 0.418   | 1        | 1      | 0.604                |
| 9   | 0.389   | 0.402    | 0.416  | 0.302                |

4. Result and Discussions

The Taguchi method and Grey relation investigation examined optimal parameters such as flexural, impact and tensile strength of CSP and hemp based hybrid epoxy composites. The investigation of the Grey Relationship and ANOVA reduces optimal restriction sets and maximum critical feature in natural composite. The Taguchi feedback table methods were utilized to determine the average grade of each factor point. For example, to discover the grey ratio score of the woven hemp diameter, the ratio value of the grey ratio coefficient of flat (level) 1 in column A would be moderated (i.e., tests 1–3), then the ratio of flat 2 in column A would be moderated (i.e., tests 4–6), then again the ratio of flat 3 in column A would be moderated (i.e., tests 7–9). Similarly, the number of hemp layers, the CSP content and the cryogenic temperature range are planned for the exact flats; this is exposed in Table 6. Fig.1 revealed the response details of the Grade of Gray Relationship at various levels of the composite constraints.

The figures show the optimum level of process constraint produced by the maximum degree of Grey relation. For constraints such as woven hemp diameter, number of hemp layer, CSP content, and cryogenic temperature range respectively, the levels A3, B2, C1 and Grey relational grade value is maximum in D3. The essential values of the hybrid composites were measured from the investigation are woven hemp diameter of 0.7 mm, 2 layers of hemp, CSP content of 10%, and cryogenic temperature of -130°C.

4.1 Analysis of Variance

The ANOVA is formulated using the average value of the grey relation grade. ANOVA results are used to measure the process prompting parameters of CSP and hemp-based hybrid composites. The square sum deviations from the overall mean grade are used to calculate by isolating the entire variation of the Grey relationship grades. ANOVA can observe the quality objective, which is influenced by process criteria. The impact of process parameter shift on performance characteristics can be assessed through the percentage contribution through the total squared sum deviations [16, 17].
Table 6. Grey Relational Grade

| Levels | A   | B   | C   | D   |
|--------|-----|-----|-----|-----|
| L1     | 0.36| 0.404| 0.438| 0.322|
| L2     | 0.427| 0.513| 0.418| 0.503|
| L3     | 0.479| 0.348| 0.409| 0.44 |

The following equations can be used to calculate the percentage contributions of variance:

1. Total sum of the square deviations:
   \[ ss_d = \frac{F_1^2 + F_2^2 + F_3^2}{3} - \frac{1}{m} \left[ \sum_{i=1}^{m} y_i \right]^2 \]  
   (7)
2. Sum of square deviations
   \[ ss_T = \sum_{i=1}^{m} y_i^2 - \frac{1}{m} \left[ \sum_{i=1}^{m} y_i \right]^2 \]  
   (8)
3. Percentage of contribution
   \[ \rho = \frac{ss_d}{ss_T} \]  
   (9)

Where F denotes the process factor, and 1, 2, 3 are the corresponding levels. m is the number of levels in the orthogonal array and \( y_i \) is the Grey relation grade mean.

Table 7. ANOVA outcomes for the Grey Relational Grade

| Factors | Degree of Freedom | Sum of Squares | Mean Sum of Squares | % of Contributions |
|---------|------------------|----------------|---------------------|--------------------|
| A       | 2                | 0.007          | 0.0035              | 18.70              |
| B       | 2                | 0.014          | 0.007               | 37.39              |
| C       | 2                | 0.00044        | 0.00022             | 1.18               |
| D       | 2                | 0.016          | 0.008               | 42.74              |
| Error   | 0                | 0              | 0                   | 0                  |
| Total   | 8                | 0.03744        | 0.01872             | 100                |

The effect of each process restriction is defined in the ANOVA table, showing in Table 7 that the diameter of woven hemp has a contribution of 18.70%, the amount of hemp layers has 37.39%, the content of CSP has 1.18% and the temperature range of cryogenics has 42.74% on the various concert physiognomies. This recommends that cryogenic treatments be an additional key to natural fiber hybrid-reinforced epoxy composites based on CSP and hemp.

4.2 Confirmation Test

Confirmation testing was conducted to validate the optimum parameters which yield better composite performance characteristics. The natural fiber composites are produced using the set of parameters that resulted in the best results in the L9 table (woven hemp diameter of 0.3 mm, 2 layers of hemp, 12% of CSP content and -130 °C of cryogenic temperature range) and the optimum parameters were obtained by means of Grey logical analysis (woven hemp diameter of 0.7 mm, 2 layers of hemp, 10% of CSP content and 130 °C of Cryogenic temperature) are compared in Table 8. It shows an
improvement of 19.72 per cent in tensile strength, 20.61 per cent in flexural strength and 29.55 per cent in impact energy.

![Graphs showing improvement in tensile strength, flexural strength, and impact energy.]

**Figure 1.** Shows the Response graph of overall grades of Grey relation for various parameters.

| Responses                  | Initial parameters | Final parameters | % of Improvement |
|----------------------------|--------------------|------------------|------------------|
| Setting level              | A2 B2 C3 D1 E1 F2 | A3 B2 C3 D3 E2 F2 |                  |
| Tensile strength (MPa)     | 28.97              | 31.61            | 8.35             |
| Flexural strength (MPa)    | 40.01              | 44.72            | 10.53            |
| Impact energy (KJ/m^2)     | 2.07               | 2.92             | 29.11            |

### Table 8. Comparison between initial and optimal results

5. Conclusion

In this article after study is provided the report for the optimization of the composite material having different performance characteristics using Grey relational analysis and Taguchi method. The result reads as follows:

1. The parameter levels prescribed are 0.7 mm woven hemp diameter, two hemp layers, 10 percent CSP content weight, and -130°C cryogenic temperature range obtained from the response graph and table. It gives maximum energy of impact, tensile strength and flexural strength.

2. The Grey-Taguchi method confirms test results showing an increase of 19.72 percent in tensile strength, an increase of 20.61 percent in flexural strength and 29.55 percent in impact energy compared to the introductory parameters.
3. ANOVA has identified the cryogenic treatment as the most compelling performance enhancement factor, with 42.74 percent. It is wrapped up saying that the composites mainly contribute and have a significant effect on the different performance characteristics.

References

[1] Espert A, Vilaplana F and Karlsson S 2004 Composites Part A: Applied Sci and Man 35 1267-76.
[2] Bledzki AK, Reihmane S and Gassan J 2006 Polymer-Plastics Tech and Eng 37 451-68.
[3] Kabir MM, Wang H, Lau KT and Cardona F 2012 Composites Part B: Eng 43 2883-92.
[4] Gururaja MN and Hari Rao AN 2012 Int. J. Soft Comput. Eng 1 352–55.
[5] Shahzad A 2011 J. of Reinf Plast Composites 30 1389–98.
[6] Vignesh K, Natarajan U and Anbalagan M 2015 Int. J. of Applied Eng. Res 10, issue 13 11066-79.
[7] Vignesh K, Natarajan U and Vijayasekar A 2014 international conference on recent trends in engineering and management IOSRJ. Mecha. Civil Engi 53-57.
[8] Le Troedec M, Sedan D, Peyratout C 2008 Composites Part A: App Scie and Mang 39 514-22.
[9] Sawpan MA, Pickering KL and Fernyhough A 2011 Composites Part A: App Sci and Manu 42 888-95.
[10] Mwaikambo LY and Ansell MP 2002 J. of. App. Pol. Sci 84 2222-34.
[11] Hermans PH and Weidinger A 1949 J. of Poly Sci Part A: Polymer Chemistry 4 135-44.
[12] Liu X, Cheng L, Zhang L 2011Mate Sci and Eng: A 528 7524-28.
[13] Kalia S 2010 J.of Low Temp Physics 158 934-45.
[14] Haq AN, Marimuthu P and Jeyapaul R 2008 The Int. J. of Adv Manu Tech 37 250-55.
[15] Kuo C-FJ and Wu Y-S 2006 The Int.J. of Adva Manu Tech 27 525-30.
[16] Navaneethakrishnan S and Athijayamani A 2015 Int.J.of Plas .Tech 19 227-40.
[17] Sri Siva R, Mohan Lal D and Jaswin MA 2012 Tribology Transactions 55 854-62.