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OPTIMIZATION OF PROCESS PARAMETERS TO ENHANCE THE MECHANICAL PROPERTIES OF BONE POWDER AND COIR FIBER REINFORCED POLYESTER COMPOSITES BY TAGUCHI METHOD

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ABSTRACT

This study investigated the optimization of the process parameters to enhance the mechanical properties of bone powder impregnated coir fiber reinforced polyester composites using Taguchi method in combination with Grey relational analysis. The factors considered for the optimization are the coir fiber diameter, coir fiber length, bone powder content and bone powder size, each at three different levels. The mechanical properties such as the tensile strength, flexural strength, compressive strength and impact strength are selected as the quality targets. Nine experimental runs based on L9 (3^4) orthogonal array of the Taguchi method are performed. An optimal parameter combination of the composites is obtained through the Grey relational analysis. The analysis of variance is applied to identify the most influential factor and it is found that the composites. A confirmation experiment is performed to verify the optimal result. The results of the confirmation tests prove that the tensile strength, flexural strength, compressive strength and impact strength of the composite samples enhanced simultaneously through the optimal combination of the composite parameters obtained from the proposed method. The improvement in the tensile strength, flexural strength, compressive strength and impact strength of the composite samples at the optimized condition are evaluated.

Keywords: bone powder, coir fiber, composite, polyester, grey-taguchi method.

INTRODUCTION

In recent years, the continuous and increasing demand for environmentally friendly materials such as bio-composites from plant-derived fiber and from recycled fiber based products has been on the increase due to their potential characteristics. Natural fibers like coir, flax, zea, jute, hemp, banana and sisal are emerging as realistic alternatives to glass fibers in various industrial sectors owing to their low cost, low specific weight which result in higher specific strength and stiffness, non-abrasiveness, availability, biodegradability and problem-free disposal [1]. In the past two decades significant efforts were therefore undertaken in the materials research community to elucidate the microstructure and mechanisms behind these mechanical performances, in order to duplicate them in artificial materials. This approach to design, called biomimetics, has now started to yield materials with remarkable properties. The first step in this biomimetic approach is the identification of materials performances in natural materials, together with a fundamental understanding of the mechanisms behind these performances [2]. Composites made from the filler particles and epoxy resin, which performed several characterization studies on composites prepared from coconut shell filler particles at three different filler contents 5%, 10%, and 15%. Their Experimental results showed that tensile and flexural properties of the composites increased with the increase in the filler particle content. The composite materials demonstrate somewhat linear behavior and sharp fracture for tensile and slight non-linear behavior and sharp fracture for flexural testing [3].

The uniform distribution of the bone particles in the microstructure of the polymer composites is the major factor responsible for the improvement in the mechanical properties. Absence of volatile matters, high carbon content and high density of carbonized bone are believed to be responsible for its relatively superior properties [4]. A fiber reinforced polymer (FRP) is a composite material consisting of a polymer matrix imbedded with high-strength fibers, such as glass, aramid or carbon or natural fiber [5]. In general, high fiber content is required to achieve high performance of the composites. Therefore, the effect of fiber content on the properties of natural fiber reinforced composites is particularly significance. It is often observed that the increase in fiber loading leads to an increase in tensile properties [6]. The incorporation of egg shell and fish bone powder into polypropylene resulted in improvement in the tensile strength, tensile modulus, flexural, and impact strength of the composites, and these properties increased with increase in filler contents, and decrease in filler particle sizes. Generally, egg shell, and fish bone powder fillers have shown greater property improvement over talc in the prepared composites [7].

The natural fiber-containing composites are more environmentally friendly, and are used in transportation (automobiles, railway coaches, aerospace), military applications, building and construction industries (ceiling paneling, partition boards), packaging, consumer products, etc [8]. The mechanical properties of cancallous bone dependence of strength and elastic modulus on trabecular orientation. The mechanical properties of tranbecular bone in tension and compression by non-destructive testing of the same specimens in tension and compression, followed by random allocation to a destructive test in either tension or compression. They reported that there was no difference between young's modulus in tension and compression. Strength ultimate strain and work to failure was significantly higher in tensile testing than in compressive testing [9].

Nowadays, there are more and more applications in which friction and wear are critical issues. Polymers containing different fillers and/or reinforcements are frequently used for these purposes. However, how these materials must exactly be designed depends on the requirement profile of the particular application. These means tribological characteristic i.e. the friction coefficient and the wear resistance are no real material properties, but depend on the system in which these materials have to function [10]. There are two types of bone, compact or corical, and cancellous or trabecular (spongy) bone. The anisotropic structure of bone leads to mechanical properties that exhibit directionally. This directionality results from the fact that bone has evolved to be both tough and stiff, two competing properties which are optimized in bone but with an inherent loss in isotropy. In fact, bone exhibits extraordinary mechanical properties, displaying both elastic and semi-brittle behavior. Compact bone has a compressive strength in the range of 131 - 224 MPa, and Young's modulus ranging from 17-20 GPa, while compressive strength and Young's modulus for trabecular bones are 5-10 MPa and 50 -100 MPa, respectively [11].

The matrix forms a significant volume fraction of a polymer composite and it has a number of critical functions; it binds the reinforcements together, maintains the shape of a component and transfers the applied load to the reinforcing fibers. It protects the reinforcing fibers from degradation, due to abrasion or environmental attack. It contributes significantly to the mechanical properties of structural polymer composites, acting to resist delamination between plies of reinforcements and to inhibit fibre buckling during compression [12]. Among the various fillers, sea shell could be very interesting material as filler in biodegradable polymer composites, due to its good thermal stability compared to other. The sea shell can be easily crushed into chips or particles; the sea shell is mainly composed of calcium carbonate ($CaCO_3$) in two forms Calcite and aragonite or a mixture of them with some organic compounds. Advantages of natural fillers over traditional ones are their low cost, high toughness, low density, good specific strength properties, reduced tool wear (non-abrasive to processing equipment), and enhanced energy recovery [13].

Manufacturers seeking to remain competitive rely on their engineers and production personnel to quickly and effectively set up manufacturing processes for new products [14]. As per the Grey- Taguchi technique, nine experimental trials based on the L9 (3^4) orthogonal array were conducted [15]. The Taguchi parameter design is a powerful and efficient method for optimizing the quality performance of manufacturing processes. The Taguchi method is used to achieve high-quality targets without increasing the cost. This effective method utilizes an orthogonal array (OA) from the experimental design to study more variables in fewer experiments [16]. The S/N is meant to be used as the measure of the effect of noise factors on the target characteristics [17]. In general, there are three categories of the performance characteristics in the analysis of the S/N ratio: lower-the-better, higher-the-better, and nominal the- better. The S/N ratio, which condenses the multiple data points within a trial, depends on the type of characteristic being evaluated [18].

EXPERIMENTATION

The process parameters of polymer matrix composite are coir fiber diameter, coir fiber length, bone powder content and bone powder size. Coir fiber is uniformly added with all specimens in the amount of 4gms. Bone powder (BP) generally has some moisture content. So, BP is kept at atmospheric temperature to diminish the moisture. The development of the various composite materials is carried out in the way of the traditional method i.e., hand lay-up method.

Taguchi created a transformation of the repetition in data to another value, which is the response measure of the variation present. This transformation is the signal-to-noise (S/N) ratio. The S/N is meant to be used as the measure of the effect of noise factors on the target characteristics. The Grey-Taguchi technique has been used for different multi response problems in the manufacturing process and optimum results are obtained. Taguchi's L9 orthogonal array is used to investigate the optimum parameters. Taguchi's L9 orthogonal array is used to examine the process parameters. The objective of the research is to identify the optimum conditions that enhance the flexural strength, tensile strength, compressive strength and impact strength of the composites using the Grey- Taguchi technique. The optimum results of the composites are determined by Grey relation analysis and L9 orthogonal array, which engaged nine experiments, by changeable the three levels with four parameters. The object of ANOVA is to identify the influence of individual factors by applying statistical approaches and summarizing the effect of the experiment. Taguchi method is making use of an orthogonal array (OA) from the experimental design to study more variables in lesser amount experiments. The design of the experiment is formulated for the composites, with the intention to improve the tensile strength, flexural strength, compressive strength and impact strength as the responses of the composite materials. When perform tests of the composite materials, four parameters on three levels are considered. It is shown in Table-1. These levels of the

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factors are assigned to the L9 orthogonal array and there are obtainable in Table-2.

Table-1. Parameters and their levels.

Parameters	Symbols	Units	Levels		
			1	2	3
Coir Diameter	D	mm	0.2	0.5	0.8
Coir Length	L	mm	30	50	70
Bone powder Content	C	%	10	15	20
Bone powder Size	S	µm	80	100	120

Table-2. L9 Orthogonal array.

Runs	Levels of parameter-A	Levels of parameter-B	Levels of Parameter-C	Levels of Parameter-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

Tensile test, compressive test and flexural test are conducted in universal testing machine and the ASTM testing standards are ASTM D638-03, ASTM D695 and ASTM D790-03 respectively. Impact test is conducted in Izod impact testing machine and the ASTM testing standard is ASTM D256-05. Testing is conducted in two samples for each and every test as each and every proportion. The responses for the experiment sets are tabulated, as shown in Table-3.

Table-3. Responses for the experiment sets.

Exp. No.	**Tensile strength** (MPa)		**Flexural strength** (MPa)		**Compressive strength** (MPa)		**Impact energy** (kJ/m^2)	
	y1	y2	y1	y2	y1	y2	y1	y2
1	27.35	28.32	54.42	54.63	55.69	56.18	62.40	63.83
2	28.40	28.93	57.46	58.38	59.33	60.62	64.32	64.94
3	32.49	31.36	57.66	58.26	61.72	62.14	65.32	63.71
4	30.39	31.21	59.04	58.16	61.56	62.17	60.91	62.13
5	30.44	32.22	58.73	58.12	53.20	56.73	68.28	66.63
6	31.78	31.05	56.94	57.63	55.34	56.43	65.43	65.29
7	29.24	29.56	54.65	55.87	55.72	55.84	66.23	65.65
8	28.78	27.64	55.28	55.36	54.35	54.79	64.93	63.04
9	27.39	27.56	54.28	54.99	55.29	55.40	62.57	62.46

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RESULTS AND DISCUSSIONS

Taguchi produced a transformation of the replica in data into another value, which is the response calculate of the variation present. This transformation is the signal-to-noise (S/N) ratio. 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. Two replications (y1and y2) are executed for all the factor-level settings, as per the Taguchi orthogonal array. Here, the S/N ratio is calculated based on the higher the better. S/N ratio values are tabulated in Table-4. This characteristic is a non-negative measurable characteristic that has an extreme state value of infinity. Normalization is a transformation execution on a single data input to share out the data evenly and scale it into an acceptable range for further analysis. It should be used for S/N ratio with higher-the-better. The quality characteristics are chosen in this study integrated with Flexural strength (higher-the- better), Tensile strength (higher-the- better), Compressive strength (higher-the- better), Impact strength (higher-the- better) that is better the performance of all parameters. These characteristics are adopted for both the S/N ratio and Normalized S/N ratio.

Table-4. S/N ratio and normalized S/N ratio values.

Exp. No	S/N ratio				Normalized S/N ratio			
	Tensile strength (MPa)	Flexural strength (MPa)	Compressive strength (MPa)	Impact energy (kJ/m^2)	Tensile strength (MPa)	Flexural strength (MPa)	Compressive strength (MPa)	Impact energy (kJ/m^2)
1	28.89	34.81	34.95	36.00	0.085	0.098	0.191	0.275
2	29.15	35.26	35.56	36.21	0.285	0.836	0.746	0.538
3	30.08	35.26	35.84	36.19	1	0.836	1	0.513
4	29.77	35.36	35.83	35.78	0.762	1	0.991	0
5	29.91	35.33	34.79	36.58	0.869	0.951	0.045	1
6	29.94	35.16	34.95	36.31	0.892	0.672	0.191	0.663
7	29.37	34.85	34.93	36.38	0.454	0.163	0.173	0.750
8	29.00	34.86	34.74	36.12	0.169	0.180	0	0.425
9	28.78	34.75	34.86	35.92	0	0	0.109	0.175

Table-5. Grey relational co-efficient and grey relational grade values.

Exp. No.	Grey relational co-efficient				Grey relational grade
	Tensile strength (MPa)	Flexural strength (MPa)	Compressive strength (MPa)	Impact energy (kJ/m^2)	
1	0.353	0.357	0.382	0.408	0.375
2	0.412	0.753	0.663	0.520	0.587
3	1	0.753	1	0.507	0.815
4	0.678	1	0.982	0.333	0.748
5	0.792	0.911	0.344	1	0.762
6	0.822	0.604	0.382	0.597	0.601
7	0.478	0.374	0.377	0.667	0.474
8	0.376	0.379	0.333	0.465	0.388
9	0.333	0.333	0.360	0.377	0.351

The computed S/N ratios and normalized S/N ratios for each quality characteristic are exposed in Table-4. The Grey relational coefficient is calculated using the normalized S/N ratio values in Table-5. The results are shown in Table-5. The Grey relation coefficient and Grey relation grade are carried out for all experiments consequent to L9 orthogonal array. In Grey-based Taguchi method, only performance feature is overall Grey relational grade and the aim should be searched for a

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parameter setting that can achieve the highest overall Grey relational grade.

The mechanical properties of the coir fiber and bone powder reinforced polyester composites are prepared. To examine the composite material and to identify the optimum parameters for the composites, prediction of the Taguchi technique and Grey relation analysis is used. Grey relation analysis and ANOVA table provide the optimum constraint settings and the most significant factor in composites. In order to establish the average Grey relation grade for each factor level, the response table of the Taguchi method is employed. First, the Grey relation grades are grouped by the factor level for each column in the orthogonal array and then averaged. It is calculated for particular levels of coir fiber diameter, coir fiber length, BP content and BP size. This is shown in Table-6. From Table-6, it can be seen that a higher value is the better multi response characteristic of the composites.

Table-6. Response table for the grey relational grade.

Levels	Coir diameter (A)	Coir length (B)	BP content (C)	BP size (D)
L_1	0.592	0.532	0.455	0.496
L_2	0.704	0.579	0.562	0.554
L_3	0.404	0.589	0.684	0.650

Therefore, levels A2, B3, C3 and D3 have the highest Grey relational grade value for the factors Coir diameter, Coir length, BP content and BP size respectively. Based on above study, best possible values of composites are coir diameter is 0.5mm, coir length is 80mm, BP content is 20% and BP size is 120 µm. It is noted that enrichment is high for the coir diameter is 0.5mm. When the coir diameter is less than 0.5mm, the impact energy is decreased. If the coir diameter is increases as above 0.5mm, the flexural and tensile strength will be decrease. Then, the coir length is 80mm level is optimum level. Because, if the coir fiber length level is minimized as 80mm compressive strength will be decreased, if the coir length is above 80mm impact energy is decreased.

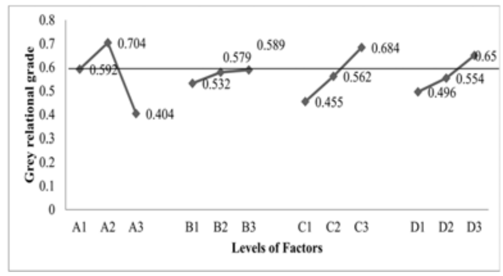

Figure-1. Response graph of overall grey relational grade.

In BP content, the level is gone to below 20% of weight the impact strength is decreased. At the same time, BP content level is gone to above 20% of weight tensile strength is decreased. BP mesh size is 120 µm which level is optimal level. If BP size is gone to below 120 µm, impact strength is decreased and the level is gone to 120 µm, flexural strength is decreased. Grey-Taguchi analysis shows better improvement for multiple responses. Response data of Grey relation grade at various levels of composite parameters are plotted in Figure-1. It shows the optimal process parameter level yielded by highest Grey relation grade.

Table-7. Results of the Anova for the grey relational grade.

Factors	Parameters	Degree Of freedom	Sum Of squares	Mean sum of squares	% Contribution
A	Coir diameter	2	0.046	0.023	53.49
B	Coir length	2	0.002	0.001	2.33
C	BP content	2	0.026	0.013	30.23
D	BP size	2	0.012	0.006	13.95
Error		0	0	0	0
Total		8	0.086	0.043	100

The contribution of each process parameter is given in the ANOVA table, exposed in Table.7, it can be seen that coir fiber diameter has 53.49% contribution, coir fiber length has 2.33%, BP content has 30.23% and BP size has 13.95% on the multiple performance characteristics. This suggests that the BP content is more important in the bone powder and coir fiber reinforced polyester resin composites.

Confirmation experiment is conducted to verify the improvement in performance characteristics of composites. Table.8 shows final result for initial values of process parameters, viz. coir fiber diameter is 0.5mm, coir fiber length is 50mm, BP content is 20% and BP size is

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120 µm (A2, B2, C3, and D3). The process parameters by confirmation test at optimal level are as follows: coir fiber diameter is 0.5mm, coir fiber length is 80mm, BP content is 20% and the BP size is 120µm (A2, B3, C3 and D3).

Table-8. Comparison of initial and optimal results.

Responses	Initial parameters	Optimal parameters	% Improvement
Setting level	A2 B2 C3 D3	A2 B3 C3 D3	
Tensile strength (MPa)	31.58	33.56	5.90
Flexural strength (MPa)	58.54	61.71	5.14
Compressive strength (MPa)	55.62	58.23	4.48
Impact energy (kJ/m^2)	65.44	69.75	6.18

Through confirmation test, optimal parameters are compared to that of the initial values of the process parameters and are shown in Table-8. It shows 5.90% improvement in tensile strength, 5.14% improvement in flexural strength, 4.48% improvement in compressive strength and 6.18% improvement in impact energy. After the mechanical testing, the fractured surfaces of the bone powder along with coir fiber polyester composites are studied and analyzed. SEM pictures are clearly evident the incorporation bone powder and coir fiber in the polymer matrix composites. Figure-2 represents the SEM picture of the bonding of coir fiber and bone powder in bone powder impregnated coir fiber reinforced polyester composite after the tensile testing. When the tensile test, the coir fiber are withstand the maximum amount of load and then ruptured. The ruptured fibers are also shown in the SEM picture.

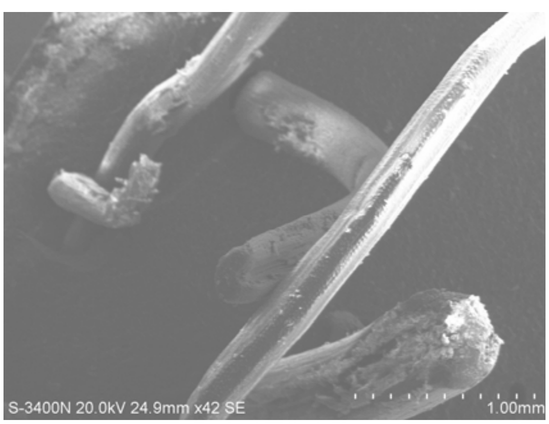

Figure-2. SEM picture of the composite after the tensile testing.

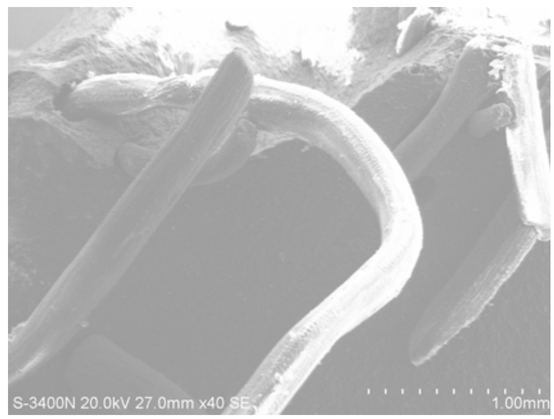

Figure-3. SEM picture of the composite after the compressive testing.

Figure-3 represents the SEM image of the bone powder and coir fiber reinforced polyester composite after the compressive testing. It also shows the fiber orientation after the compressive testing. Figure-4 represents the SEM image of the bone powder and coir fiber reinforced polyester composite after the flexural testing. The bone powder and coir fiber are absorb the flexural load and fracture the coir fiber. The fractured coir fiber and bone powder are visible in the SEM image. Figure-5 represents the SEM image of the fractured coir fiber in the bone powder impregnated coir fiber reinforced polyester composite after the impact testing. Coir fiber is ruptured due to the impact testing.

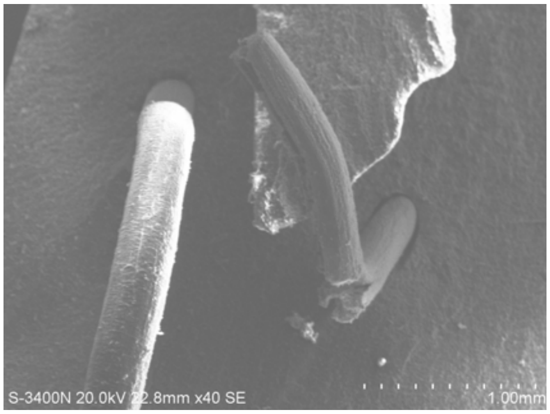

Figure-4. SEM picture of the composite after the flexural testing.

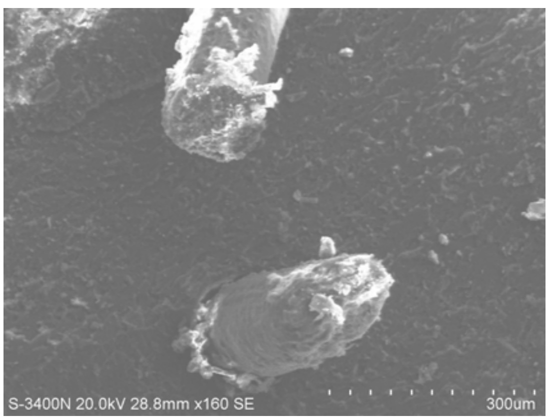

Figure-5. SEM picture of the composite after the impact testing.

CONCLUSIONS

Bone powder impregnated coir fiber reinforced polyester composites are developed on the basis of Grey-Taguchi method and the mechanical tests are conducted as per ASTM standard. Then determine the optimum parameters of the composites and the following conclusions are drawn:

The recommended parameter levels are 0.5mm coir fiber diameter, 80mm coir fiber length, 20% weight of BP content and 120μm 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.

The confirmation test results of the Grey-Taguchi method shows 5.90% improvement in tensile strength, 5.14% improvement in flexural strength, 4.48% improvement in compressive strength and 6.18% improvement in impact energy compared to the initial parameters. The most significant factor for the performance improvement is identified by the ANOVA as the coir fiber diameter as 53.49. The fractured surfaces are studied and analyzed with the help of SEM images.

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