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STUDY ON MECHANICAL PROPERTIES OF DEVELOPED ECO-FRIENDLY BRAKE PADS USING GRAY RELATIONAL ANALYSIS IN BOX BEHNKEN DESIGN OF EXPERIMENT

***Eziwhuo SJ, Ossia CV and Ojapah MM**

Department of Mechanical Engineering, University of Port Harcourt, Port Harcourt, Nigeria - 500004

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Abstract

Over the years, asbestos has been a leading material for developing automobile brake pads. However, due to its hazardous nature to human health, many researchers have found that organic materials possess the potential for replacement. The organic materials used in this research were the hybrid of coconut fruit fibre CFF and oyster sea shell OSS. These materials were gathered from the river bank, dried, crushed, washed, ground, sieved, and moulded with different additives: CuO (abrasive), graphite (friction modifier or solid Lubricant), epoxy resin (binder), hardener (catalyst) by Box Behnken design BBD of L27 experiment. Therefore, an experimental test on mechanical properties was performed to check the developed brake pad's characterization. Then, grey relational analysis was used to analyze grey relational grade GRG to convert a multiple response process optimization problem into a single response optimization using maximization of maximum GRG. The optimum parameter values producing the highest value of grey relational grade were chosen as rank one, pertained to the factors setup for experiment number S3232 having moulding pressure of 11.25MPa, moulding temperature of 180oC, and heat treatment time of 180min. The optimized response values obtained from the experiment sample S3232 give the highest values on all the responses, i.e., density of 3.483g/cm3, hardness of 52.91BHN, compressive strength of 2.78MPa, ultimate tensile strength of 3.92MPa, impact energy of 17.87N, cold water absorption of 0.2863%, hot water absorption of 0.4785%, and oil absorption of 0.4402%. After that, the optimized brake pad sample (S3232) was applied to the automobile and was suitable for braking owing to its high mechanical properties.

Keywords: Grey relational grade; optimization values; Box Behnken design; input parameter; Mechanical Properties

1. Introduction

The braking system has many parts, including the wheel cylinder, brake pads, hydraulic control system and master cylinder. We have four different types of materials used in the formulation of braking systems: Fillers, Reinforcement, Binders, and Friction modification. It was known from the literature reviewed that brake lining converts a vehicle's kinetic energy to thermal energy by friction. The two brake lining surfaces facing each other in the rotor are contained in the brake calliper. Recent scholars have moved towards using organic and industrial waste as raw materials for developing various tribological materials coupled with the hazardous nature of asbestos, which was done for replacement.

Asbestos materials have lost their usefulness due to their carcinogenic nature and were replaced by organic materials [1]. Using organic materials to produce brake pads has gained great interest in automobile engineering and material science due to its usefulness as eco-friendly materials [2, 3, 4]. The organic brake pads were produced using the Box Behnken experiment design, and optimum response data were utilized using grey relational analysis. The objective of this report was to use grey relational analysis for optimized responses.

This report aimed to use grey relational analysis for optimized responses since it produces robust results from the literature reviewed [7]. The grey relational analysis was established by Deng in 1982, which concentrated on a gap between known and unknown decision-making [5, 6]. The gap between known and unknown information is known as grey information. The grey relational theory was widely used in solving complex problems subjected to complex data [7, 8, 9, 10]. GRA can effectively be used in logistic and financial problems influencing two or more responses. Therefore, it helps in reducing a multiple problem to a single problem decision [9]. [7,8] stated that the GRA optimized

**Corresponding Author - E- mail: ufuomaluv@gmail.com*

process encompasses merging all recital characteristics into a specific value, which can be applied as a single characteristic in optimization problems. Hence, in this research, coconut fruit fibre and oyster sea shell are used as reinforcement materials, combined with other addictive such as Copper Oxide (Abrasive), Graphite (Friction Modifier or Solid Lubricant), Epoxy Resin (Binder), and Hardener (Catalyst). The coconut fruit fibre contains primarily carbonate, and oyster seashells consist primarily of calcium carbonate (CaCO3), which has been naturally above 80% CaCO3 by mass with a protein content of 2% [4]. In this report, the mechanical properties (density, cold water absorption, hot water absorption, oil absorption, hardness, tensile strength, impact strength, compressive strength, and impact strength) of the produced brake pad were evaluated. The produced sample of brake lining was tested in an automobile.

2. Materials and Methods

2.1 The experimental materials

(a) Oyster Sea Shell (OSS) (*Magallana-Gigas L*) (Reinforcement), (b) Coconut Fruit Fiber (CFF) (*Coir L*) (Reinforcement), (c) Copper Oxide (Abrasive), (b) Graphite (Friction Modifier or Solid Lubricant), (d) Epoxy Resin (Binder), (e) Hardener (Catalyst), and control material: Commercial asbestos brake pad (model: ICER 140403-700) see [4].

2.2 Design of Experiments

Generally, experimental design refers to the preparation of the experiments, assembly and data analysis of closed optimum use of the obtainable resources [2]. This experimental technique was built to design and develop many experiments carried out as the input parameters changed. The experiment determines the process parameters and levels which affect the response input variables. The experimental design comprises a good selection of independent variables and their collaborations. For the report, Box Behnken's design of four factors and three levels 43 with twenty-seven runs were used to determine optimal moulding parameters for maximum mechanical properties. The 4n Box Behnken design consists of all combinations of the n factors on three levels. The input parameters and their levels are shown in Table 1.

However, before constructing an orthogonal array, the following requirements must be defined.

(a). number of levels for each experiment: The number of levels considered for each factor is also three levels.

(b). number of factors reported: In the present study, there are four factors to be studied. They are Reinforcement Material, Molding Pressure, Molding Temperature, and Heat Treatment Time.

(c). The experimental responses: The response values considered are density, hardness, cold water absorption, hot water absorption, oil absorption, compressive strength, Tensile strength, and Impart energy.

Table 1 Input parameters and their three levels

Factors	**Levels**		
	(-1)	(0)	(+1)
Reinforcement Material (RM)	V1 (0 CFF /100 OSS)	V2 (50 CFF /50 OSS)	V3 (100 CFF /0 OSS)
Molding Pressure, Pm (KPa)	9.93	11.25	12.57
Molding Temperature, Tm (^{0}C)	120	150	180
Heat Treatment Time, T_{ht} (min)	60	120	180

2.3 Box Behnken Orthogonal Array Design

The Box Behnken orthogonal array designs are frequently used in experiments with multiple factors and levels [2]. The coded symbol for the experimental matrix was L27 (4^3), which shows the total number of experiments to be conducted, which is twenty-seven in this study, with the number of levels and factors to be represented as 3 and 4. Therefore, twenty-seven experiments were analyzed or designed via the Box Behnken orthogonal array (Table 2). After setting four different parameters for the individual experiments, the responses for the developed brake pad are characterized as density, hardness, cold water absorption, hot water absorption, oil absorption, compressive strength, Tensile strength, and Impart energy.

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Table 2 Experimental layout plan for Box-Behnken orthogonal array design

No of exp.	RUNS ORDER	X1	X2	X3	X4	Reinforcement Material (X_1)	P_m (Pa) (X_2)	T_m (°C) (X_3)	T_{ht} (minute) (X_4)
1	6	-1	-1	0	0	V1	9.93	150	120
2	3	1	-1	0	0	V3	9.93	150	120
3	14	-1	1	0	0	V1	12.57	150	120
4	19	1	1	0	0	V3	12.57	150	120
5	8	0	0	-1	-1	V2	11.25	120	60
6	2	0	0	1	-1	V2	11.25	180	60
7	26	0	0	-1	1	V2	11.25	120	180
8	20	0	0	1	1	V2	11.25	180	180
9	4	-1	0	0	-1	V1	11.25	150	60
10	21	1	0	0	-1	V3	11.25	150	60
11	27	-1	0	0	1	V1	11.25	150	180
12	10	1	0	0	1	V3	11.25	150	180
13	11	0	-1	-1	0	V2	9.93	120	120
14	13	0	1	-1	0	V2	12.57	120	120
15	17	0	-1	1	0	V2	9.93	180	120
16	25	0	1	1	0	V2	12.57	180	120
17	5	-1	0	-1	0	V1	11.25	120	120
18	16	1	0	-1	0	V3	11.25	120	120
19	15	-1	0	1	0	V1	11.25	180	120
20	9	1	O	1	0	V3	11.25	180	120
21	24	0	-1	0	-1	V2	9.93	150	60
22	23	0	1	0	-1	V2	12.57	150	60
23	1	0	-1	0	1	V2	9.93	150	180
24	22	0	1	0	1	V2	12.57	150	180
25	18	0	0	0	0	V2	11.25	150	120
26	7	0	0	0	0	V2	11.25	150	120
27	12	0	0	0	0	V2	11.25	150	120

2.4 Method of Grey Relational Analysis

Grey relational analysis is broadly used to quantify the degree of relationship between sequences by grey relational grade [11, 12, 13]. Numerous scholars have practically used the grey relational technique [14, 15, 16, 17] to optimize the input parameters, which have multiple complicated responses, to optimize a single response via grey relational grade.

Furthermore, the grey relational technique is customarily used to chain all the deliberated performance characteristics into one sole assessment that can be used as the single characteristic in optimization difficulties. The methods are [18]:

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i. Identify the response variables and corresponding Normalization
ii. Identification of input parameters, interactions and their levels
iii. Identification of orthogonal array and assign parameter levels to each column
iv. Conduction of experiment and collection of data for response variables
v. Data preprocessing by Normalization for all sequences
vi. Calculation of grey relational coefficients for each sequence
vii. Determination of the grey relational grade by averaging the grey coefficients
viii. Determining the optimum sequence from the higher grey relational grade
ix. Determine the optimum parameters
x. Prediction of GRG for optimal parameters

3. Result and Discussion

3.1 Normalization of response values

Normalization of response values is allocated into three types, conferring to the projected nature of response values. There is 'the smaller, the better', which means that the lowest values of the objective function are better. The Second is 'nominal the better', where the objective function has the average values. The third one is 'higher the better', where the highest values of the responses are expected [19, 20, 21].

Table 3 Normalized values for the responses (Normalized comparable sequences)

SAMPLES	Density (g/cm^3)	Normalized value	Brinell Hardness Number (BHN)	Normalized Value	Compressive Strength (M_{pa})	Normalized value	Ultimate Tensile Strength (M_{pa})	Normalized Value
S1122	3.266	0.480	49.92	0.335	2.50	0.685	3.33	0.536
S3122	3.512	0.842	47.79	0.088	2.41	0.584	2.98	0.397
S1322	3.473	0.785	55.60	0.993	2.09	0.225	3.15	0.464
S3322	3.019	0.116	52.79	0.667	1.98	0.101	1.98	0.000
S2211	2.940	0.000	49.14	0.245	2.46	0.641	4.50	1.000
S2231	3.258	0.468	54.02	0.8100	2.32	0.483	4.09	0.837
S2213	3.402	0.680	51.98	0.574	2.19	0.337	3.93	0.774
S2233	3.024	0.124	48.05	0.118	2.49	0.674	2.19	0.083
S1221	3.209	0.396	53.36	0.734	1.99	0.112	1.99	0.004
S3221	3.020	0.118	55.19	0.946	2.50	0.685	2.47	0.194
S1223	3.293	0.512	47.07	0.005	2.49	0.674	3.48	0.595
S3223	3.295	0.523	47.46	0.050	1.89	0.000	3.24	0.500
S2112	3.383	0.652	54.99	0.922	2.53	0.712	2.51	0.210
S2312	3.110	0.250	50.00	0.344	2.59	0.787	4.17	0.869
S2132	3.619	1.000	51.93	0.568	2.54	0.730	4.5	1.000
S2332	3.500	0.825	48.11	0.125	2.49	0.674	2.5	0.206
S1212	3.297	0.526	55.66	1.000	2.60	0.798	2.93	0.377
S3212	3.081	0.208	49.09	0.239	2.61	0.809	2.12	0.056
S1232	3.559	0.912	53.16	0.710	1.92	0.337	2.65	0.266
S3232	3.483	0.800	52.91	0.681	2.78	1.000	3.92	0.770
S2121	3.164	0.330	51.22	0.486	2.64	0.843	3.77	0.710
S2321	2.954	0.021	54.75	0.895	2.70	0.910	4.10	0.841
S2123	3.039	0.146	47.03	0.000	1.92	0.3337	2.43	0.179
S2323	3.034	0.138	48.08	0.122	2.49	0.674	4.42	0.968
S2222	3.381	0.649	48.99	0.227	2.50	0.685	3.95	0.782
S2222	3.381	0.649	48.99	0.227	2.50	0.685	3.95	0.782
S2222	3.381	0.649	48.99	0.227	2.50	0.685	3.95	0.782
CBP	3.199	0.381	53.50	0.750	2.48	0.663	3.15	0.464

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Table 4 Normalized values for the responses (Normalized comparable sequences)

SAMPLES	Impact energy (N)	Normalized value	Percentage, % of Cold Water Absorption	Normalized Value	% of Hot Water Absorption	Normalized value	% of Oil Absorption	Normalized Value
S1122	18.98	0.997992	0.3052	0.466877	0.4221	0.265903	0.3286	0.195854
S3122	14.44	0.086345	0.284	0.132492	0.4798	1	0.3487	0.339528
S1322	15.06	0.210843	0.2871	0.181388	0.4741	0.927481	0.3507	0.353824
S3322	16.93	0.586345	0.3301	0.859621	0.4216	0.259542	0.3012	0
S2211	14.67	0.13253	0.339	1	0.4012	0	0.3252	0.171551
S2231	17.33	0.666667	0.306	0.479495	0.4798	1	0.4411	1
S2213	18.91	0.983936	0.2931	0.276025	0.4409	0.505089	0.4406	0.996426
S2233	14.32	0.062249	0.3296	0.851735	0.4798	1	0.3401	0.278056
S1221	18.45	0.891566	0.3107	0.553628	0.4462	0.572519	0.3524	0.365976
S3221	14.09	0.016064	0.33	0.858044	0.4064	0.066158	0.3034	0.015726
S1223	17.53	0.706827	0.3027	0.427445	0.4385	0.474555	0.349	0.341673
S3223	17.29	0.658635	0.3025	0.42429	0.4573	0.71374	0.3013	0.000715
S2112	18.21	0.843373	0.2948	0.302839	0.4296	0.361323	0.3319	0.219442
S2312	14.77	0.15261	0.3205	0.708202	0.4385	0.474555	0.3142	0.092924
S2132	14.02	0.002008	0.2756	0	0.4032	0.025445	0.3501	0.349535
S2332	14.04	0.006024	0.2849	0.146688	0.4012	0	0.4017	0.71837
S1212	18.84	0.96988	0.3024	0.422713	0.4195	0.232824	0.4401	0.992852
S3212	14.04	0.006024	0.3236	0.757098	0.4265	0.321883	0.3302	0.207291
S1232	14.09	0.016064	0.2802	0.072555	0.4469	0.581425	0.3381	0.26376
S3232	17.87	0.7751	0.2863	0.16877	0.4785	0.983461	0.4402	0.993567
S2121	18.99	1	0.3151	0.623028	0.4201	0.240458	0.3012	0
S2321	17.99	0.799197	0.3373	0.973186	0.4789	0.98855	0.3056	0.031451
S2123	18.92	0.985944	0.328	0.826498	0.4578	0.720102	0.3032	0.014296
S2323	18.27	0.855422	0.3285	0.834385	0.4213	0.255725	0.3389	0.269478
S2222	14.01	0	0.2949	0.304416	0.4421	0.520356	0.3628	0.440315
S2222	14.71	0.140562	0.2949	0.304416	0.4421	0.520356	0.3628	0.440315
S2222	14.01	0	0.2949	0.304416	0.4421	0.520356	0.3628	0.440315
CBP	16.89	0.578313	0.3116	0.567823	0.4412	0.508906	0.3799	0.562545

In the present study, the values for mechanical properties should be higher. Hence, the 'higher the better' normalization criteria (see Tables 3 and 4) is considered for mechanical properties (Eq. 1). The formula for 'higher the better' normalization criteria considered is as follows:

$$a_i^x(k) = \frac{a_i^y(k) - \min a_i^y(k)}{\max a_i^y(k) - \min a_i^y(k)} \qquad (1)$$

Where $a_i^x(k)$ = value after the grey relational generation

Min $a_i^y(k)$ = smallest value of $a_i^y(k)$ for the kth response

Max $a_i^y(k)$ = largest value of the $a_i^y(k)$ for the kth response

The analytical formula for the 'lower the better' criteria considered is as follows:

$$a_i^x(k) = \frac{\max a_i^y(k) - a_i^y(k)}{\max a_i^y(k) - \min a_i^y(k)} \qquad (2)$$

According to sample calculation, the normalization values for all the mechanical responses are calculated and presented in Table 4.18 below.

$$a_i^x(k) = \frac{a_i^y(k) - \min a_i^y(k)}{\max a_i^y(k) - \min a_i^y(k)} = \frac{3.266 - 2.940}{3.619 - 2.940} = \frac{0.326}{0.679} = 0.480$$

3.2 Grey analysis of deviation sequence

After normalized sequences are obtained, the deviation sequence is calculated between reference and comparable sequences [21].

$$\Delta_{0i}(k) = \|a_0^x(k) - a_i^x(k)\| \quad (3)$$

Δ_{0i}: difference of total value between the target sequence $a_0^x(k)$ and the evaluation sequence $a_i^x(k)$

$a_0^x(k)$ = ideal sequence or the target sequence;

$a_i^x(k)$ = given sequence or the evaluation sequence;

The values in Table 5 are equal to the absolute value of the difference between the reference sequence and the comparable sequence. For instance, the deviation sequence of density was calculated as follows using Eq. 3.30

$$\Delta_{0i}(k) = \|a_0^x(k) - a_i^x(k)\| = \Delta_{01}(1) = \|a_0^x(1) - a_1^x(1)\| = 1 - 0.480 = 0.520$$

Table 5 Deviation sequence

SAMPLES	Density	Brinel hardness	Compressive strength	Ultimate tensile strength	Impact energy	% cold water absorption	% hot water absorption	% oil absorption
S1122	0.520	0.665	0.315	0.464	0.002008	0.533123	0.734097	0.804146
S3122	0.158	0.912	0.416	0.603	0.913655	0.867508	0	0.660472
S1322	0.215	0.007	0.775	0.536	0.789157	0.818612	0.072519	0.646176
S3322	0.884	0.333	0.899	1.000	0.413655	0.140379	0.740458	1
S2211	1.000	0.755	0.359	0.000	0.86747	0	1	0.828449
S2231	0.532	0.190	0.517	0.163	0.333333	0.520505	0	0
S2213	0.320	0.426	0.663	0.226	0.016064	0.723975	0.494911	0.003574
S2233	0.876	0.882	0.326	0.917	0.937751	0.148265	0	0.721944
S1221	0.396	0.266	0.888	0.996	0.108434	0.446372	0.427481	0.634024
S3221	0.882	0.054	0.315	0.806	0.983936	0.141956	0.933842	0.984274
S1223	0.488	0.995	0.326	0.405	0.293173	0.572555	0.525445	0.658327
S3223	0.477	0.950	1.000	0.500	0.341365	0.57571	0.28626	0.999285
S2112	0.348	0.078	0.288	0.79	0.156627	0.697161	0.638677	0.780558
S2312	0.750	0.656	0.213	0.131	0.84739	0.291798	0.525445	0.907076
S2132	0.000	0.432	0.270	0.000	0.997992	1	0.974555	0.650465
S2332	0.175	0.875	0.326	0.794	0.993976	0.853312	1	0.28163
S1212	0.474	0.000	0.202	0.623	0.03012	0.577287	0.767176	0.007148
S3212	0.792	0.761	0.191	0.944	0.993976	0.242902	0.678117	0.792709
S1232	0.088	0.290	0.663	0.734	0.983936	0.927445	0.418575	0.73624
S3232	0.200	0.319	0.000	0.230	0.2249	0.83123	0.016539	0.006433
S2121	0.670	0.514	0.157	0.290	0	0.376972	0.759542	1
S2321	0.979	0.105	0.090	0.159	0.200803	0.026814	0.01145	0.968549
S2123	0.854	1.000	0.666	0.821	0.014056	0.173502	0.279898	0.985704
S2323	0.862	0.878	0.326	0.032	0.144578	0.165615	0.744275	0.730522
S2222	0.351	0.773	0.315	0.218	1	0.695584	0.479644	0.559685
S2222	0.351	0.773	0.315	0.218	0.859438	0.695584	0.479644	0.559685
S2222	0.351	0.773	0.315	0.218	1	0.695584	0.479644	0.559685
CBP	0.619	0.250	0.337	0.536	0.421687	0.432177	0.491094	0.437455

3.3 Calculation of Grey Relational Coefficient, GRC

Grey relational coefficients (GRC) for all the sequences express the association between the ideal (best) and actual normalized response variables [22].

The grey relation coefficient $\mu_i(k)$ can be calculated using the below-given equation.

$$\psi_i(k) = \frac{\Delta \min + \mu\Delta maxx}{\Delta_{0i}(k) + \mu\Delta max} \quad (4)$$

Where

$\Delta_{0i}(k) = \|a_0^x(k) - a_i^x(k)\|$

Δ_{0i}: difference of the absolute value between the target sequence $a_0^x(k)$ and the comparison sequence $a_i^x(k)$

μ = distinguishing coefficient between 0 and 1. Moreover, its value is usually 0.5 in the literature [23].

$a_0^x(k)$ = ideal sequence or the target sequence;

$a_i^x(k)$ = given sequence or the comparison sequence;

Δ_{min} = ∀j min∈i$\forall_k$ min$\|a_0^x(k) - a_i^x(k)\|$= smallest value of Δ_{0i}

Δ_{min}: The absolute value of the minimum difference of the comparison sequence and the target sequence.

Δ_{max} = ∀j max∈i$\forall_k$ max$\|a_0^x(k) - a_i^x(k)\|$= largest value of Δ_{0i}

Δ_{max}: The absolute value of the maximum difference of the comparison sequence and the target sequence.

For instance, the first deviation sequence of density was calculated using Eq. 3.

$$\Delta_{max} = \forall j\ \max\in i\forall_k \max\|a_0^x(k) - a_i^x(k)\| =$$

$$\Delta_{max} = \max\|a_0^x(k) - a_i^x(k)\| = 1 – 0 = 1$$

$$\Delta_{min} = \min\|a_0^x(k) - a_i^x(k)\| = =$$

$$\min\|a_0^x(k) - a_j^x(k)\| = 1- 1 = 0$$

$$\psi_i(k) = \frac{\Delta\min + \mu\Delta max}{\Delta_{0i}(k) + \mu\Delta max} = \frac{0 + (0.5)1}{0.52+(0.5)1} = \frac{0.5}{1.02} = 0.490196$$

Similarly, the other grey relational coefficient values are calculated.

The grey relational coefficient results for the experimental data are shown in Table 6.

Table 6 Grey relational coefficient of each performance characteristics

SAMPLES	Density	Brinel hardness	Compressive strength	Ultimate tensile strength	Impact energy	% cold water absorption	% hot water absorption	% oil absorption
S1122	0.490196	0.429185	0.613497	0.518672	0.996	0.483969	0.405155	0.383393
S3122	0.759878	0.354108	0.545852	0.453309	0.353693	0.365629	1	0.430859
S1322	0.699301	0.986193	0.392157	0.482625	0.38785	0.379187	0.873333	0.436233
S3322	0.361272	0.60024	0.357398	0.333333	0.547253	0.780788	0.403077	0.333333
S2211	0.333333	0.398406	0.582072	1	0.365639	1	0.333333	0.376379
S2231	0.484496	0.724638	0.491642	0.754148	0.6	0.489954	1	1
S2213	0.609756	0.539957	0.429923	0.688705	0.968872	0.408505	0.502558	0.992903
S2233	0.363372	0.361795	0.605327	0.352858	0.347765	0.77129	1	0.409184
S1221	0.558036	0.652742	0.360231	0.334225	0.821782	0.528333	0.539095	0.440908
S3221	0.361795	0.902527	0.613497	0.382848	0.336942	0.77887	0.348713	0.336865
S1223	0.506073	0.334448	0.605327	0.552486	0.63038	0.466177	0.487593	0.431657
S3223	0.511771	0.344828	0.333333	0.5	0.594272	0.464809	0.635922	0.333492
S2112	0.589623	0.865052	0.634518	0.387597	0.761467	0.417655	0.439106	0.390455
S2312	0.4	0.432526	0.701262	0.792393	0.371088	0.631474	0.487593	0.355347
S2132	1	0.536481	0.649351	1	0.33378	0.333333	0.339085	0.434607
S2332	0.740741	0.363636	0.605327	0.386399	0.334677	0.369464	0.333333	0.639689
S1212	0.513347	1	0.712251	0.445236	0.943183	0.464129	0.394578	0.985905
S3212	0.386997	0.396511	0.723589	0.34626	0.334677	0.673036	0.424406	0.386785
S1232	0.85034	0.632911	0.429923	0.405186	0.336942	0.350276	0.544321	0.404452
S3232	0.714286	0.610501	1	0.684932	0.68975	0.375592	0.967981	0.987297
S2121	0.42735	0.493097	0.761035	0.632911	1	0.570144	0.39697	0.333333
S2321	0.338066	0.826446	0.847458	0.758725	0.713467	0.949102	0.977613	0.340472
S2123	0.369276	0.333333	0.428816	0.378501	0.972657	0.742388	0.641109	0.336541
S2323	0.367107	0.362845	0.605327	0.93985	0.775701	0.751185	0.40184	0.406332
S2222	0.587544	0.392773	0.613497	0.696379	0.333333	0.418206	0.510389	0.471838
S2222	0.587544	0.392773	0.613497	0.696379	0.367799	0.418206	0.510389	0.471838
S2222	0.587544	0.392773	0.613497	0.696379	0.333333	0.418206	0.510389	0.471838
CBP	0.446828	0.666667	0.597372	0.482625	0.542484	0.536379	0.504493	0.533359

3.4 Determining grey relational grades

Grey relational grades were calculated using grey relational examination, and the rank was allotted, conferring it to the grey relational grades. The uppermost value of the grey relational was deliberated as the first rank experiment. Further, ranking was arranged in descending order of magnitude from higher to lower. The experimental arrangement that produced first-rank response values will be considered an ideal experimental setup to obtain superior response values [24]. Table 7 shows the grey relational values along with the rank or order.

After averaging the grey relational coefficients, the grey relational grade β_i can be calculated using the equation (5).

$$\beta_i = \frac{1}{n}\sum_{k=1}^{n}\psi_i(k) \quad (5)$$

Where n = number of process responses.

Grey relation Grade = average of grey relational values

Grey relation Grade = 0.49096 + 0.429185 + 0.613497 + 0.518672 + 0.996 + 0.483969 + 0.405155 + 0.383393 / 8 = 0.540008

Similarly, the other grey relational grade values are calculated.

The grey relational grade results for the experimental data are shown in Table 7.

Table 7 The experimental results for the grey relational grade and its rank

Samples	Grade	Rank
S1122	0.540008	12
S3122	0.532916	14
S1322	0.57961	6
S3322	0.464587	26
S2211	0.548645	11
S2231	0.69311	3
S2213	0.642647	5
S2233	0.526449	16
S1221	0.529419	15
S3221	0.507757	19
S1223	0.501768	22
S3223	0.464803	25
S2112	0.560684	10
S2312	0.52146	18
S2132	0.57833	7
S2332	0.471658	24
S1212	0.682329	4
S3212	0.459033	27
S1232	0.494294	23
S3232	0.753792	1
S2121	0.576855	8
S2321	0.718919	2
S2123	0.525328	17
S2323	0.576273	9
S2222	0.502995	21
S2222	0.507303	20
S2222	0.502995	21
CBP	0.538776	13

3.5 Box Behnken technique of Grey relational analysis

The designed experimental layout via the Box Behnken Orthogonal Array method generated the succeeding response values of density, hardness, cold water absorption, hot water absorption, oil absorption, compressive strength, tensile strength, and impart energy (see Table 7). Experiment S3232 has the maximum grey relational grade GRG value and was selected as the first rank. The factors arranged for the experimental specimen S3232 have a moulding pressure of 11.25MPa, moulding temperature of 180^{0}C, and heat treatment time of 180min. The response values obtained from the experimental sample (Figure 1) S3232 give maximum values on all the responses for density of 3.483g/cm3, Brinel hardness of 52.91, compressive strength of 2.78MPa, ultimate tensile strength of 3.92MPa, impact energy of 17.87N, % of cold water absorption of 0.2863%wt, % of hot water absorption of 0.4785%wt, and % oil absorption of 0.4402%wt.

Fig. 1 Optimized brake pad- S3232

Copper powder (CuO) served as an abrasive and was an excellent thermal conductivity material that took heat away from the brake pad interfaces. Low thermal conductivity increases the propensity of raising the brake pad temperature to form. It builds the temperature at the tribological contact surface.

The graphite powder served as friction modifiers. Friction modifiers reduce the coefficient of friction, resulting in less fuel consumption in the application of automobiles.

Epoxy resin (Epos-block, FIP Chemicals) was used together with a co-reactant known as a hardener (Sikadur 42 T, Sitka Corporation U.S) to form a cross-linking reaction (Abutu et al. 2018) for better mechanical properties in the produced brake pad.

4. Conclusions

The grey relational theory is generally used to determine the degree of relationship between various process variables through grey relational grade GRG. Several scholars have practised a Grey relational study

[25, 26, 27] to optimize control parameters with multiple GRG responses. The Grey relational analysis is extensively used to combine all the deliberated performance characteristics into one value that can be used as a single characteristic in a complex optimization [27].

Grey relational analysis is a system theory that does not have complete information on available facts but appreciates the information about the system achieved. Primarily, reference sequence (mechanical properties) is generated in this method through brake pad-produced sample text. For Normalization, the values for mechanical properties should increase in this research. Hence, the 'higher the better' normalization criteria is taken for mechanical properties. The Grey relational coefficient and Grey relational grade are computed on equivalent sequences. After these procedures, the correlation between the reference sequence and comparable sequences was resolved. A sequence with an upper correlation is taken as a more superlative sample so that ranking is required. The peak value of the grey relational grade was deliberated as the first rank test. Further, the ranking was fixed from larger to smaller.

The optimal performance characterization in the mechanical properties was a sample of coconut fruit fibre, with a moulding pressure of 11.25MPa, moulding temperature of 1800C, and heat treatment time of 180Min. S3232, followed by S2321, and so on. After that, the optimized sample (Figure 1. - S3232) were applied in automobiles, and it w. So therefore from Table 7, the experimental setup which produced rank one response values will be considered as a perfect experimental setup to obtain superior values of density of 3.483g/cm3, Brinel hardness of 52.91, compressive strength of 2.78MPa, ultimate tensile strength of 3.92MPa, impact energy of 17.87N, % of cold water absorption of 0.2863%wt, % of hot water absorption of 0.4785%wt, and % oil absorption of 0.4402%wt of response. Thus, the GRA yielded robust results since the optimized sample (S3232) can withstand mechanical failure due to high mechanical properties.

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