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Effects of Nigerian Plant Gum Binder in the Optimized Multi-response Performance of Cashew Nut Shells Based Composites for Automobile Brake Pads

Katsina Christopher BALA
Federal University of Technology, Minna, Niger State

Sadiq Sius LAWAL
Federal University of Technology, Minna, Niger State

Nuhu A. ADEMOH
Federal University of Technology, Minna, Niger State

Asipita Salawu ABDULRAHMAN
Federal University of Technology, Minna, Niger State

Oyewole ADEDIPE
Federal University of Technology, Minna, Niger State

Abstract: There are emerging growing needs to develop automobile brake pad materials from agro-biomass sustainable sources which are lung and environmentally friendly towards replacing asbestos which has been reported to cause other cancerous diseases. It has been established that many research works have been done towards replacing asbestos with other environmentally friendly reinforcement materials but not much has been reported on the replacement of inorganic resins like Phenolic or Formedehyde and the epoxy resins mostly used as the binder which have toxic health concerns and also known to corrode plates of brake pad assembly. Therefore, Agro-biomass such as agricultural residues, wastes and products especially from fibers and plant exudates have now emerged as the new and inexpensive materials that could be used to form parts of brake pads composite matrix that are commercially viable and environmentally acceptable. This study reveals a substitute research direction with the replacement of the inorganic resin binder with Plant Gum binder like the Nigerian Gum Arabic-NGA. Taguchi Design of Experimental method was deployed to generate twenty seven (27) trial composites of particle size 300 µm for the brake pads production. The Analysis of Variance (ANOVA) from the optimized Grey Relational Analysis indicated that the Nigerian Gum Arabic-NGA has significant effects on the multi-response performance of the developed brake pads with percentage contribution (p-value) of 18.503%.

Keywords: Brake-pad, Binder, Plant-Gum, Taguchi, Composites

Introduction

The components of brake pads in automobiles consist of composites made of reinforcement materials and some additives that a bonded together in the matrix mix. Brake pads are placed in wheel assembly to continuously clamp holding the wheels to slow down or stop a moving automobiles (Aigbodion & Agunsoye, 2010). Since over 117 years ago, the production of these automobile materials are usually made with blends of asbestos, metals and ceramics and the commonly used binders are epoxy phenol or formaldehyde resins. Many efforts in recent times of researchers is geared primarily towards replacing of the asbestos which Bala *et al.* (2016)

reported to cause lung and other cancerous diseases. Interestingly, very few works have reported efforts towards alternative binders to replace the commonly used inorganic resins with a biomass that do not corrode any parts of the brake pads assembly. Deepika, *et al.* (2013) developed and evaluated the performance of a composite materials for wear resistance application, made use of palm kernel shells –PKS as filler material with sulphur, brass, ceramics, liquid of cashew nut shells, quartz, calcium carbonate, iron ore, and carbon black. In 1930s, Ferodo changed to thermosetting resins and produced moulded instead of knitted linings. Moulded linings were made by combining fiber with resin and polymerizing resin under elevated pressure and temperature (Deepika *et al.*, 2013). It was reported that the additive effects of different non-asbestos materials on friction lining has sensitized and increased the use of asbestos-free organic, semi-metallic and metallic friction lining materials, (Blau, 2001).

Bashar *et al.* (2012) uesd coconut shells to produce hazard free and non-asbestos brake pads experimentally. Their constituent materials included grounded coconut shells as filler, reinforced with iron chips, catalyzed with methyl ethyl ketone peroxide, Cobalt nephthanate as the accelerator, silica and iron serving as the abrasive component with brass modifying the friction. The binder used in the matrix was epoxy resin. Yawas, Aku and Amaren (2013) produced brake pads from Periwinkle shells that was characterized for its morphology and properties. The formulation of periwinkle shell powder, engine oil (SEA 20/50), water were bonded with phenolic resin (an inorganic binder).

A geological studies on kaolin clay group within the sedimentary mineral material zone of Ise-Orun-Emure local government areas of Ekiti State, Nigeria carried out by Aderiye (2014) examined, beneficiated, processed and characterized clay for automobile brake frictional materials. The study revealed kaolin clay to be of good heat resistance for friction lining material in automotive industry, and its refractoriness was not only suitable for electronic products, technical works and ceramic manufacturing industries but can also be a material used for eco-friendly and asbestos free brake pads production. Similarly, in the research work by Aderiye (2014), kaolin clay was explored, exploited and employed specifically for ceramic disk brake pads by investigating the thermal properties of kaolin samples between 1000°C to 1400^{o}C temperatures in order to ascertain their suitability for producing automobile brake pads.

Idris *et al*. (2015) investigated the production of banana peels based brake pads with phenol formaldehyde as the binder. The binder was varied from 5% to 30% weight and the physical, mechanical, wear and morphological properties of brake pad were determined. The results showed that compressive strength, hardness and specific gravity of the samples increased with increased in percentage weight of resin addition. Edokpia, *et al*. (2014) used Egg Shells (ES) based eco-friendly (biodegradable) materials to develop brake pads that was evaluated for physical, tribological and mechanical properties. Interestingly, a plant gum known as Gum Arabic (GA) was used as the binder in the mix. The study investigated the possible replacement for asbestos and formaldehyde resin which are carcinogenic in nature and non-biodegradable. The brake pad formulation was produced by varying the GA from 3 to 18 wt%. Tests carried out on samples included wear rate, thickness swelling in water and SAE oil, thermal resistance, specific gravity, compressive strength, hardness values and microstructure. Results showed that formulations containing 15 to 18 wt% of GA produced fair bonding with the sample containing 18 wt% of GA in ES particles giving the best brake lining properties.

Recent efforts by many researchers have been on to discover eco-friendly material replacement not only for asbestos constituents in brake lining pad composites but also finding an alternate agro-based biomass materials as organic binder in the composite mix that is human, ecological, economic and environmentally friendly.Brake pads are frictional components bound to the surface of brake disc in wheel assembly of automobiles to continuously clamp and hold wheels to slow down or completely stop their motion (Aigbodion *et al.,* 2010). Brake pads control the speed of moving automobile by converting the kinetic energy to thermal energy by friction and dissipating the heat produced through brake disc to the surroundings.

Therefore, this research does not only strives to address the hazardous health concerns associated with asbestos based brake pad materials by using cashew nut shells, but to present an alternative material to replace the toxic inorganic resins commonly used with plant gum binder of an acacia species exudates known as Gum Arabic. The plant binder provide a green based, natural resin that contains arabin which is a semi solidified sticky fluid oozing from incision made on bark of acacia trees. Nigeria produces different grades of exudates and is ranked as the second largest world producer after Sudan with average production of 20,000 tonnes in 2005 (Ademoh & Abdullahi, 2010).

Cashew Nut Shells

The tree called cashew botanically named *Anarcardium Occidentale* is a native of Brazil in Southern America. The tree has nuts in a kernel with a colorful cashew apple shown in figure 1, is an overdeveloped pedicel which is edible. The cashew nut (kernel) is the primary commercial product of cashew plantation as it is very appreciated as a snack and is also used in the Asiatic cuisines, especially Thai and Chinese. Cashew nuts can be processed industrially and commercially into jam, juice, syrup, chutney and beverage (Winterhaler, 1991). According to Ohler (1979) ,the world production and consumption has increased rapidly with an estimated over 1,260,000tonnes for the next twenty years from major producing countries like Nigeria, India, Mozambique, Malawi, Thailand, Tanzania, Sri Lanka, Kenya, Madagascar, Malaysia, Indonesia, Senegal and Angola. In 2010,Nigeria produced 594,000 tonnes of cashew nuts and there has been need to increase the production for the economic development in Nigeria (Olife *et al.*,2013).This pericarp of a nut which is the cashew nutshell has an alveolar mesocarp filled with a dark and caustic oily substance called cashew nutshell liquid (CNSL), obtained as a by-product during the industrial processing of the cashew nut as reported by Akinhanmi, (2008), Idah *et al.*, (2014) and Okele *et al.*, (2016).

The physical and mechanical properties of cashew nut shells and kernels have unique characteristics which set them apart from other engineering materials to be used as reinforcement material for the production of agro-based brake pad was used for this research. Okele *et al.*, (2016), Bart-Plange *et al*., (2012), and Teye and Abano, (2012) have extensively determined these physical and mechanical properties by these researchers with favorable results to exploited.

Figure 1. Cashew pedicel, fruit, and mesocarp filled with CNSL, cashew nut and cashew kernel (Source: Lomonaco *et al*., 2017 and Bart-Plange *et al*., 2012).

Plant Gum Binder – Nigerian Gum Arabic

The plant gum known as Gum Arabic was obtained from the dried exudates obtained from stems and branches of *Acacia Senegal* wild plant belonging to *Acacia species* and the *Fabaceae* family (Tunde, 2018). It is a semi solidified sticky fluid oozing from incision made on bark or branch of acacia trees as shown in Figure 2.

Figure 2. Gum Arabic as seen on an Acacia tree

(Source: REUTERS/Mohamed Nureldin Abdallah, 2012 and www.finelib.com/, 2019)

These tree species that produces the plant gum is found in the dry, hot, and barren regions of African countries like Nigeria, Mauritania, Senegal, Mali, Niger, Sudan and Chad. Nigeria happened to be ranked the second largest producer in the World with an average production of 20,000 tonnes in 2005 after Sudan (Ademoh & Abdullahi, 2010). The major Nigerian producing states are Adamawa, Sokoto, Niger, Taraba, Borno, Yobe, Bauchi, Jigawa, Kebbi, Gombe, Plateau, Nasarawa, Katsina, and Zamfara state as shown in Figure 3. There are three major grades of Gum Arabic as shown in Figure 4 that are produced in commercial quantities.

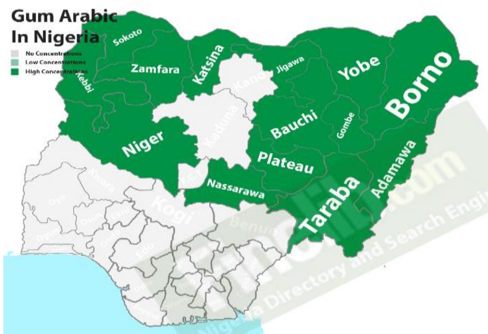

Figure 3: Map of gum Arabic producing states in Nigeria
(Source: www.finelib.com, 2019; Lawal, 2021).

Figure 4: Different grades of gum arabic (Source: Tunde, 2018).

Materials

The constituent compositions used in this study were sourced locally while the equipments in the workshop and Laboratory at the Federal Institute of Industrial Research, Oshodi, (FIIRO) in Lagos State, Nigeria were used. The base materials for the formulation and production of the composites were Cashew Nut Shell (CNS), Nigerian Gum Arabic (NGA), Steel Dust (SD), Graphite (G) and Silicon Carbide (SC). The base and other additive materials bonded with plant gum binder that were selected and their roles for their selection according to Lawal, (2021) are shown in Table 1.

Table 1. Materials selected and their roles

S/No	Materials	Role	Reason(s) for Material Choice
1	Cashew Nut Shell	Base/Filler Material	Cheaply available as Agro-allied material, rarely used and chosen to investigate its usage to replace asbestos, improve resilience in the binder system and reduces brake noise
2	Nigerian Gum Arabic	Binder	Good bindery properties, chosen for the production of brake pad as binder and to increase the chances of substantially green agro-allied (plant) based brake pad
3.	Steel Dust	Reinforcement and Abrasiveness	It is a reinforcement that influences adhesion and dispersion of polymer composite fabrication, it also has abrasive functions.
4	Silicon Carbide	Thermal Conductivity and Abrasiveness	Easy and cheap to obtain. It increases friction and also helps in controlling the build-up of friction film. That is, it effectively controls the thermal conductivity of the brake pad during usage
5.	Graphite	Friction Producer/Modifier	Cheap and widely used and it is non-hazardous for improving wet friction

The Equipment used

The equipment that were used for the study are: Hammer Crushing and Milling Machine, Ball Milling Machine, Hydraulic Press Model Piooeh-type, 100T-Capacity, Serial No 38280, Electric Oven, Europer Bench Grinder of

MD-250F, 750W, 380V-50Hz, R 29500 rpm, Ø(50-27)mm by 65mm mould, and Digital Weighing Machine. Other equipment used were BS 410 standard sieve sizes of aperture 300µm, micrometer screw gauge, Stirrer, Bowls, Optical Electron Microscope(OEM), Steel Spatula, and desiccators.

Method

The study was experimentally designed and carried out by adopting the Taguchi $L_{27}3^5$ orthogonal array Design of Experiment (DOE) for twenty seven (27) different formulations of five constituent materials (Sadiq *et al.*, 2020). The Cashew Nut Shells, Silicon Carbide and Nigerian Gum Arabic compositions were varied while the other constituents such as Graphite and Steel Dust were kept constant. The five (5) input factors (ingredients) composition is presented as percentage (%) as well as in grams in Tables 2 and 3.

Table 2. Factor levels for composition parameters in percentage

		Percentage Composition (%)		
		Level 1	Level 2	Level 3
1	Cashew Nut Shell	35	45	55
2	Steel Dust	15	15	15
3	Graphite	5	5	5
4	Silicon Carbide	20	15	10
5	Nigerian Gum Arabic	25	20	15

Table 3. Factor levels for composition parameters in grams

		Percentage Composition (Grams)		
		Level 1	Level 2	Level 3
1	Cashew Nut Shell	52.5	67.5	82.5
2	Steel Dust	22.5	22.5	22.5
3	Graphite	7.5	7.5	7.5
4	Silicon Carbide	30	22.5	15
5	Nigerian Gum Arabic	37.3	20	22.5

The experimental Layout of the $L_{27}3^5$ orthogonal array as obtained from Minitab 17 is shown in Table 4 while Table 5 is the eventual Experimental Design Matrix.

Development of the Composites

The development of the composites involved the preparation of the constituent materials into 300µm particle size and formulated into twenty seven (27) different compositions as shown in Table 5 as carried out by Lawal, (2021). The powder metallurgy method also known as the compression moulding method was successfully adopted and reported by Yawas, *et al* (2013), Fono and Koya (2013) and Bashar, *et al* (2012) were used in the development of the brake pad composites. The powdered Cashew Nut Shells was sieved into grades of 300 µm and the component materials of Cashew Nut Shells Powder, Gum Arabic Powder, the Steel Dust, Silicon Carbide and Graphite were weighed in the Digital weighing Machine correspondingly with formulations designed via Taguchi. The composition of the constituents was thoroughly mixed using Homogenizer or Mixer of Model 89.2 Rid Scale & Co Ltd, Middleborough, England.

The mixing of the composition was done for 20 to 30 minutes to achieve almost complete homogeneous mixture inside the mixer before pouring into the mould kept in a hot plate press at temperature of 150°C and 100,000N/cm^2 pressure for two minutes. They were then subjected to cold pressing and hot pressing before being allowed to cool at room temperature. After removing from hot press, the composites were removed from the mould and properly cleaned. It was then heat treated at a temperature of 120°C for 8 hours in the hot air oven. These procedures were repeated for all the twenty seven (27) formulations to produce the respective composites. Grey Relational Analysis as outlined by Yiyo *et al*, (2008) and successfully deployed by Abutu *et al*, (2018) and Lawal, (2021) was used to optimize the multi-response performance of the Wear rate, Coefficient of Friction, Hardness and Compressive Strength of the brake pad samples produced while ANOVA was used to determine the significant contribution of the Nigerian Plant Binder in the optimized performance of the brake pad samples.

Table 4. Experimental layout of the $L_{27}3^5$ orthogonal array

Trial No	CNS	SD	G	SC	NGA
1	1	1	1	1	1
2	1	1	1	1	2
3	1	1	1	1	3
4	1	2	2	2	1
5	1	2	2	2	2
6	1	2	2	2	3
7	1	3	3	3	1
8	1	3	3	3	2
9	1	3	3	3	3
10	2	1	2	3	1
11	2	1	2	3	2
12	2	1	2	3	3
13	2	2	3	1	1
14	2	2	3	1	2
15	2	2	3	1	3
16	2	3	1	2	1
17	2	3	1	2	2
18	2	3	1	2	3
19	3	1	3	2	1
20	3	1	3	2	2
21	3	1	3	2	3
22	3	2	1	3	1
23	3	2	1	3	2
24	3	2	1	3	3
25	3	3	2	1	1
26	3	3	2	1	2
27	3	3	2	1	3

Table 5. Three (3) Level $L_{27}3^5$ orthogonal array experimental matrix for the compositions

Trial No	Cashew Nut Shells CNS (Grams)	Steel Dust SD (Grams)	Graphite G (Grams)	Silicon Carbide SC (Grams)	Nigerian Gum Arabic (Grams)
1	52.5	22.5	7.5	30	37.5
2	52.5	22.5	7.5	30	30
3	52.5	22.5	7.5	30	22.5
4	52.5	22.5	7.5	22.5	37.5
5	52.5	22.5	7.5	22.5	30
6	52.5	22.5	7.5	22.5	22.5
7	52.5	22.5	7.5	15	37.5
8	52.5	22.5	7.5	15	30
9	52.5	22.5	7.5	15	22.5
10	67.5	22.5	7.5	15	37.5
11	67.5	22.5	7.5	15	30
12	67.5	22.5	7.5	15	22.5
13	67.5	22.5	7.5	30	37.5
14	67.5	22.5	7.5	30	30
15	67.5	22.5	7.5	30	22.5
16	67.5	22.5	7.5	22.5	37.5
17	67.5	22.5	7.5	22.5	30
18	67.5	22.5	7.5	22.5	22.5
19	82.5	22.5	7.5	22.5	37.5
20	82.5	22.5	7.5	22.5	30
21	82.5	22.5	7.5	22.5	22.5
22	82.5	22.5	7.5	15	37.5
23	82.5	22.5	7.5	15	30
24	82.5	22.5	7.5	15	22.5
25	82.5	22.5	7.5	30	37.5
26	82.5	22.5	7.5	30	30
27	82.5	22.5	7.5	30	22.5

All the produced brake pad samples were tested and evaluated for the physical, mechanical and tribological properties such as Microstructure analysis, Brinell hardness, compressive strength, Wear rate, (abrasion resistance), Ash content (Flame Resistance), Density Test, Specific Gravity, Swell Growth Analysis, and Oil/Water absorption.

Results and Discussion

The experimental responses for the wear rate, Compressive Strength, Coefficient of Friction and Hardness were characterized as presented in Table 6. These values were used to obtain the respective Signal-to-Noise Ratio as in Table 6, as well obtaining Grey Relational Generating, Grey Relational Coefficient and the Grade as presented in Table 7.

Table 6. Experimental responses and S/N values

	Experimental Responses				Signal-to-Noise Ratios			
Runs	Wear Rate (mg/m)	Compressive Strength (N/mm2)	Coefficient of Friction	Hardness (BHN)	Wear rate (dB)	Compressive strength (dB)	Coefficient of friction (dB)	Hardness (dB)
1	2.31	3.643	0.3868	31.83	-7.272	11.229	-8.250	30.057
2	4.24	6.714	0.4554	47.49	-12.547	16.540	-6.832	33.532
3	3.47	6.332	0.3868	31.83	-10.807	16.031	-8.250	30.057
4	0.77	8.417	0.426	76.66	2.270	18.503	-7.412	37.691
5	8.48	7.976	0.4162	47.49	-18.568	18.036	-7.614	33.532
6	4.62	5.879	0.4358	76.66	-13.293	15.386	-7.214	37.691
7	1.16	4.398	0.3966	47.49	-1.289	12.865	-8.033	33.532
8	1.54	7.138	0.426	31.83	-3.750	17.072	-7.412	30.057
9	8.48	9.863	0.4456	76.66	-18.568	19.880	-7.021	37.691
10	7.71	4.209	0.4064	76.66	-17.741	12.484	-7.821	37.691
11	6.55	6.956	0.4456	76.66	-16.325	16.847	-7.021	37.691
12	5.01	5.145	0.3868	47.49	-13.997	14.228	-8.250	33.532
13	8.48	6.365	0.475	47.49	-18.568	16.076	-6.466	33.532
14	5.78	5.509	0.4848	47.49	-15.239	14.821	-6.289	33.532
15	3.47	12.187	0.4456	47.6	-10.807	21.718	-7.021	33.552
16	8.86	4.781	0.475	31.83	-18.949	13.590	-6.466	30.057
17	6.17	7.851	0.4848	47.49	-15.806	17.898	-6.289	33.532
18	3.08	5.432	0.4064	47.49	-9.771	14.699	-7.821	33.532
19	3.85	3.568	0.4554	31.83	-11.709	11.048	-6.832	30.057
20	3.08	3.927	0.4848	47.49	-9.771	11.881	-6.289	33.532
21	8.09	3.758	0.4554	76.66	-18.159	11.499	-6.832	37.691
22	3.85	5.699	0.4554	47.49	-11.709	15.116	-6.832	33.532
23	2.7	3.099	0.4554	76.66	-8.627	9.824	-6.832	37.691
24	7.71	3.081	0.426	31.83	-17.741	9.774	-7.412	30.057
25	4.24	2.267	0.478	22.26	-12.547	7.109	-6.411	26.951
26	5.01	4.437	0.4848	47.49	-13.997	12.942	-6.289	33.532
27	2.31	6.405	0.4848	47.49	-7.272	16.130	-6.289	33.532

Table 7. Results of grey relational generating (GRG) and grey relational coefficient (GRC)

	GRG				GRC				
Runs	Wear Rate	Compressive Strength	Coefficient of Friction	Hardness	Wear rate	Compressive strength	Coeff. of friction	Hardness	Grade
X_o	1.000	1.000	1.000	1.000					
1	0.450	0.282	0.000	0.289	0.476	0.411	0.333	0.413	0.408
2	0.698	0.646	0.723	0.613	0.624	0.585	0.644	0.564	0.604
3	0.616	0.611	0.000	0.289	0.566	0.562	0.333	0.413	0.469

4	0.000	0.780	0.427	1.000	0.333	0.694	0.466	1.000	0.623
5	0.982	0.748	0.324	0.613	0.965	0.665	0.425	0.564	0.655
6	0.733	0.567	0.528	1.000	0.652	0.536	0.514	1.000	0.676
7	0.168	0.394	0.111	0.613	0.375	0.452	0.360	0.564	0.438
8	0.284	0.682	0.427	0.289	0.411	0.611	0.466	0.413	0.475
9	0.982	0.874	0.627	1.000	0.965	0.799	0.572	1.000	0.834
10	0.943	0.368	0.219	1.000	0.898	0.442	0.390	1.000	0.682
11	0.876	0.667	0.627	1.000	0.802	0.600	0.572	1.000	0.744
12	0.767	0.487	0.000	0.613	0.682	0.494	0.333	0.564	0.518
13	0.982	0.614	0.910	0.613	0.965	0.564	0.847	0.564	0.735
14	0.825	0.528	1.000	0.613	0.741	0.514	1.000	0.564	0.705
15	0.616	1.000	0.627	0.615	0.566	1.000	0.572	0.565	0.676
16	1.000	0.444	0.910	0.289	1.000	0.473	0.847	0.413	0.683
17	0.852	0.739	1.000	0.613	0.771	0.657	1.000	0.564	0.748
18	0.567	0.520	0.219	0.613	0.536	0.510	0.390	0.564	0.500
19	0.659	0.270	0.723	0.289	0.594	0.406	0.644	0.413	0.514
20	0.567	0.327	1.000	0.613	0.536	0.426	1.000	0.564	0.631
21	0.963	0.301	0.723	1.000	0.931	0.417	0.644	1.000	0.748
22	0.659	0.548	0.723	0.613	0.594	0.525	0.644	0.564	0.582
23	0.514	0.186	0.723	1.000	0.507	0.380	0.644	1.000	0.633
24	0.943	0.182	0.427	0.289	0.898	0.379	0.466	0.413	0.539
25	0.698	0.000	0.937	0.000	0.624	0.333	0.889	0.333	0.545
26	0.767	0.399	1.000	0.613	0.682	0.454	1.000	0.564	0.675
27	0.450	0.618	1.000	0.613	0.476	0.567	1.000	0.564	0.652

The summary of GRA-Grade results along with their corresponding factor levels are shown in Table 8.

Table 8. Summary of GRA-grade values and factor levels

Run	Experimental Factors					GRA-Grade values
	CNS	SD	G	SC	NGA	300 µm
1	1	1	1	1	1	0.408
2	1	1	1	1	2	0.604
3	1	1	1	1	3	0.469
4	1	2	2	2	1	0.623
5	1	2	2	2	2	0.655
6	1	2	2	2	3	0.676
7	1	3	3	3	1	0.438
8	1	3	3	3	2	0.475
9	1	3	3	3	3	0.834
10	2	1	2	3	1	0.682
11	2	1	2	3	2	0.744
12	2	1	2	3	3	0.518
13	2	2	3	1	1	0.735
14	2	2	3	1	2	0.705
15	2	2	3	1	3	0.676
16	2	3	1	2	1	0.683
17	2	3	1	2	2	0.748
18	2	3	1	2	3	0.500
19	3	1	3	2	1	0.514
20	3	1	3	2	2	0.631
21	3	1	3	2	3	0.748
22	3	2	1	3	1	0.582
23	3	2	1	3	2	0.633
24	3	2	1	3	3	0.539
25	3	3	2	1	1	0.545
26	3	3	2	1	2	0.675
27	3	3	2	1	3	0.652

Factor Levels of Main Effects

The factor effects for 300 µm shown in Table 9 were obtained using the Grade values from GRA as presented in Table 8.

Table 9. Resulting factor effects of experimental factors (300 µm)

Factor level	CNS	SD	G	SC	NGA
Level 1	0.5758	0.5909	0.5739	0.5944	0.5790
Level 2	0.6656	0.6470	0.5647	0.6421	0.6522
Level 3	0.6131	0.6166	0.6410	0.6050	0.6234

Main Effect Plot

The main effect plots for GRA shown Figure 5 was plotted for the optimal compositions for the multi- response properties and characterization.

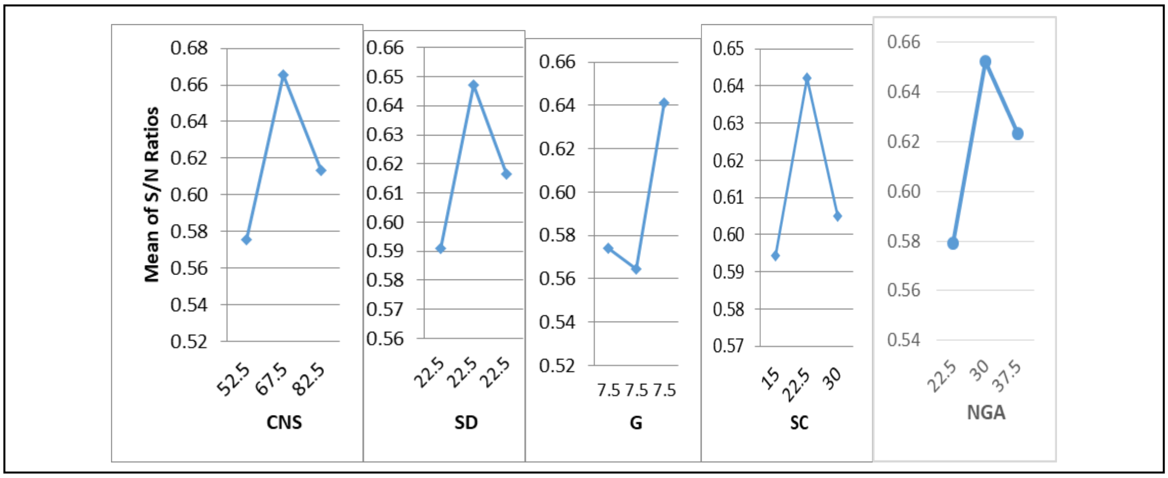

Figure 5: Main effect plot for Grey relational analysis

From the Main Effect Plot in Figure 5, the optimal composition in grams of the formulation of Cashew Nut Shells (CNS), Steel Dust (SD), Graphite (G), Silicon Carbide (SC), and Nigerian Gum Arabic (NGA) are 67.25, 22.5, 7.5, 22.5 and 30grams respectively.

Analysis of Variance (ANOVA)

ANOVA was conducted using the multi-response GRA and Grade values with the aim of identifying the significant effects of the Plant Gum Binder which affect the quality characteristics of the composite. This analysis was conducted using α = 0.05 significance level, at 95 % confidence level. These results are shown in Tables 10.

Table 10: ANOVA for Grey relational analysis

Factor	DOF	SS	MS	F	P
CNS	2	0.069	0.034	15.197	22.467
SD	2	0.046	0.023	10.233	15.129
G	2	0.058	0.029	12.921	19.102
SC	2	0.040	0.020	8.774	12.972
NGA	2	0.057	0.028	12.516	18.503
Error	16	0.036	0.002		11.827
Total	26	0.306	0.012		100.000

The ANOVA 300 µm shown in Table 10 indicates that the CNS has the highest significant effects on the multi-response performance of the developed composites with percentage contribution (p-value) of 22.467 %

Conclusion

From the results obtained the following conclusions are drawn: Agro-biomass of Cashew Nut Shells and Plant Gum Binder of Nigerian Gum Arabic are alternative replacement materials for Asbestos and inorganic resins such epoxy, Phenolic and Formaldehyde respectively. The optimal composition of the formulation for the multi response performance of 300µm particle sizes of Cashew Nut Shells (CNS), Steel Dust (SD), Graphite (G), Silicon Carbide (SC), and Nigerian Gum Arabic (NGA) are 67.25, 22.50, 7.50, 22.50 and 30.00 respectively. The Significant Contributions of the Nigerian Gum Arabic in the Mix for the multi response performance is 18.50%.

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Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

References

Abutu, J., Lawal, S. A., Ndaliman, M. B., Lafia-Araga., R. A., Adedipe, O., & Choudhury, I. A. (2018). Effects of process parameters on the properties of brake pad developed from seashell as reinforcement material using grey relational analysis, *International Journal of Engineering Science and Technology*, 21,787–797.

Ademoh, N. A., & Abdullahi, A. T., (2010). Evaluation of the effective braking conditions for grade 3 Nigerian Acacia species bonded foundry sand cores, *Research Journal of Applied Sciences, Engineering and Technology*, 2(6), 504 – 507.

Aderiye, J. (2014). Kaolin Mineral Material for Automobile Ceramic Brake Pad Manufacturing Industry. *International Journal of Technology Enhancements and Emerging Engineering Research, 2*(3), 84 - 88.

Aigbodion, V. S, & Agunsoye, J. O. (2010). Bagasse (Sugarcane waste): Non-asbestos free brake pad materials. Lambert Academic Publishing, Germany, ISBN 978-3-8433-8194-9.

Akinhami, T.F., (2008), Chemical composition and physicochemical properties of cashew nut (Anacardium Occidentale) oil and cashew nut shell liquid. *Agricultural,Food and Environmental Science, 2*(1) 1-10

Bala, K. C., Okoli, M., & Abolarin, M. S. (2016). Development of automobile brake lining using pulverized cow hooves. *Leonardo Journal of Sciences, 1*5(28), 95 – 108.

Bart-Plange, A., Mohammed-Kamil, A. P.,Addo A., & Teye, E., (2012), Some physical and mechanical properties of cashew nut and kernel growth in Ghana; *International Journal of Science and Nature*, *3*(2) 406-415.

Bashar, D., Peter B. M., & Joseph, M. (2012). Effect of material selection and production of a cold–worked composite brake pad. *Journal of Engineering of a Pure and Applied Science, 2*(3), 92 - 99.

Blau, J. P. (2001). Compositions, functions and testing of friction brake materials and their additives. *Being a report by Oak Ridge National Laboratory for U.S. Dept. of Energy. http://www.Ornl.- gov/-webworks/cppr/y2001/rpt/112956.pdf*, 78 – 80.

Deepika, K., Reddy, C., & Ramana Reddy, D. (2013). Fabrication and performance evaluation of a composite material for wear resistance application. *International Journal of Engineering Science and Innovative Technology (IJESIT*), 2(6), 1 – 6.

Edokpia, R. O., Aigbodion, V. S., Obiorah, O. B., & Atuanya, C. U. (2014). Evaluation of the properties of ecofriendly brake pad using egg shell particles–Gum Arabic. Science Direct®, Elsevier B.V. https://doi.org/10.1016/j.rinp.06.003.

Finelib.com, (2019). Gum Arabic producing states in Nigeria and its uses. Retrieved from https://www.finelib.com

Fono–Tamo, R. S., & Koya, O. A. (2013). Evaluation of mechanical properties of friction pad developed from agricultural waste. *International Journal of Advancements in Research & Technology, 2*(154), 2278–7763.

Idah, P. A., Simeon M. I., & Muhammed M. A., (2014). Extraction and characterization of cashew nut (*Anacardium Occidentale*) oil and cashew shell liquid oil. *Academic Research International,5*(3) 50-54.

Idris, U. D., Aigbodion, V. S., Abubakar, I. J., & Nwoye, C. I. (2015). Eco-friendly asbestos free brake-pad: using banana peels. *Journal of King Saud University – Engineering Sciences, 27,* 185 – 192.

Lawal, S. S. (2021). *Development and Characterization of Automobile Brake Pads from Cashew Nut Shells and Plant Gum Binder.* PhD Thesis, Mechanical Engineering Department, Federal University of Technology, Minna, Niger State.

Lomonaco D., Mazzatto S. E., & Mele G., (2017). Cashew nut shell liquid (CNSL): From an agro-industrial waste to sustainable alternative to petrochemical resources. *Springer International Publishing* AG.P. Anikumari. https://doi.org/101007/978-319-474557-2.

Ohler, J.G., (1979) Cashew. Department of agricultural research, royal tropical institute, Amsterdam.

Okele A. I., Mamza P. A. P., Nkeoye P., & Marut A. J., (2016). Mechanical properties of cashew nut shell powder (CSNP) filled natural rubber volcanizate. *Chemical Technology: An Indian Journal (CTIJ) 11*(2) 36-42.

Olife, I.C., Jolaoso, M.A., & Onwualu, A.P.,(2013). Cashew processing for economic development in Nigeria. *Agricultural Journal, 8*(1), 45-50.

Reuters/Mohammed Nureldin Abdallah/File. (2012). Gum Arabic is seen on an Acacia trees in the western Sudanese town of El-Nahud that lies in the main farming state of North Kordofan.

Sadiq**,** S. L**.,** Nuhu, A. A., Bala, K. C., & Abdulrahman, A. S. (2020). Production and testing of brake pad composites made from cashew nut shells and plant gum binder. *Journal of The Nigerian Institution of Mechanical Engineers*, 9(2) 54-63.

Teye, E., & Abano, E. E. (2012). Physical properties of two varieties of sweet potato grown in the coastal savannah zone of Ghana. *International Journal of Science and nature, 3 (1) 105-109.*

Tunde, M. (2018). *The economic, social and environmental relevance of gum Arabic with a focus on the major challenges and opportunities for producing countries of Africa: A case study of Nigeria.* United Nations Conference on Trade and Development Round Table: The Economics of Gum Arabic in Africa.

Yawas, D. S., Aku, S. Y., & Amaren, S. G. (2016). Morphology and properties of periwinkle shell asbestos–free brake pad. *Journal of King Saud University– Engineering Sciences, 28,* 103 – 109.

Yiyo, K., Taho, Y., & Guan, W. H. (2008).The use of a grey-based Taguchi method for optimizing multi-response simulation problems, *Eng. Optim. 40* (6) 517–528.

Authors Information

Katsina C. BALA
Federal University of Technology, Minna
Mechanical Engineering Department,
P.M.B. 65, Niger State, Nigeria
Contact e-mail: katsina.bala@futminna.edu.ng

Nuhu A. ADEMOH
Federal University of Technology, Minna
Mechanical Engineering Department,
P.M.B. 65, Niger State Nigeria

Oyewole ADEDIPE
Federal University of Technology, Minna
Mechanical Engineering Department,
P.M.B. 65, Niger State, Nigeria

Sadiq S. LAWAL
Federal University of Technology, Minna
Mechanical Engineering Department,
P.M.B. 65, Niger State, Nigeria

Asipita S. ABDULRAHMAN
Federal University of Technology, Minna
Material and Metallurgical Engineering Department,
P.M.B. 65, Niger State, Nigeria

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