CARITAS UNIVERSITY AMORJI-NIKE, EMENE, ENUGU STATE

Caritas Journal of Engineering Technology

CJET, Volume 2, Issue 1 (2023)

Article History: ***Received: 2nd April, 2023 Revised: 7th June, 2023 Accepted: 14th June, 2023***

Optimization of the Electrical Properties of Green Synthesized Graphene/Polyester Nanocomposite

Ezeh, Ernest Mbamalu
Department of Chemical Engineering,
Caritas University, Amorji Nike, Enugu, Nigeria.
Email: ezehernest@caritasuni.edu.ng

ABSTRACT

Graphene nanoplatelets offer exceptional properties, yet the performance and electrical conductivity of their polymer nanocomposites are often unimpressive. To overcome these obstacles, this study produced graphene from rice husk (Gr.NPs) coated with orange juice-modified green-generated silver nanoparticles (Ag.NPs)/polyester nanocomposites. The Taguchi-grey analysis was used to optimize the conductive characteristics of the developed nanocomposite. The composite's optimal performance blend was 7.5% Gr.NPs, 0.5% Ag.NPs, 100°C curing temperature, and 4ml orange juice. The remarkable electron mobility of Ag.NPs-Gr.NPs were attributed to the high electrical conductivity (2.08 x10-8 S/m), dielectric constants (5.95), and thermal conductivity (1.45 $Wm^{-1}K^{-1}$). The experimental grey relational grade of 0.615 was 95% of the way to the projected optimal grey relational grade of 0.724. This proved the sufficiency of the nanocomposite's optimal blending components for the production of electrical property furthered composites.

Keywords: *Graphene; Nanoparticles; Optimization; Rice husk; Composites*

1.0 Introduction

Polymer materials have largely supplanted many traditional materials in a wide range of applications, from kitchenware to mechanical components, over the previous several decades. Polymers' advantages over traditional materials make this possible [1]. Among them are cost savings, processability, processing simplicity, low density, sound and vibration dampening, corrosion resistance, mechanical toughness, and other advantages. However, they have several drawbacks, such as poor thermal stability; at high temperatures, they may oxidise. In their saturated state, they typically have low conductivity and strength [2,3].

Polymeric nanocomposites have thus been a focus of research for the last 30 years. Conducting composites is of particular importance because, in terms of anti-static coatings and flexible electronics, they outperform typical metal and rare earth element devices [4,5]. A variety of chemicals have been added to plastics to create conductive composites. Metal fibres and particles have been made from aluminium, steel, iron, copper, and nickel-coated glass fibre [6,7]. Carbonaceous materials such as carbon black, carbon fibre, graphite, and carbon nanotubes (CNTs) have been utilised to improve electrical conductivity. Graphene, on the other hand, outperforms these carbon materials in several ways, including exceptional carrier mobility at room temperature (250,000 cm2V-1s-1), mechanical strength (Young's modulus of 1TPa), electrical conductivity (6000 Scm-1), thermal conductivity (5000 Wm-1K-1), and large surface area (2600 m2g-1) [8,9].

When the concentration of these fillers reaches a certain point, the filler particles collide, resulting in a continuous conduit for electrons to travel through [10]. This concentration is known as the percolation threshold [11]. The percolation threshold is greatly influenced by the shape of the conductive filler. For three conventional approximately spherical-shaped fillers, for example, 10-20 wt. per cent loading levels are required to make the composite electrically conductive. When CNTs are used as conductive fillers, a carbon black loading of 8-40% is required for commercialization, but a filler loading of 1-20% is required for optimal exploitation [12,13].

Because a wide range of devices, sensors, and equipment are powered by electricity, the creation and production of a material that successfully conducts electricity have become a critical research topic in modern society [14,15]. Metals have traditionally been widely used in a variety of electric applications due to their superior electrical conductivity and mechanical toughness. Nonetheless, the development of an electrically conductive polymer composite has been highly sought after due to its numerous advantages, which include great chemical stability and corrosion resistance, lightweight, better processability, and low production costs. Conductive fillers such as graphite, carbon fibres, carbon black, metal fibres, graphene, metal powder, carbon nanotubes (CNTs), and others have been utilised successfully in the manufacturing of conductive polymers [16,17]. Graphene has been used in the creation of conductive polymers in all of the conductive fillers mentioned [18,35].

Despite graphene nanoplatelets' (GNP) remarkable characteristics, the performance of their polymer nanocomposites is frequently poor. Nanofiller agglomeration is one of several explanations for this performance failure, but it is currently understudied. The goal of this project is to thoroughly investigate and improve the electrical properties of polyester nanocomposites by reinforcing them with graphene produced from rice husk coated with orange juice-modified green manufactured silver nanoparticles. This study will focus on improved reinforcement distribution within the polymer matrix, avoiding agglomeration, and improving the electrical characteristics of the produced nanocomposites.

2.0 Materials and Method

2.1 Materials

In this investigation, a thermosetting unsaturated polyester resin was used. Petroleum jelly was used as a releasing agent to keep the polyester from adhering to the mould during removal. Other ingredients supplied by Tony Chemical Enterprise, Enugu, Nigeria, include cobalt naphthalate and methyl-ethyl-ketone (MEK) peroxide. Waste rice husks were gathered from rice mills in Abakaliki, Ebonyi State, Nigeria. The rice husk was cleansed and rinsed with tap water to eliminate dirt before being sun-dried for one month before milling into powder (75um) (Figure 1). Cashew leaf extract was used to create AgNPs. The fresh cashew leaves used in this piece came from the Caritas University campus in Enugu State, Nigeria.

Figure1: Photograph of rice husk [34]

2.2 Method

2.2.1 Production of Graphene from Rice Husk

In this work, rice husk (RH) Fig1 was used as a raw material, which is a multi-tonnage and renewable waste in Nigeria. As a typical chemical reagent, KOH was used to create porosity. The method for obtaining graphene oxide from rice husks was modified somewhat from [19]. Pre-carbonization, Desilication, Activation, and Exfoliation are the four phases in the production of graphene from carbonised rice husk (CRH). To remove impurities, the rice husk was pre-carbonized, and the RH was washed numerous times with distilled water before drying for 1 hour at 110°C. RH was carbonised in a rotating reactor in an inert medium at 250-300°C for 45 minutes with an argon supply rate of 5 cm3/min [20,21]. The carbonised (CRH) samples were submerged in 3L of 1M NaOH solution and heated to 110° for 3 hours to remove SiO2, before settling. The solution was decanted to remove the sodium silicate. The solution was then washed 5-7 times with distilled water through boiling, sedimentation, and decantation) to achieve pH 7 equilibrium, then dried for at least 2 hours at 110° in a hot air oven [22,33].

A total of 5 dried CRH samples were mixed with crushed 0.5M KOH for activation. The combinations were crushed in an iron crucible before being annealed at 850° for two hours. To prevent oxidation, argon was supplied at a rate of 5 Standard cubic centimetres per minute (SCCM) (standard cubic centimetre per minute). Following activation, the samples were washed several times with distilled water to achieve a pH of 7, and the filtered samples were dried at 100° for 24 hours. The CRH was exfoliated in hydrogen peroxide (H_2O_2,37%) solution for 48 hours to release laminae of amorphous carbon from the samples. After exfoliation, the samples were washed and dried following the previous tests. The yield was approximately 3% by weight.

2.2.2 Synthesis of Silver nanoparticles (Ag.NPs)

As a reducing agent, cashew leaf extract was used to create the AgNPs. 200g of fresh leaves were washed and dried with distilled water. After 1 hour, 100ml of ethanol was added to the washed cashew leaves, followed by 100ml of AgNO3 solution. The addition of AgNO3 to the cashew leaf extract samples resulted in a rapid colour change from a yellow to a dark brown solution (Figure 3.2). The reaction was left for 30 minutes before heating in an electric oven at 100oC with stirring at a speed of 2000rpm for 1 hour to generate the solid green Synthesized Silver nanoparticles GAgNPs (Fig2) [23].

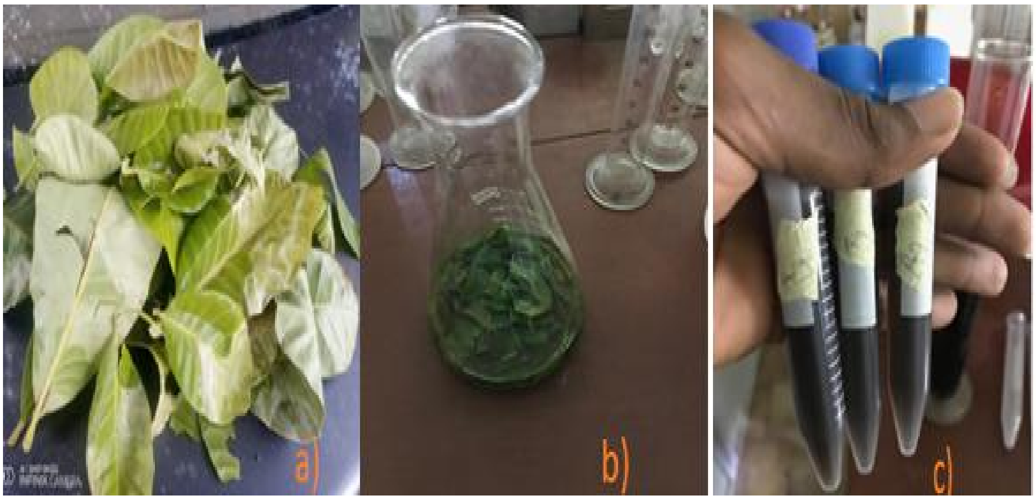

Figure 2: Photograph of the synthesis of Ag-nanoparticles [(a: Cashew leaves) (b: Cashew leaves + $AgNO_3$) (c: Produced GAgNPs)]

2.2.3 Design of Experiments

The experiment was designed using Taguchi's experiment design. Taguchi's methodologies, rather than advanced statistical tools, emphasize the effective implementation of technical concepts. The Taguchi approach to parameter design gives the design engineer a systematic and efficient method for identifying near-optimal design parameters for performance and cost. Taguchi's basic concept is what he refers to as the "noise factor," defined as anything that causes quantifiable product or process attributes to deviate from their desired value. The following are some examples of target values.

Orthogonal Array Selection (OA)

These considerations must be considered while selecting an orthogonal array (OA) to run the tests [24]. (i) The number of relevant parameters and their interactions. (ii) The number of levels available for the relevant parameters.

Non-linear behaviour among process parameters can be studied only when more than two tiers of process parameters are used [25,26]. In this study, each parameter was investigated on three levels. The number of process parameters and their level values is listed in Table 1. The parameter values and levels were set following early experiments to provide a broad enough range for analysing the influence of the variables on the qualities. At room temperature, orange juice (OJ) was employed as a replacement for vitamin C as an environmentally friendly reducing agent to adjust the dimensions of Ag nanoparticles-graphene (GAg.NPs/Gr.NPs) [27].

Table 1: The process parameters for composite blending and their values at various levels.

Process parameters	Low (1)	Medium (2)	High (3)
Gr.NPs(%)	2.5	5.0	7.5
GAg.NPs(%)	0.5	1.0	1.5
Orange juice (OJ)ML	2	4	6
Curing Temperature(°C)	60	80	100

The L9 orthogonal array was formed using the Taguchi technique since we are evaluating four components with three levels each.

2.2.4 Development of Composite Samples

The Gr.NPs were functionalized before sample manufacturing. Gr.NPs were dispersed in orange juice for 30 minutes using an ultrasonic bath sonicator: the process of delivering sound energy to agitate particles, followed by the addition of specific amounts of GAg.NPs (Table 2) [19,28)] The suspension was sonicated for 30 minutes to create a stable brown colloid solution. After that, the reaction was magnetically agitated for 10 hours at 60°C. The hybrid composites were created using the process parameters listed in Table 2, and the nanocomposites were created using the modified solution cast technique.

After curing, petroleum jelly was applied to make the composite simpler to extract from the mould [21,31]. Before reinforcing, 2% cobalt naphthalene (as an accelerator) was completely mixed into the polyester resin with%. Furthermore, post-curing therapy was used to strengthen particle-matrix interaction by training; this procedure is sometimes referred to as a fast treatment [17,32]. The Taguchi design and grey relational analysis were used to develop the composite for maximum performance. Figure 3 depicts the generated composite samples. Taguchi array responses were the yield of a combination of Gr.NPs, GAg.NPs, Orange juice (OJ), and curing temperature. The data was evaluated following the dielectric constant, capacitance, and electrical conductivity tests. The results were translated into S/N ratio values.

Table 2: Orthogonal array of Taguchi Experimental Design layout.

Gr.NPs	Gag.NPs	Orange juice	Temperature
1	1	1	1
1	2	2	2
1	3	3	3
2	1	2	3
2	2	3	1
2	3	1	2
3	1	3	2
3	2	1	3
3	3	2	1
Control			

2.2.5 Electrical Properties Determination

The KAISE Insulation Test (model SK5010) (Figure 3) was used to assess electrical conductivity, capacitor, and dielectric constant. The capacitor and dielectric constant were obtained by adjusting the frequency from 103 to 106Hz. Equation 1 was used to calculate electrical conductivity.

$$\sigma = \frac{1}{\rho} = \frac{d}{(R_p)A} \qquad (1)$$

Equation 2 was used to get the dielectric constant. For maximum performance, the Taguchi design and grey relational analysis were utilized to create the composite. Figure 3 illustrates the composite samples that were generated. The yield of a combination of Gr.NPs, GAg.NPs, Orange juice (OJ), and the curing temperature were the Taguchi array response. Following the dielectric constant, capacitance, and electrical conductivity tests, the data was examined. The results were converted into S/N ratios.

$$\varepsilon^{1} = \frac{C_P(A)}{A(\varepsilon_0)} \quad (2)$$

where: A is the area, d is the thickness, Cp= the capacitance, ϵ_0=dielectric constant of free space, and ϐ=electrical resistivity.

Figure 3: KAISE Insulation Test for the electrical properties

2.2.6 Multi-Response Optimization

Equation 3.3 was used to compute the grey relational generation (GRG) for higher the better from the ranges of $0 \leq S/N \leq 1$

$$X_i(K) = \frac{X_i(K) - \min X(K)_i}{\max X - \min X_{Ii}(K)} \quad (3)$$

Equation 3.4 was used to compute the deviation sequence

$$\Delta_{0i}(k) = |x_0^{\,x}(k) - x_i^{\,x}(k)| \quad (4)$$

Where k = 1 for i = 1 to 9.

The grey relational coefficients (GRC) were calculated from Equation 5

$$\zeta_1(K) = \frac{\Delta_{mm} + \zeta\Delta_{\max}}{\Delta_{0i}(k) + \zeta\Delta_{\max}} \quad (5)$$

Where: (Δoi(k) i,) = deviation from the normalized S/N value, Δmax (1)= maximum normalized S/N ratios, Δmin= minimum normalized S/N ratios, ξ= identification coefficient ($0 \leq \xi \leq 1$, and ξ equal = 0.5 was used.

Equation 6 was used to compute the Grey Relational Grade (GRG).

$$\frac{1}{n}\sum_{k=1}^{n}\zeta_1(k) \qquad (6)$$

Where: Yi= GRG (nth experiment), n= number of performance features.

3.0 Results and Analysis

3.1 Electrical Properties of the Developed Composites

The designed nanocomposite samples were developed and their electrical properties were measured using the KAISE Insulation Tester (model SK5010) Fig 3. The data generated are shown in Table 3.

Table 3: Electrical Properties of the developed composites at various nanocomposite fabrication blends

Gr.NPs	GAg.NPs	Orange juice	Temperature	thermal conductivity $Wm^{-1}K^{-1}$	dielectric constant	electrical conductivity S/m
1	1	1	1	0.9	5.94	9.78E-09
1	2	2	2	1.3	5.45	8.81E-09
1	3	3	3	1.4	4.56	8.67E-12
2	1	2	3	0.9	5.34	9.52E-12
2	2	3	1	1.4	5.67	5.56E-09
2	3	1	2	1.4	4.35	2.54E-08
3	1	3	2	0.8	3.22	2.05E-08
3	2	1	3	1.3	3.56	2.34E-09
3	3	2	1	0.9	5.81	2.54E-09
Control				0.84		

Graphene-polyester nanocomposites are novel materials that exhibit unique electrical properties due to the incorporation of graphene nanoplatelets into the polyester matrix. Graphene is a one-atom-thick layer of graphite with exceptional electrical conductivity, which makes it an attractive material for use in composite materials. The electrical properties of the developed nanocomposites were tuned by varying the concentration and dispersion of graphene within the polyester matrix. The addition of graphene nanoplatelets to the polyester matrix significantly increased the electrical conductivity of the composite. This is due to the high intrinsic electrical conductivity of graphene combined with its large surface area, which allowed for efficient electron transport through the material. The developed nanocomposite also exhibited a high dielectric constant, which is a measure of the material's ability to store electrical energy. The dielectric constant of the composite was tuned by varying the concentration and dispersion of graphene within the matrix. This property makes graphene-polyester nanocomposites useful for applications such as capacitors and energy storage devices.

The electrical conductivity of the graphene/polyester nanocomposite is influenced by several factors, including the concentration and size of graphene particles, the quality of graphene dispersion, and the type of polymer used. The electrical conductivity of the developed nanocomposite increased as graphene concentration increased, resulting in a percolation threshold where a continuous conductive network was formed. The size of graphene particles impacted the electrical conductivity. Smaller particles are known to exhibit higher conductivity because they provide a greater surface area for electron transfer. The quality of graphene dispersion in the polymer matrix also played a significant role in the electrical conductivity of the nanocomposite. Poor dispersion of graphene particles hinders the formation of a continuous conductive network, leading to decreased conductivity.

3.2 Multiple response optimization

The processing parameter was optimized using Taguchi Grey relational analysis. The output responses of thermal conductivity, electrical conductivity, and dielectric constant were chosen due to the projected area of the utilization of these developed nanocomposite materials. The input variables for the study were Gr.NPs, GAg.NPs, Orange juice, and curing temperature. (Table 3). Table 4 displays the results of the L9 Taguchi method's grey relational generation and deviation results.

Table 4: Grey relational generation and deviation

S/NO	**Grey relational generation**			**Deviations**		
	Thermal conductivity	Dielectric constant	Electrical conductivity	Thermal conductivity	Dielectric constant	Electrical conductivity
1	0.16666666	1	0.38551229	0.83333333	0	0.61448770
2	0.83333333	0.81985294	0.34731028	0.16666666	0.180147059	0.65268971
3	1	0.49264705	0.00068291	0	0.507352941	0.99931709
4	0.166666667	0.7794117	0.00071638	0.83333333	0.220588235	0.99928361
5	1	0.90073529	0.21931383	0	0.099264706	0.78068616
6	1	0.41544117	1	0	0.584558824	0
7	0	0	0.80770365	1	1	0.19229634
8	0.83333333	0.12500000	0.09249889	0.16666666	0.875000000	0.90750110
9	0.16666666	0.95220588	0.10037560	0.83333333	0.047794118	0.89962439

The results of the Grey Relational Grade (GRG) and Grey relational coefficient are given in Table 5.

Table 5: Grey Relational Coefficient (GRC) and Grey Relational Grade (GRG)

S/NO	**Grey relational coefficient**			**Grey Relational Grade (GRG**
	Thermal conductivity	Dielectric constant	Electrical conductivity	
1	0.66666666	0.250000	0.557243851	0.491303506
2	0.33333333	0.340074	0.576344859	0.416583907
3	0.25000000	0.503676	0.749658545	0.501111672
4	0.66666666	0.360294	0.749641807	0.592200864
5	0.25000000	0.299632	0.640343082	0.396658478
6	0.25000000	0.542279	0.250000000	0.347426471
7	0.75000000	0.750000	0.346148173	**0.615382724**
8	0.33333333	0.687500	0.703750552	0.574861295
9	0.66666666	0.273897	0.699812200	0.546791975

3.3

Relationship Diagram in Grey

Figure 4 depicts the grey relational grade diagram, and the grey relational grade mean is depicted on the centre line. The four variables under investigation show no discernible pattern. The electrical conductivity, dielectric constant, and thermal conductivity are all affected by the higher grey relationship grade in the wt per cent Gr. The grey relational grade increased as the weight per cent Gr.NPs increased from level 1(2.5) to level 3(7.5), but the weight per cent Ag.NPs decreased from level 1(0.5) to level 3. (1.5). The increase in GRG above level 1 may be due to weak interfacial adhesion between the epoxy resin and reinforcement (Ag.NPs). The evolution of Gr.NPs-Ag.NPs conductive network topologies and 3-D dense structures in the polyester matrix were linked to an increase in the grey relational grade, which coincided with increases in the weight per cent Ag.NPs at level 1 and Gr.NPs at level 3. The conductive pathways in the polyester matrix allow charge carriers in the system to travel fast. The ohmic and non-ohmic conduction caused by the Gr.NPs direct Ag.NPs contact with the polyester resulted in indirect contact between the Gr.NPs-Ag.NPs and the matrix [29)]

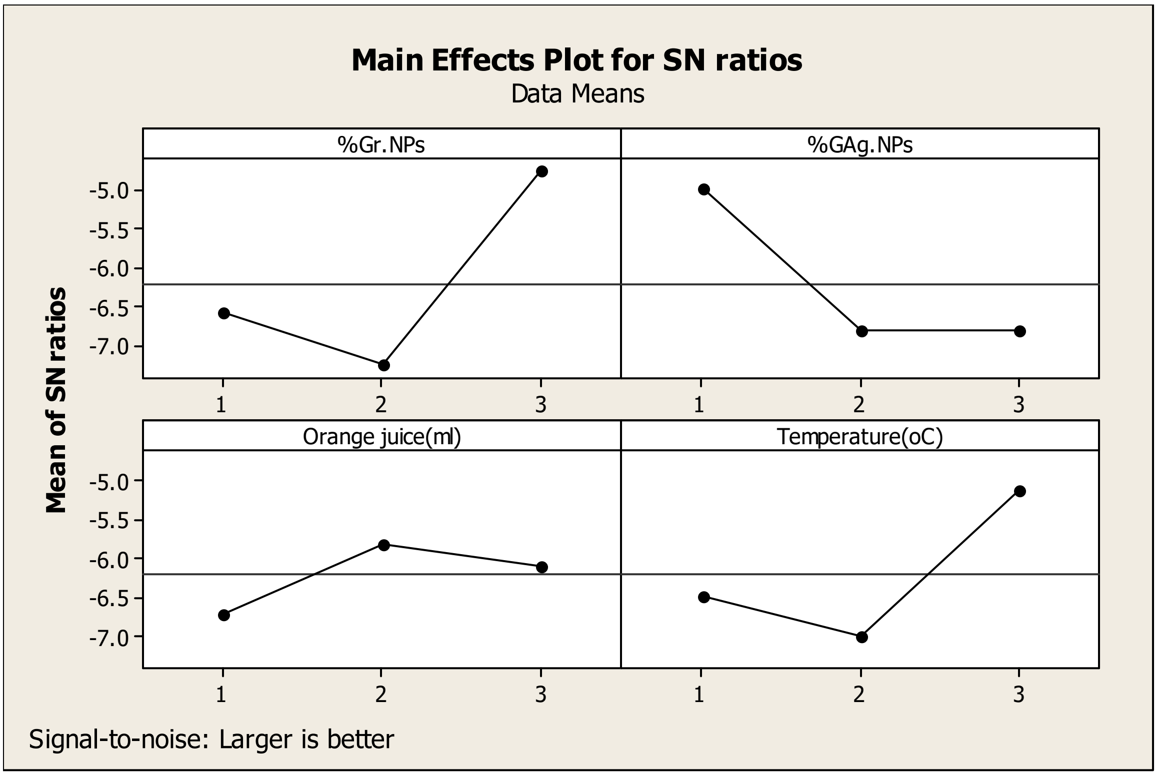

Figure 4: Grey relational grade diagram for the multi-response

While increasing the volume (ml) of orange juice as the reduction agent from level 1(2) to level 2(4) and decreasing to level (6) level 3, the curing temperature increased the GRG from level 1 (60 ^{o}C) to level 3 (60 ^{o}C) (100 ^{o}C). Thermal curing composites improve their heat stability and setting. The study found that as the temperature rose to 100 ^{o}C, electrical conductivity, dielectric constant, and thermal conductivity all increased. The GRG grew clearly as the curing temperature increased.

3.4 Response Surface Analysis

An investigation of surface response was used to further examine the impact of the four parameters on the GRG. Figures 5a-5e illustrate the various plots of the surface response developed in this experiment. Figures 5a-5b demonstrated that the GRG was marginally reduced as the percentage of Ag.NPs increased from level 1 to level 3. A similar finding was observed in the study [30], implying that a higher weight percentage of Ag.NPs than the ideal may not have any beneficial effects. Figures 5a-5c indicate that at the highest amount of %Gr.NPs, electrical conductivity, dielectric constant, and thermal conductivity all increased. Figures 5b-5c clearly illustrate that temperature had a substantial impact. The maximum concentration of Gr.NPs and Ag.NPs improved the electrical properties of composite materials and increased their thermal conductivity. The orange was found to be a reducing agent in the plots. Figure 7e shows how the four factors interact to affect electrical conductivity, dielectric constant, and thermal conductivity. The greatest electrical conductivity, dielectric constant, and thermal conductivity values were discovered to be at level 1 for Ag.NPs (0.5%), level 3 for Gr.NPs (7.5%), level 3 for curing temperature (100 ^{o}C), and level 2 for orange juice (4 ml).

The increased electrical conductivity found may be due to the greater surface area to volume of the AgNPs, which contributes to the creation of conductive pathways in the polymer resin. The high thermal conductivity of the Ag.NPs was attributed to the rise in the thermal conductivity of the polyester-Ag.NPs+Gr.NPs. The Ag.NPs aid the matrix network, boosted phonon conduction, reduced boundary scattering, and improve the conductance of the Gr.NPs.

Ag.NPs were discovered to be promising materials for increasing the electrical and thermal conductivity of polyester-Gr.NPs nanocomposites.

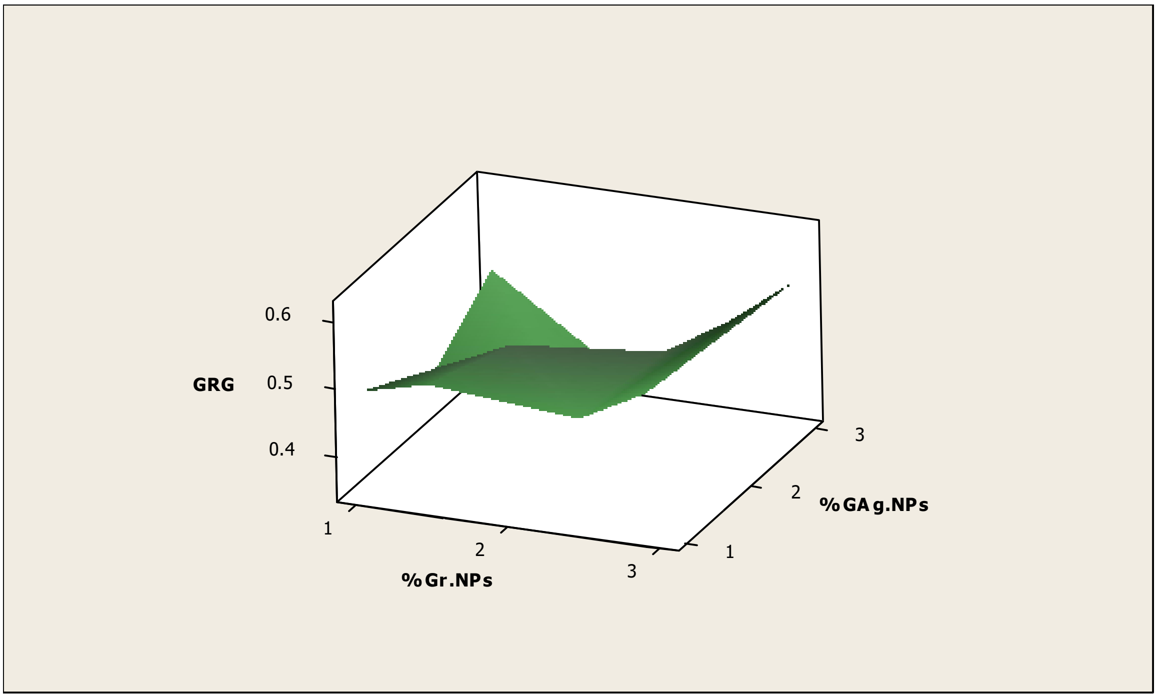

Figure 5a: Response plots of GRG with %Gr.NPs and %Ag.Nps

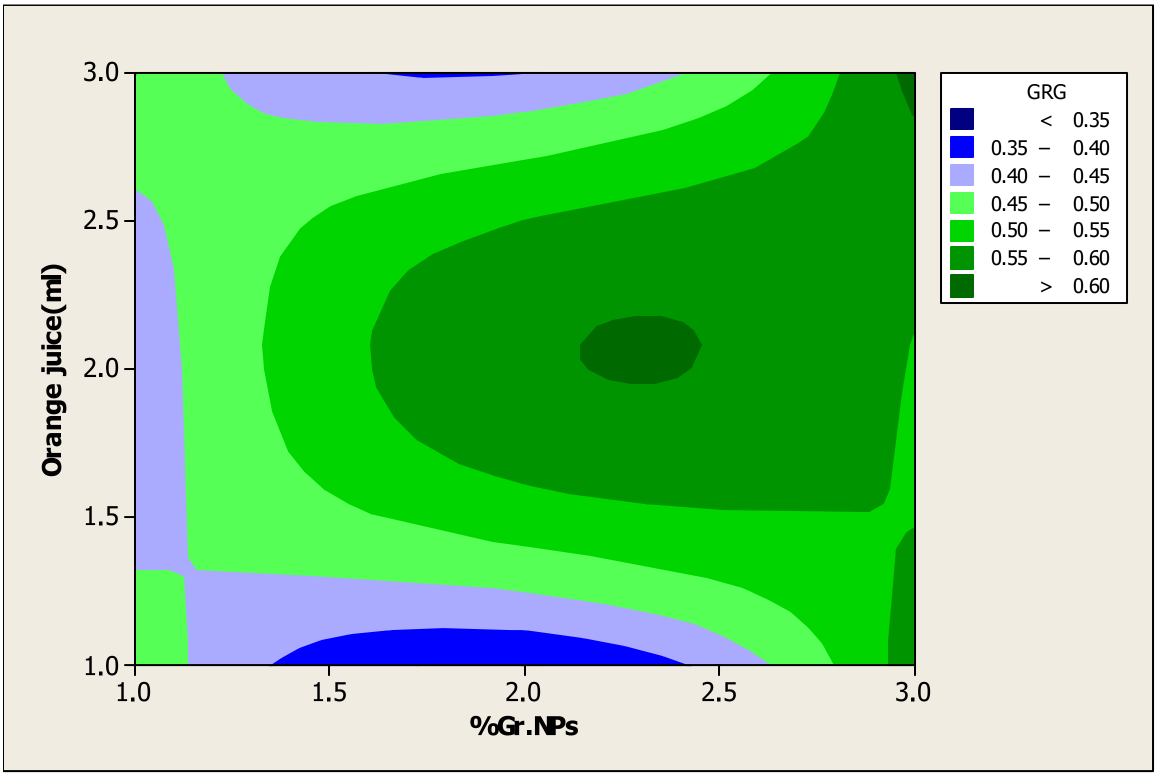

Figure 5b Response plots of GRG with %Gr.NPs and orange juice(ml)

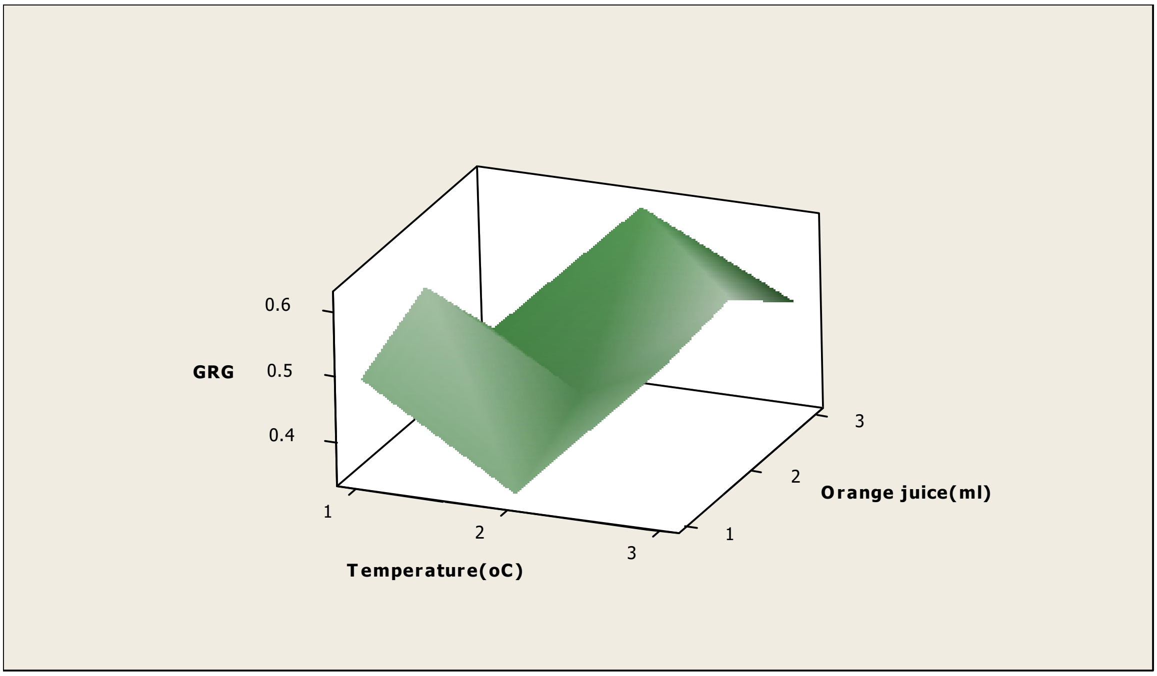

Figure 5c: Response plots of GRG with curing temperature and orange juice

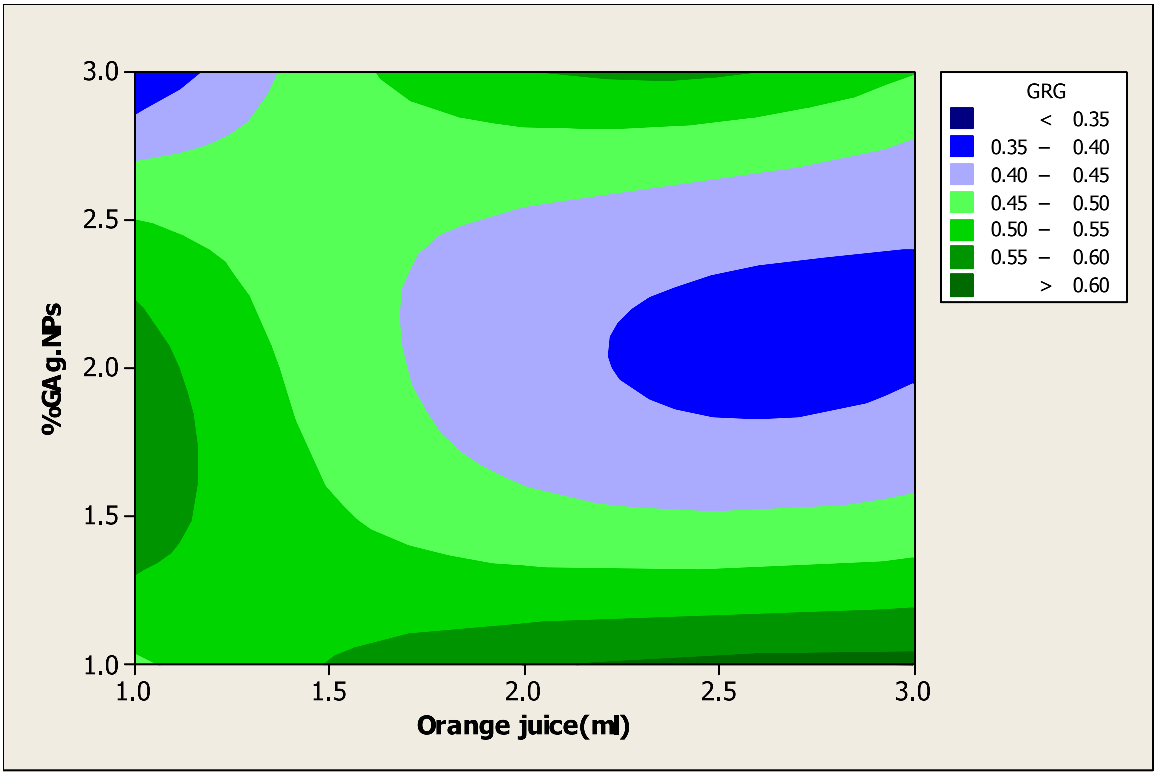

Figure 5d: Response plots of GRG with Ag.NPs and orange juice

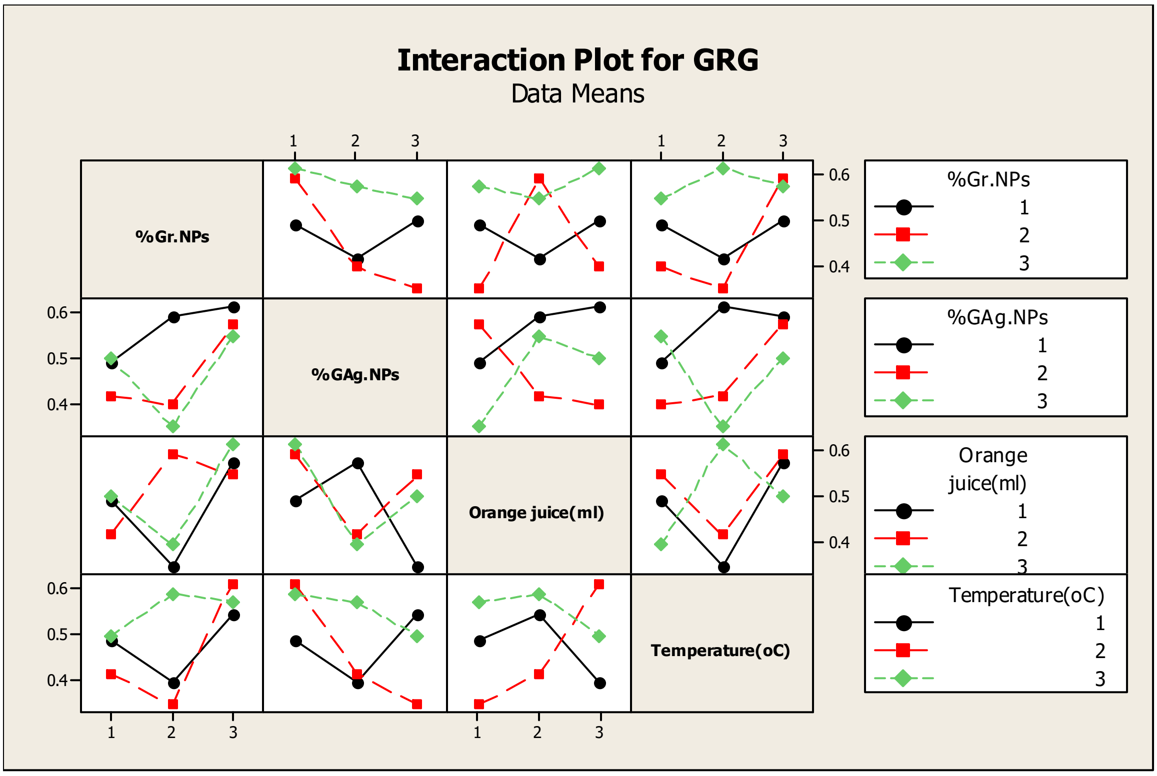

Figure 5e: Interaction plots of GRG with Gr.NPs, Ag.NPs curing temperature and orange juice

3.5 The optimum GRG configuration

Table 6 displays the mean-to-mean values for the GRG. Table 6 was used to select the best study setting. The %Gr.NPs had the highest delta values, ranking first with the highest value at level 3 (0.1336), followed by the % GAg.NPs with the second-highest setting at level 1 (0.1036), the Curing temperature with the third-highest setting at level 3 (0.0963), and the Orange juice(ml) with the lowest delta values, ranking fourth with the lowest value at level 2 (0.1336). (0.4741). As a result, high electrical and thermal conductivity has a greater impact on electrical conductivity, dielectric constant, and thermal conductivity in the order of % Gr.NPs, % GAg.NPs, curing temperature, and Orange juice (ml). The best settings for this experiment are %Gr.NPs (level 1),%GAg.NPs (level 1), curing temperature (level 3), and Orange juice (level 2). (Table 7). As a result, the best circumstances are 7.5% Gr.NPs, 100 ^{o}C curing temperature, 0.5% GAg.NPs, and Orange juice (2 ml).

Table 6: Response Table of Means for GRG

Level	**%Gr.NPs (A)**	**%GAg.NPs (B)**	**Orange juice(ml(C)**	**Curing temperature(D)**
1	0.4697	**0.5663**	0.4712	0.4783
2	0.4454	0.4627	**0.5185**	0.4598
3	**0.5790**	0.4651	0.5044	**0.5561**
Delta	0.1336	0.1036	0.0473	0.0963
Rank	**1**	**2**	**4**	**3**

The Mean of the GRG value is 0.498

Equation 7 shows the predicted GRG values under ideal conditions.

Predicated GRG= 0.498+(0.579 -0.498) +(0.566- 0.498) +(0.519- 0.498) +(0.556- 0.498) (7)

Predicated GRG =0.498+0.081+0.068-0.021+0.058

Predicated GRG=0.724

The values of the experimental and predicted grey relational generation are expressed in Table 7 using the process parameters' optimal levels and the GRG levels under ideal conditions.

Table7: Process Parameter Optimum Levels

Process parameter	**Parameter designation**	**Optimal level**	**GRG**	
%Gr.NPs	A	L3 (7.5 %)	Prediction	Experiment
%Ag.NPs	B	L1 (0.5 %)	**0.724**	**0.615**
Orange juice(ml)	C	L3 (100°C)		
Curing temperature	D	L2 (4ml)		

The following are the findings of an experiment using the ideal processing settings: electrical conductivity (2.08 x10-8 S/m) and dielectric constants (5.95). as well as thermal conductivity (1.45 Wm-1K-1). The values of the ideal state are within the range that is suitable for microelectronic devices. The enhanced thermal conductivity was attributed to a reduction in the thermal barrier that existed in the composites system between the polyester and the Gr.NPs-GAg.NPs. When Gr.NPs, Ag.NPs and polyester were positioned in the ideal area, they had a favourable synergistic effect on electrical and thermal conductivity. The thermal conductivity of an Ag-NPs deposited Gr.NPs were improved by the interfacial thermal resistance. The thermal conductivity of the resultant composites was improved. This method could be used to create thermally conductive polymer composites as well as applications for future electronic packaging. The composite has been discovered to have a low dielectric loss and strong electrical conductivity due to the Coulomb barrier provided by the Ag nanoparticles in the polymer. The experimental grey relational grade of 0.615 is within the confidence range because of the expected ideal grey relational grade of 0.724. (95 per cent). This validated the usefulness of the discovered optimal processing parameters, as shown in Fig 7f. This proved the efficacy of the optimal processing parameters determined.

3.6 Analysis of Variance and Regression Model (ANOVA)

Table 8 shows the Results of ANOVA for GRG. The optimal setting results in Table 7 were supported by the results of ANOVA for GRG, showing a direct relationship. From Table 8 it could be seen that Gr.NPs contributed the most to GRG (40.71% with the lowest P-value), followed by Ag.NPs (34.94%), curing temperature (20.62%), and orange juice (3.75%). This study yielded a mean of 0.45, a standard deviation of 0.042, a Pred R-Squared of 0.9571, and an Adj R-Squared of 0.9643. The Pred R-Squared is near the Adj R-Squared, indicating that the model has physical and statistical importance and can be utilized to explore the design space.

Table 8: Results of ANOVA for GRG

Source	Sum of squares	DF	Sum of mean	F-value	P-value	%Contribution
Regression	0.0440254	4	0.0110064	1.65877	0.317974	
Gr.NPs	0.0179347	1	0.0179347	2.70294	0.175508	40.71
Ag.NPs	0.0153578	1	0.0153578	2.31458	0.202814	34.94
Orange juice	0.0016521	1	0.0016521	0.24899	0.643984	3.75
Curing temperature	0.0090808	1	0.0090808	1.36857	0.307007	20.62
Error	0.0265410	4	0.0066353			
Total	0.0705664	8				

Equation 8, gives the model regression equation;

GRG = 0.378882 + 0.0546728 %Gr.NPs - 0.0505928 %GAg.NPs + 0.0165936 Orange juice (ml) + 0.0389033Temperature(°C) (8)

The coefficients for Gr.NPs, curing temperature, and orange juice are all positive; however, the coefficient for Ag.NPs are negative, meaning that raising the Ag.NPs reduced the GRG. The actual values are close to the projected values in Fig 5f since the points were randomly distributed along the line. This demonstrates the model's significance.

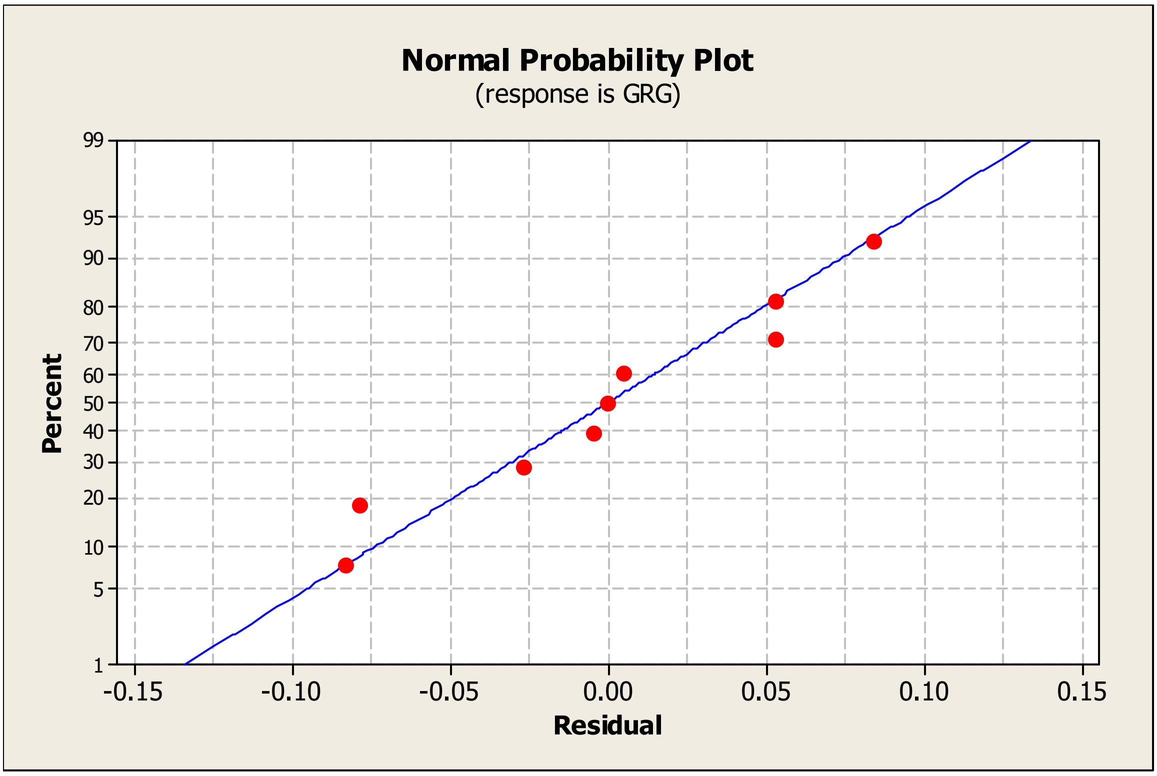

Figure 5f: Normal probability plot for the GRG

4.0 Conclusions

The Taguchi-grey experiment revealed new insights into the production of high Dielectric materials and the high thermal conductivity of polyester-Gr.NPs modified with Ag.NPs. During the project, the following conclusions were reached. Polyester reinforced with Gr.NPs modified with Ag.NPs and orange juice composite were successfully produced using the solution stir cast method. The optimal condition of the composite was obtained at 7.5%Gr. NPs, 0.5%Ag. NPs, 100 ^{o}C curing temperature, and 4ml orange juice. The high electrical and thermal conductivity, and dielectric constant obtained in optimal conditions were attributed to the high electron mobility of Ag.NPs-Gr.NPs help to enhance the conductivity of the polyester. The experimental grey relational grade of 0.615 is within the confidence interval (95%) of the predicted optimal grey relational grade of 0.724. This validated the efficacy of the obtained optimal processing parameters. The electrical conductivity (2.08 x10^{-8} S/m), and dielectric constants (5.95). and thermal conductivity (1.45 $Wm^{-1}K^{-1}$). The values obtained for the optimal condition are within the acceptable limit for microelectronic devices A 92.35 per cent increase in tensile strength of the pure polyester was obtained in comparison to polyester-7.5 %Gr.NPs +0.5%Ag.NPs. Waste rice husk was used effectively in the production of graphene nanoparticles for the production of conducting polymer. It was established that Ag.NPs synthesized using cashew leaf extract were effective at ensuring good dispersion of Gr.NPs for the production of conductive polymer. Orange juice is an effective replacement for vitamin C (ascorbic acid), as a nontoxic reducing agent dimensions control of Ag.NPs on Gr.NPs. The developed composite is suitable for application in the production of microelectronic devices

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and material

Not applicable

Competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Funding

The author received no funding for this study.

Author’s contribution

EME conceived and initiated the research work, sourced the literature and materials and developed the article, and ACP performed the instrumentation.

Acknowledgements

This work received administrative support from the Department of Chemical Engineering, Caritas University Enugu, Nigeria.

References

[1] Xiang Y, Xin L, Hu J, Li C, Qi J, Hou Y, et al. Advances in the applications of graphene-based nanocomposites in clean energy materials. Vol. 11, Crystals. 2021.

[2] Ramalingam RJ, Al-Lohedan H, Tawfik AM, Periyasamy G, Muthumareeswaran MR. Synthesis and characterization of mos2 –graphene oxide on ni-co-mno2 nanofiber-like binary composite for nickel foam-based flexible electrode fabrication. Chalcogenide Lett. 2020;17(8).

[3] Smith AT, LaChance AM, Zeng S, Liu B, Sun L. Synthesis, properties, and applications of graphene oxide/reduced graphene oxide and their nanocomposites. Nano Mater Sci. 2019;1(1).

[4] Elkady OA, Yehia HM, Ibrahim AA, Elhabak AA, Elsayed EM, Mahdy AA. Direct observation of induced graphene and sic strengthening in al–ni alloy via the hot pressing technique. Crystals. 2021;11(9).

[5] Szeluga U, Pusz S, Kumanek B, Olszowska K, Kobyliukh A, Trzebicka B. Effect of graphene filler structure on electrical, thermal, mechanical, and fire retardant properties of epoxy-graphene nanocomposites - a review. Vol. 46, Critical Reviews in Solid State and Materials Sciences. 2021.

[6] Ramalakshmi V, Balavijayalakshmi J. Decoration and functionalization of graphene oxide nanocomposites for sensing applications. In: Materials Today: Proceedings. 2019.

[7] Zhou R, Li X, Pang H. VOx/VSx@Graphene nanocomposites for electrochemical energy storage. Vol. 404, Chemical Engineering Journal. 2021.

[8] Yao H, Wu LP, Chen GQ. Synthesis and Characterization of Electroconductive PHA- graft-Graphene Nanocomposites. Biomacromolecules. 2019;20(2).

[9] Bilisik K, Akter M. Graphene nanocomposites: A review on processes, properties, and applications. Journal of Industrial Textiles. 2021.

[10] Ikram R, Jan BM, Vejpravova J, Choudhary MI, Chowdhury ZZ. Recent advances of graphene-derived nanocomposites in water-based drilling fluids. Vol. 10, Nanomaterials. 2020.

[11] Feng H, Bao M, Lian M, Li G. Glypican-3 electrochemical aptasensor based on CuO-rGO nanocomposite. In: Journal of Physics: Conference Series. 2021.

[12] Arifin NFT, Yusof N, Nordin NAHM, Bilad MR, Jaafar J, Ismail AF, et al. Comparison of different activated agents on biomass-derived graphene towards the hybrid nanocomposites with zeolitic imidazolate framework-8 for room temperature hydrogen storage. J Environ Chem Eng. 2021;9(2).

[13] Fatihah N, Arifin T, Yusof N, Fauzi Ismail A, Jaafar J, Aziz F, et al. Graphene from waste and bio precursors synthesis method and its application: A review. Vol. 16, / Malaysian Journal of Fundamental and Applied Sciences. 2020.

[14] Arifin NFT, Yusof N, Adam MR, Pauzan MAB, Md Nordin NAH, Ismail AF, et al. Optimization of Hydrogen Storage at Ambient Temperature Via Central Composite Design Using Hybrid Nanocomposites of Zeolitic

Imidazolate Frameworks-8 Incorporated Rice Husk Graphene-Like as Adsorbent. SSRN Electron J. 2022;

[15] Liou TH, Tseng YK, Liu SM, Lin YT, Wang SY, Liu RT. Green synthesis of mesoporous graphene oxide/silica nanocomposites from rich husk ash: Characterization and adsorption performance. Environ Technol Innov. 2021;22.

[16] Ezeh EM, Onukwuli OD. Comparative Cone calorimetric analysis of the fire retardant properties of natural and synthetic additives in banana peduncle fibre reinforced polyester composites. Moroccan J Chem. 2021;9(3).

[17] Ezeh EM, Onukwuli OD. Physicochemical characterization of cow horn ash and its effect as filler material on the mechanical property of polyester-banana fibre composite. World J Eng. 2020;17(6).

[18] Zhu P, Weng L, Zhang X, Wang X, Guan L, Liu L. Graphene@poly(dopamine)-Ag core–shell nanoplatelets as fillers to enhance the dielectric performance of polymer composites. J Mater Sci. 2020;55(18).

[19] O.D. O, Ezeh EM. Assessment of the fire retardant effect potential of carbonized cow horn ash additive in banana peduncle fibre reinforced polyester composites. World J Eng. 2021;

[20] Somasekaran B, Thirunarayanaswamy A, Palanivel I. Green synthesis of clean edge graphene nanosheets using natural precursor. Mater Plast. 2021;58(3).

[21] Ernest E, Onyeka O, C. M. A, C. C. A, J. O N. Adsorption Efficiency of Activated Carbon Produced from Corn Cob for the Removal of Cadmium Ions from Aqueous Solution. Acad J Chem. 2019;(44).

[22] Liang S, Yu K, Li Y, Liang C. Rice husk-derived carbon@SnO2@graphene anode with stable electrochemical performance used in lithium-ion batteries. Mater Res Express. 2019;7(1).

[23] Naik MJP, Debbarma J, Saha M, Bhargava A. Graphene oxide nanoflakes from various agro wastes. Materwiss Werksttech. 2020;51(3).

[24] Arifin NFT, Yusof N, Ismail AF, Jaafar J, Aziz F, Wan Salleh WN. Graphene from waste and bio precursors synthesis method and its application: A review. Vol. 16, Malaysian Journal of Fundamental and Applied Sciences. 2020.

[25] Yeleuov M, Seidl C, Temirgaliyeva T, Taurbekov A, Prikhodko N, Lesbayev B, et al. Modified activated graphene-based carbon electrodes from rice husk for supercapacitor applications. Energies. 2020;13(18).

[26] Ezeh EM, Onukwuli OD, Odera RS. Novel flame-retarded polyester composites using cow horn ash particles. Int J Adv Manuf Technol. 2019;103(5–8).

[27] Muramatsu H, Kim YA, Hayashi T. Synthesis and characterization of graphene from rice husks. Carbon N Y. 2017;114.

[28] Singh P, Bahadur J, Pal K. One-Step One Chemical Synthesis Process of Graphene from Rice Husk for Energy Storage Applications. Graphene. 2017;06(03).

[29] Seitzhanova MA, Mansurov ZA, Yeleuov M, Roviello V, Capua R Di. The characteristics of graphene obtained from rice husk and graphite. Eurasian Chem J. 2019;21(2).

[30] Tay CH, Norkhairunnisa M. Mechanical Strength of Graphene Reinforced Geopolymer Nanocomposites: A Review. Vol. 8, Frontiers in Materials. 2021.

[31] OD Onukwuli, EM Ezeh, RS Odera. Effect of different chemical treatments on the properties of banana peduncle fibres Journal of the Chinese Advanced Materials Society 2018; 6 (4), 755 765.

[32] EM Ernest, AC Peter. Application of selected chemical modification agents on banana fibre for enhanced composite production Cleaner Materials 2022;5, 100131

[33] RS Odera, OD Okechukwu, EM Ezeh, MC Menkiti, PC Agu.The exchange of Musa spp. in fibre composite fabrication: a systematic review Bulletin of the National Research Centre. 2021; 45(1), 1-18

[34] Ezeh, E M. Assessment of selected Properties of Rice Husk -Derived Graphene - Modified with Green Synthesized Silver Nanoparticles / Polyester Nanocomposite. Caritas Journal of Engineering Technology. 2023 2 (1), 18-41

[35] EM Ezeh. Assessment of the fire-retardant effect potential of carbonized cow horn ash additive in banana peduncle fibre reinforced polyester composites. World Journal of Engineering 20 (3), 399-408