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A grey relational analytical approach to orange peel filler particulates for tapped density experiments of green composite reinforcements

Oluwaseyi Ayodele Ajibade[1], Johnson Olumuyiwa Agunsoye[1] and Sunday Ayoola Oke[2]*

[1]Department of Metallurgical and Materials Engineering, University of Lagos, Lagos, Nigeria.
[2]Department of Mechanical Engineering, University of Lagos, Lagos, Nigeria.

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Abstract

Monitoring density changes during transportation of composite fillers is the principal reason for composite industries implementing the tapped density concept. Till date, very sparse literature information exists on tapped density optimisation for orange peel particles (OPPs). A unique application of grey relational analysis (GRA) in the optimisation of tapped process parameters for OPPs is contributed in this paper. Experimental results on the principal process parameters indicate $G_1H_1I_2J_3$ as the best experimental run, which translates to 257.956 g and 78.076 cm^3 as well as 254.939 g and 72.94 cm^3 for masses and volumes of the 0.425 and 0.600 mm OPPs, respectively. In addition, Taguchi method was applied to arrive at an optimal parametric setting of $G_2H_2I_1J_1$ for comparative purposes which translate to 257.723 g and 75.031 cm^3 for mass and volume of the 0.425 OPPs, as well as 254.952 g and 77.982 cm^3 for the mass and volume of 0.600 mm OPPs. By comparison, the GRA values produced positive percentage improvement over other optimal values. The unique contribution of this paper are principally the (i) application of GRA in a novel manner, incorporating harmonic mean in factor-level determination and computation of S/N responses; (ii) development of new indices of tapped density; and (iii) introduction of economic factors in tapped density computations, incorporating inflation and interest factors. The practical utility of the demonstrated approach lies in reducing the uncertainties about density measurements in the transportation of green fillers for use as composite reinforcements.

Keywords: Optimisation, Grey relational analysis, Taguchi method, Economic factors

1. Introduction

In the past several years, green fillers have been well-recognised as strategic materials, used as effective weapons to reduce environmental hazards [1-3], as reinforcements in composite manufacturing. The rapid advancement and industrialisation globally, with restrictions of manufacturing impacts on environments have given green fillers a leading edge in composite manufacture. Furthermore, these organic fillers have been well known for cost-cutting activities during manufacturing-related processes of composite manufacture and even in the life-cycle process of composites in the current era of material revolution. Green fillers have been used with matrices to produce with success, high performance composites. They have become commercially-important both in household and industrial settings due to other potential benefits that they have, such as abundant availability at sources, low density, ability to be degradeable in addition to low cost and reduced health hazards. The wide spectrum of organic materials with the above-mentioned attributes includes rubber wood flour [4], and wastes of orange, coconut, pineapple, oil palm, kenaf, sugarcane, betel nut, sisal, jute, cotton, borassus and bamboo [5], flax [6]. Green fillers stems from their so-called bio-degradability and bio-material nature, which are terms coined for their ability of being able to decompose after use as opposed to non-biodegradable plastics and metals that retain their forms almost perpetually.

Green fillers are strategically-positioned to help design engineers improve the properties of their composites when used as reinforcing agents in terms of mechanical, physical, chemical, thermal, rheological etc. It is not within the scope of the current work to explore avenues of improving the mechanical, chemical, thermal and rheological properties of orange peels and their particulates (see [7]), which is the material of choice for investigation. However, the most important physical property for powdered materials that is always in transit, being transported for use from one place to another, in terms of tapped density (see [8]) is investigated for orange peel particulates.

From the literature on green fillers, it has been undoubtedly demonstrated that some physical properties of orange peel particulates (OPPs) are promising and need to be studied. For instance, the free-swell behaviour and water resistance of OPPs and the positive influence that they have on the mechanical properties of the green filler have been of increasing interest of researchers in the recent times. As such, an extensive understanding of physical properties of OPPs as

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*Corresponding author.
Email address: sa_oke@yahoo.com
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a first step toward radically changing and improving on other properties of OPPs, is yet unknown. However, after an extensive literature search concerning the physical properties of OPPs, it was found that research lacks deep explanations relevant how tapped density could be optimised [9-12] and used to the best advantage of OPPs in transportation activities, in reality and by implication, during an effort to fabricate composites composed of particulate orange peels. In other words, there are strong doubts that previous researchers have been motivated into evaluating the optimal condition in which OPPs are placed when trying to understand its tapped density. Even if reports were previously given on tapped density of OPPs, they are scanty and not yet in regular prints. In reality, the design engineer may rely more on tapped density than normal density in order to make decisions on green fillers, particularly only when it involves the transportation of the powders (fillers) for composite development. The green fillers at this time are subject to quite a number of factors, including compressibility, particle size variations, compactibility, etc and these in combination dictate the values of the tapped density for the green filler. The factors could be tamed through optimisation procedures.

Motivated by the afore mentioned issues, in the current study, orange peel particulates were used in tapped density experiments, in which the compaction, compressibility and other behaviour of the orange peel composites were implied. Grey relational analysis involving the development of grey relational coefficients, S/N ratios, S/N response table and more were made [13-15]. The harmonic method of means was used to evaluate the factor/levels and the S/N response table. Two methods of grey relational analysis were adopted in this study. There is a wide recognition of grey relational analysis (GRA) as being an outstanding statistical technique with powerful ability in revealing complicated interrelationships of multiple engineering factors, in composite design and development. In establishing an understanding of this relationship, grey relational analysis could perform reasonably well with minimal data requirement [13-16]. Another outstanding benefit of GRA is that for the compared series, the influential degree on the so called reference series, denoted as the relative space between these entities, measured as imaging grey-space [16-17]. Keeping in view the advantages of the GRA and the complex nature of the tapped density problem, involving factors of compressibility, compaction, grain size variation, among others, it is expected that the application of GRA to tapped density process parameters could serve as a useful avenue for the achievement of optimal parametric values and for parametric analysis and evaluation process. Consequently, the current study aims at applying the GRA for the process parametric optimisation of the tapped density process.

The key contributions of the article are listed hereunder:

- Proposing a novel approach of modified grey relational analysis, incorporating harmonic means method of factor/level and S/N response determination in the evaluation of optimal conditions for tapped density optimisation based on Fung's [28] framework.
- For the first time, analyzing the optimal tapped density of particulate orange peels using grey relational analysis of 0.425 and 0.600 mm sizes of specimens
- Comparing the obtained results with the output of Taguchi's experimental results.

The remaining part of this article are organised as follows. The literature review is the next section following the introduction. Then is the section on materials and methods containing the materials, methods (the experimental procedure, setup, including equipment for the experiments and the method of investigation), some discussions on grey relational analysis, experimental design and the Taguchi optimisation. The fourth section concerns itself with compressibility/compactibility and associated indices. Section five contains the conclusions from the experiments analysed and discussed in a scientific manner earlier. It indicates the concluding remarks and future scope.

2. Literature review

A brief review of literature related to the current work is presented here. Aigbodion et al. [7] experimentally investigated composites with the use of particulate orange peels in uncarbonised and carbonized forms. Accordingly, the investigation studied the mechanical as well as microstructural properties of the formulated composite. They came to the assertion that the particulate orange peels were uniformly distributed in the examination of the microstructure of the composite developed. The authors came to the conclusion that the wastes from the orange peels are eco-friendly, biodegradable from the fabricated composites. Nevertheless, they failed to explore the effect of compactness or compressibility of the mechanical properties of the composite formed bearing in mind that the particulate orange peels changes in density as they are transported from one place to another during effort to fabricate composites.

Acharya and workers [18-20] in descriptive reports analysed and experimentally determined mechanical properties and erosive wear behaviour of OPPs using localised varieties from India. In the first report, Kumar [20] concluded that good bonding existed between orange peel fiber and the matrix from the results of the SEM, which revealed breakage of the fibers as opposed to fiber pull-out. Furthermore, the flexural strength and tensile strength were highest at 20 % wt of orange fiber while the hardness value of the composite increased with increased fiber content. For the second article, Ojha et al. [19] investigated the mechanical properties of OPPs in depth. However, the author's focus excluded optimization issues. Acharya's group fostered more investigations committed to orange peel fiber composite experimental testing. The third investigation by the Archarya's group [20] was not much different in philosophy compared to Ojha et al.'s [19] report. Kishor and Naidu [21] investigated the effects of orange filler loading on the physical as well as the mechanical performance of jute fibre reinforced epoxy-based composites. A significant effect of filler loading on the performance of the hybrid composite fabricated was reported. However, the investigators did not expatiate on density apart from the assertion that the filler loading did not influence the density of the specimen. In fact, the influence of compaction to which tapped density is related was not explored. In their review of relevant literature, the research workers scarcely referred to orange peel composites despite the few available literature sources on the subject.

From the review of literature highlighted above, it appears safe to claim that mechanical and physical properties can be beneficial for the improvement of the lifespan and real-life performance of OPPs. However, it is not clear, in what way the density for powdered fillers in seperation from the composites from the composites could influence other properties such as flexural and impacts since tapped density is not yet optimised in all the situations encountered in literature.

An analysis of the literature reveals some finding, which provoke deeper investigation in experimental analysis. Of particular note, the literature review appears to show that: (1) orange peels and their particulate forms could be used for fabricating polymer composites with acceptable quality characteristics in terms of tensile strength, impact strength and flexural strength. (2) by implication, the tapped density of the aforementioned properties may be improved upon in a meaningful way if explored since it is known that some transportation of some sorts are possible for the particulate orange peel particulates from the location of grinding to that of composite fabrication and some compaction, minimal and insignificant may have taken place during the transit of the particulates. The effects may be in a positive manner. (3) the current debate in literature is restricted to measured and theoretical density investigations on orange peel particulate composites. A situation in which the tapped density, indicating the relative compactment and compressibility as well as effect of particle sizes and other factors on bi- or multi-fillers such as orange peel particulates and particulates of coconut shell or other filler of varying characteristics has not been reported in literature. (4) the literature contains discussions on carbonized and non-carbonised orange peel particulates, which had been studied (see [7]) but their tapped density characteristics in these two forms, which may be different is not explored in literature (5) the effects of particulate sizes on tapped density behaviour on orange peel particulates either in their carbonised or non-carbonised forms has been omitted in literature by researchers (6) for all the cases mentioned above, better values for scientific usage may be the optimal conditions, which may be possible for all the above cases. Unfortunately, optimisation using the grey relational analysis for tapped density of orange peel particulates has not been reported in literature.

From a comprehensive review of literature, it was realized that there exists several studies which have dealt with the tapped density of powders but they are largely of pharmaceutical origin and products [22-25], while for composite fillers an appreciable volume of research has been conducted. Such studies, including Ghosh and Chatterjee [26] contribution, Naglieri et al.'s [27] work, to name a very few, focused on metallic fillers and are not on green fillers, which is the pursuit of the current work. To the best of the author's knowledge, no concrete report in open literature has been given on tapped density optimisation with respect to orange peel particulates. Even if there were studies on tapped density for fillers on green composite fillers, in general, the extensive literature review carried out in this study classify them as a tiny minority of the composite studies, and hence calls for aggressive and intensive investigations of researchers in the green composite community. Thus, both for metallic and green filler powders, there is still a clear lack of investigations on optimisation using grey relational analysis for orange peel particulates and this optimisation problem may arise in real life situations.

The objective of the current work is to propose solution by grey relational analysis of tapped density optimisation problem drawn from real-life experience during the transportation of bulk powders (particulate fillers) to sites where fabrication of the composites are to be made. The problem is conceived as being solvable with experimental data collection and analysis from the laboratory. However, the results were drawn from literature. But no optimisation techniques have been tested on the problem and comparison of results obtained from the use of grey relational analysis with those of Taguchi methods is necessary to deepen our understanding of the tapped density optimisation behaviour of orange peel particulates. The next section explores the experimental procedure and details out the experiment used to achieve the stated goals of the current paper.

3. Materials and methods

3.1 Materials

Orange peel particulates were prepared by drying freshly collected greenish-yellow orange peels under sunlight to remove moisture. This is necessary to allow for further processing of the orange peels. Drying was completed when moisture was removed and the orange peels became dry and crisp with brownish colouration. This ensures that the orange peels can be further processed into a different form. The orange peels were pulverized by grinding in a local grinding mill for 12 times till fine particulate form was obtained. Sieve analysis was carried out using a British Standard Test Sieve (Wykheham Farrance) to obtain 0.425 and 0.600 mm OPPs as the desired particulate sizes for the experiment.

3.2 Methods

The optimisation of the tapped density parameters for both the 0.425 and 0.600 mm particulates was done using the GRA. The motivation for the choice of these grades of filler orange peel particulates is that the 0.425 and 0.600 mm particles are abundant in quantities during the filler post-grinding activities. Thus, sufficient quantities are available for experimentation. However, the approach could be applied to grain sizes of the range 0.075 to 0.300 m. In this case, multiple regrinding activities of the filler will be required. The first stage of grinding requires 12 runs of grinding in a local grinding mill and achieving 0.075 to 0.300 mm particles may require multiples of this number in subsequent grindings. Thus, the choice of 0.425 and 0.600 mm fillers was not grinded by any theoretical concept but by the availability of the filler, after grinding, for experimentation. The GRA was used to find the best experimental run and most influential factors affecting the particulates. Tapped density indices describing the relationship between the parameters of tapped density with transportation, time, inflation and interest factors were obtained. A performance analysis was carried out to know the percentage improvements of the optimal results from different methods. A methodology chart illustrating the optimisation, performance analysis and statistical processes is described by Figure 1.

Grey relational analysis (GRA)

Fung's [28] novel grey relational analytical framework is wholly applied in this work and the definitions of the framework are given in this section.

Normalisation

By representing the primary and specific comparison sequences as $\beta_0^{(o)}(b)$ and $\beta_i^{(o)}(b)$, $i = 1,2,\ldots,m$; $b = 1,2,\ldots,n$, respectively. Normalisation of data is carried out to bring the different values of data within range. It is also a means of relocating the primary sequence to the specific comparison sequence. The normalisation of data in grey relational analysis depends largely on the characteristics of the data sequence [29].

When the desired value of the primary sequence is a minimum, it can be regarded as "smaller-the-better" characteristic which is normalised as follows:

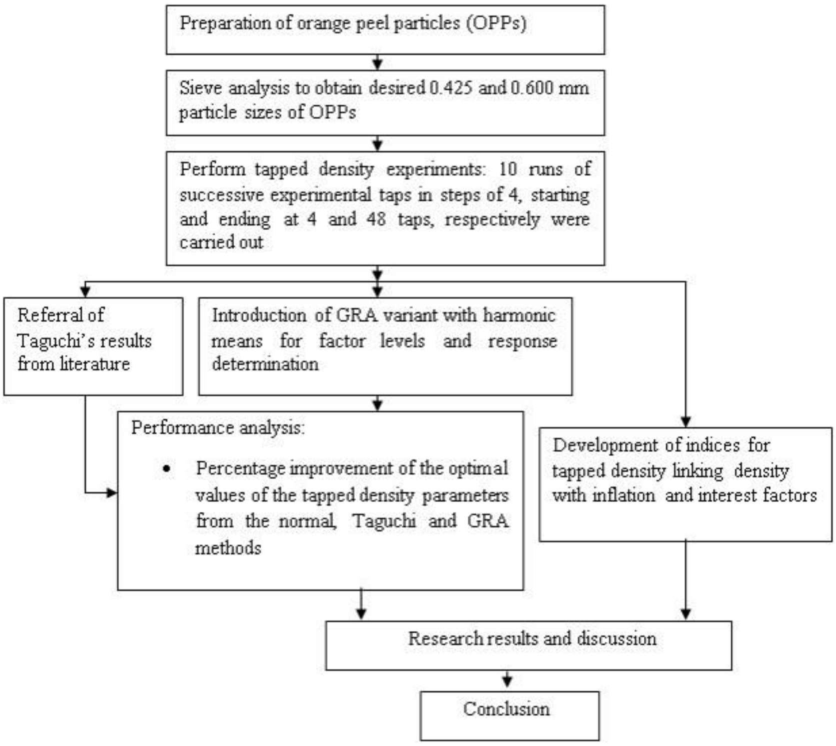

Figure 1 Methodology chart illustrating the tapped density process optimisation, performance analysis

$$\beta_i^*(b) = \frac{\max \beta_i^{(O)}(b) - \beta_i^{(O)}(b)}{\max \beta_i^{(O)} - \min \beta_i^{(O)}(b)} \tag{1}$$

If "larger-the-better" is a characteristic of the primary sequence, then it is normalised using the following [30]:

$$\beta_i^*(b) = \frac{\beta_i^{(O)}(b) - \min \beta_i^{(O)}}{\max \beta_i^{(O)}(b) - \min \beta_i^{(O)}(b)} \tag{2}$$

If there exists an achievable set target, the primary sequence can be normalised using:

$$\beta_i^*(b) = 1 - \frac{|\beta_i^{(O)}(b) - OB|}{\max\{\max \beta_i^{(O)}(b) - OB, OB - \min \beta_i^{(O)}(b)\}} \tag{3}$$

The primary sequence can also be normalised by a simple methodology, i.e. by dividing the values of the primary sequence by the first value of the sequence:

$$\beta_i^*(b) = \frac{\beta_i^{(O)}(b)}{\beta_i^{(O)}(1)} \tag{4}$$

where $\beta_i^{(o)}(b)$ is the primary sequence, $\beta_i^{(*)}(b)$ is the sequence after normalisation, $\max \beta_i^{(o)}(b)$ is the highest value of $\beta_i^{(o)}(b)$, while $\min \beta_i^{(o)}(b)$is the lowest value of $\beta_i^{(o)}(b)$.

Grey relational coefficient and grey relational grade

After normalising the data, a grey relational coefficient can be calculated using the normalised sequences. The grey relational coefficient is derived mathematically as follows:

$$\Omega\left(\beta_0^*(b), \beta_i^*(b)\right) = \frac{\Delta \min + \psi \Delta \max}{\Delta_{0i}(b) + \psi \Delta \max} \tag{5}$$

$$0 < \Omega(\beta_0^*(b), \beta_i^*(b)) \le 1$$

where $\Delta_{0i}(b)$ is the sequence of divergence of the primary sequence $\beta_i^{(o)}(b)$ and specific comparison sequence $\beta_i^{(*)}(b)$,i.e.

$$\Delta_{0i}(b) = |\beta_0^*(b) - \beta_i^*(b)|$$

$$\Delta \max = \max_{\forall j \in i} \max_{\vee b} |\beta_0^*(b) - \beta_j^*(b)|,$$

$$\Delta \min = \min_{\forall j \in i} \min_{\vee b} |\beta_0^*(b) - \beta_j^*(b)|$$

Ψ is a distinguishing effect used to adjust to regulate the scope of the comparative environment and the differences of the relational coefficients (see [28])

The grey relational grade $\Omega(\beta_o^*, \beta_i^*)$ is the average sum of the grey relational coefficients which is defined by the form:

$$\Omega(\beta_0^*, \beta_i^*) = \sum_{b=1}^{n} \Omega_b \chi(\beta_0^*(b), \beta_0^*(b)), \sum_{b=1}^{n} \Omega_b = 1 \tag{6}$$

From here, the grey relational grade denotes the level of correlation between the primary sequence and the specific comparison sequence. The grey relational grade also denotes the level of influence the specific comparison sequence has over the primary sequence. In other words, if a certain specific comparison sequence is more influential than the other specific comparison sequence with respect to the primary sequence, then the grey relational grade for that specific comparison sequence and primary sequence will be greater than other grey relational grades. Thus, grey relational analysis can be used to measure the total value of differences between data sequences and estimated correlation between sequences.

3.3 Experimental design

Tapped density has been known to be affected by a number of factors, such as mass, volume, number of taps, compacting pressure, good packing properties etc. Chevanan et al. [31] observed that volume and number of taps were influential in the tapped densities of chopped switchgrass, corn stover and wheat straw, while Minne et al. [32] as well as Ghosh and Chatterjee [26] also identified volume as a key parameter influencing the tapped density of particulates. Therefore, this experiment was carried out using mass and volume of the tapped 0.425 and 0.600 mm OPPs as process parameters (see also [26]). Ajibade et al. [33] concluded from their investigation into the Taguchi methodical approach that the Harmonic mean can be used to obtain better optimal results in the face of scarce economic resources than the conventionally used arithmetic mean.

In order to obtain low optimal tapped density values of the OPPs for improved variety demand, the same innovation will be pursued in the current investigation. The average mass and volume of 0.425 and 0.600 mm OPPs at every application of taps were bifurcated using the harmonic mean to produce a four factor, 4-level optimisation problem with two output variables. The response variables are the 0.425 and 0.600 mm OPPs tapped densities. Sixteen experimental trials will be performed based on Taguchi method's L_{16} $(4)^4$ orthogonal array. The orthogonal array was generated using Minitab 16, commercially available statistical software. The problem considered in the current paper is of four factor and four-level orientation. However, borrowing ideas from the Taguchi's orthogonal array design, an appropriate orthogonal array must be chosen to be able to show the distribution of all the factor level combinations. The appropriate orthogonal array that fits this need is L_{16} (4^4) and is therefore chosen in this study.

The best experimental run

In this investigation, the tapped densities of 0.425 and 0.600 mm OPPs have been presented in Table 1. This Table 1 displays four factors, namely, G, H, I and J, which are 0.425 mass, 0.425 volume, 0.600 mass as well as 0.600 volume. Here, the volumetric measurements are in cm^3 while the mass measurements are in grammes. It should be noted that mass and volume are the principal dimensions of the parameters analysed here. So, the experimental 1 factors and levels worked on consists of four factors and four levels, as shown in Table 1. The experimental trials are 16 while the four factors (*G*, *H*, *I* and *J*) together with the introduction of 0.425 and 0.600 tapped density are shown. The lower the tapped density of the OPPs, the better the quality of the low density composite filler variety which gives the "lower-the-better" quality characteristic. Therefore, the "lower-the-better" methodology, in which Equation (2) served the purpose of normalising the data. The data concerning the orthogonal array L_{16} (4^4) for the experimental trials and the tapped density of 0.425 and 0.600 mm OPPs is shown in Table 2. The lowest tapped densities of 0.425 and 0.600 mm OPPs are fixed as the primary sequence $\beta_i^{(o)}(b)$, *i* = 1–16, *b* = 1,2. The sequences obtained normalising the data with the use of Equation (1) are described by Table 3, denoted as $\beta_0^*(b)$ and $\beta_i^*(b)$ for primary and specific comparison sequence, respectively. The divergence sequence Δ_{01} was obtained using the following:

$$\mathrm{A}_{01} = \beta_0^*(1) - \beta_1^*(1) |=| 1.00 - 0 |= 1,\ \Delta_{01} = \beta_0^*(1) - \beta_1^*(1) |=| 1.00 - 0 |= 1$$

$$\text{so } \mathrm{A}_{01} = |1{,}1|$$

The same operation was carried out at *i* = 1-16 and the outcome of all Δ_{01} for *i* = 1–16 are described by Table 4

Table 1 Experimental factors and levels for the tapped density of 0.425 and 0.600 mm OPPs

Level	Factors			
	G(0.425 mass, g)	H(0.425 vol, cm^3)	I(0.600 mass, g)	J(0.600 vol, g)
1	257.956	78.076	254.952	77.982
2	257.723	75.031	254.939	74.131
3	257.719	73.665	254.929	72.94
4	257.715	72.736	254.931	71.598

Table 2 Orthogonal array L_{16} (4^4) for the experimental trials and the tapped density of 0.425 and 0.600 mm OPPs

Experimental trial	G(0.425m)	H(0.425v)	I(0.600m)	J(0.600v)	0.425 tapped density	0.600 tapped density
1	1	1	1	1	3.22	3.19
2	1	2	2	2	3.27	3.24
3	1	3	3	3	3.33	3.30
4	1	4	4	4	3.37	3.36
5	2	1	2	3	3.30	3.27
6	2	2	1	4	3.40	3.42
7	2	3	4	1	3.44	3.44
8	2	4	3	2	3.46	3.46
9	3	1	3	4	3.43	3.44
10	3	2	4	3	3.48	3.47
11	3	3	1	2	3.51	3.50
12	3	4	2	1	3.51	3.53
13	4	1	4	2	3.50	3.50
14	4	2	3	1	3.53	3.55
15	4	3	2	4	3.54	3.56
16	4	4	1	3	3.56	3.58

Table 3 Sequences of normalised data

Primary/Specific comparison sequence	0.425 mm OPPs	0.600 mm OPPs
Primary sequence	1.0000	1.0000
Specific comparison sequence		
Experimental trial, 1	1	1
Experiemental trial, 2	0.8529	0.8717
Experiemental trial, 3	0.6764	0.7179
Experiemental trial, 4	0.5588	0.5641
Experiemental trial, 5	0.7647	0.7948
Experiemental trial, 6	0.4705	0.4102
Experiemental trial, 7	0.3529	0.3589
Experiemental trial, 8	0.2941	0.3076
Experiemental trial, 9	0.3823	0.3589
Experiemental trial, 10	0.2352	0.282
Experiemental trial, 11	0.1471	0.2051
Experiemental trial, 12	0.1471	0.1282
Experiemental trial, 13	0.1764	0.2051
Experiemental trial, 14	0.0882	0.0769
Experiemental trial, 15	0.0588	0.051
Experiemental trial, 16	0	0

Table 4 Divergence sequences

Divergence sequences	Δ_{01}	Δ_{02}
Experimental trial, 1	0	0
Experiemental trial, 2	0.1471	0.1283
Experiemental trial, 3	0.3236	0.2821
Experiemental trial, 4	0.4412	0.4359
Experiemental trial, 5	0.2353	0.2052
Experiemental trial, 6	0.5295	0.5898
Experiemental trial, 7	0.6471	0.6411
Experiemental trial, 8	0.7059	0.6924
Experiemental trial, 9	0.6177	0.6411
Experiemental trial, 10	0.7648	0.718
Experiemental trial, 11	0.8529	0.7949
Experiemental trial, 12	0.8529	0.8718
Experiemental trial, 13	0.8236	0.7949
Experiemental trial, 14	0.9118	0.9231
Experiemental trial, 15	0.9412	0.949
Experiemental trial, 16	1	1

By observing the data described in Table 4, we find that $\Delta\max(b)$and $\Delta\min(b)$are given as follows:

$$\Delta\max = \Delta_{16}(1) = \Delta_{16}(2) = 1,\ \Delta\min = \Delta_{1}(1) = \Delta_{1}(2) = 0$$

The unique effect Ψ can be substituted into Equation (4) to calculate the grey relational coefficient. For parameters of the same load, Ψ is 0.5. Table 5 displays the grey relational coefficient and grey grade for all sixteen comparison sequences.

In the current investigation, the Taguchi's method response table was adopted to obtain the average grey relational grade for each factor level [29]. This was done by grouping the grey relational grades for every factor level combination for the four columns in the orthogonal array and finding their means. Considering the first column pertaining to the orthogonal array, trials 1, 2, 3 and 4 were the experimental trials for factor G when it is described as level 1. The grey relational grade for G_1 is the mean grey relational grades obtained at the aforementioned experimental trials. Specifically, grey relational grade for G_1 will be obtained using the harmonic mean. It is well known that the factor-level computations are traditionally being made using the average method of means in which the means of numbers for each cell is computed as the mere addition of numbers and the division of the sum by the number of entries. This is the method in all existing studies as shown in Fung [28] and Xu et al. [14]. Following a new perspective, the harmonic mean approach is introduced. The issue is that there is need for a change in the way researchers think in computing the grey grades from the factor level combinations. Being at variance from the norm, the current work applies the harmonic means of computation in the determination of factor levels. This has not been previously attempted in literature on grey relational analysis. In fact, harmonic method of evaluation of means is generally not new. However, it is new in its applied form to the grey relational analysis computation. The contribution has been borrowed from mathematics and is applied to grey relational analysis in the computation of moisture optimisation for the first time. It is hoped that harmonic mean provides an alternative to the average method of determining means, and would move this area of grey relational analysis forward. Thus, the values of the various G_is are as follows:

G_1 = 4/ (1/1 + 1/0.8789 + 1/0.7677 + 1/ 0.6951)
G_2 = 4/ (1/0.8196 + 1/0.6414 + 1/0.6082 + 1/0.5885)
G_3 = 4/ (0.6137 + 1/0.5743 + 1/0.5484 + 1/0.5369)
G_4 = 4/ (0.5527 + 1/0.5214 + 1/0.5140 + 1/0.5)

The same operation was carried out for every factor-level combination which produced the response table described by Table 5. Fung et al. [28] noted that grey relational grades denote the relationship between the reference sequence as well as comparability sequence. The higher value of the grey relational grade signifies that the comparability sequence has a strong relationship to the reference sequence. In this work, the primary (reference) that was chosen has the “lower-the-better” characteristic. Thus, the specific comparison (comparability) sequence with higher values of the grey relational grade would produce lower tapped densities for 0.425 and 0.600 mm OPPs. Using this principle, the levels that had the highest responses were chosen. In Table 5, G_1, H_1, I_2, J_3 has the highest grey grades for factors *G*, *H*, *I* and *J*, respectively. Consequently, G_1, H_1, I_2, J_3 were chosen as the optimal grey setting based on their factor level combination.

Table 5 Responses for grey relational grade

Factor	Levels			
	1	2	3	4
G	0.8198*	0.6533	0.5668	0.5214
H	0.7069*	0.6293	0.5956	0.5714
I	0.6267	0.6487*	0.6108	0.6030
J	0.6226	0.6182	0.6386*	0.6086

The grey relational analysis can be used to determine the parameters which had the greatest influence on the tapped densities of 0.425 and 0.600 mm OPPs. By setting the tapped densities of 0.425 and 0.600 mm OPPs of sixteen experimental trials as the primary sequences $\beta_{0.425}^{(0)}(b)$ and $\beta_{0.600}^{(0)}(b)$, b = 1–2, while the values of the factor level in the sixteen experimental trials are fixed as the specific comparison sequences $\beta_A^{(0)}$, $\beta_B^{(0)}$, $\beta_C^{(0)}$ and $\beta_D^{(0)}$, b= 1–2 (Table 6). Normalisation of the data was performed using Equation (4), i.e. normalised by the first value of each sequence. The divergence sequences were obtained using the same methodology as used in the previous section, Table 7. The distinguishing coefficient and divergence sequences were used to calculate the grey relational coefficient using Equation (5). The grey grades were obtained from the average of the grey relational coefficients.

Table 6 The primary sequence and specific comparison sequence for 0.425 and 0.600 mm OPPs tapped densities and experimental factor levels

Experimental trial	Specific comparison sequences				Primary sequence	
	G(0.425m)	H(0.425v)	I(0.600m)	J(0.600v)	0.425 tapped density	0.600 tapped density
1	257.956	78.076	254.952	77.982	3.22	3.19
2	257.956	75.031	254.939	74.131	3.27	3.24
3	257.956	73.665	254.929	72.94	3.33	3.30
4	257.956	72.736	254.931	71.598	3.37	3.36
5	257.723	78.076	254.939	72.94	3.30	3.27
6	257.723	75.031	254.952	71.598	3.40	3.42
7	257.723	73.665	254.931	77.982	3.44	3.44
8	257.723	72.736	254.929	74.131	3.46	3.46
9	257.719	78.076	254.929	71.598	3.43	3.44
10	257.719	75.031	254.931	72.94	3.48	3.47
11	257.719	73.665	254.952	74.131	3.51	3.50
12	257.719	72.736	254.939	77.982	3.51	3.53
13	257.715	78.076	254.931	74.131	3.50	3.50
14	257.715	75.031	254.929	77.982	3.53	3.55
15	257.715	73.665	254.939	71.598	3.54	3.56
16	257.715	72.736	254.952	72.94	3.56	3.58

Table 7 Sequences after normalisation of Table 6

Experimental trial	Specific comparison sequences				Primary sequence	
	G(0.425m)	H(0.425v)	I(0.600m)	J(0.600v)	0.425 tapped density	0.600 tapped density
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	1.0000	0.9610	0.9999	0.9506	1.0155	1.0157
3	1.0000	0.9435	0.9999	0.9353	1.0342	1.0345
4	1.0000	0.9316	0.9999	0.9181	1.0466	1.0533
5	0.9991	1.0000	0.9999	0.9353	1.0248	1.0251
6	0.9991	0.9610	1.0000	0.9181	1.0559	1.0721
7	0.9991	0.9435	0.9999	1.0000	1.0683	1.0784
8	0.9991	0.9316	0.9999	0.9506	1.0745	1.0846
9	0.9991	1.0000	0.9999	0.9181	1.0652	1.0784
10	0.9991	0.9610	0.9999	0.9353	1.0807	1.0878
11	0.9991	0.9435	1.0000	0.9506	1.0901	1.0972
12	0.9991	0.9316	0.9999	1.0000	1.0901	1.1066
13	0.9991	1.0000	0.9999	0.9506	1.0870	1.0972
14	0.9991	0.9610	0.9999	1.0000	1.0963	1.1129
15	0.9991	0.9435	0.9999	0.9181	1.0994	1.1160
16	0.9991	0.9316	1.0000	0.9353	1.1056	1.1223

The grey relational coefficient and grey grade for the primary sequence $\beta_p^*(b)$ and specific comparison sequences $\beta_A^*(b), \beta_B^*(b), \beta_C^*(b)$and $\beta_D^*(b)$are shown in Tables 8 and 9.

The grey relational grades in Tables 8 and 9 can be organised into a matrix form in the following manner

$$\Omega = \begin{bmatrix} \Omega(0.425, G) & \Omega(0.425, H) \\ \Omega(0.600, I) & \Omega(0.600, J) \end{bmatrix} = \begin{bmatrix} 0.6251 & 0.9612 \\ 0.9999 & 0.9541 \end{bmatrix}$$

This gives

Row 1 = (Ω (0.425, *G*), Ω (0.425, *H*)) = (0.6251, 0.9612)
Row 2 = (Ω (0.600, *C*), Ω (0.600, *J*)) = (0.9999, 0.9541)
Col 1 = (Ω (0.425, *G*), Ω (0.600, *I*)) = (0.6251, 0.9999)
Col 2 = (Ω (0.425, *H*), Ω (0.600, *J*)) = (0.9612, 0.9541)

According to Fung's [28] model, in the grey relational grade matrix, Rows 1 and 2 indicate the values of the grey relational grade for the adjustable factors to the physical properties of 0.425 and 0.600 mm OPPs tapped densities, respectively. This indicates that the sphere of influence which these factors exercise over the output variables could be determined. The output variable which is most easily affected is the maximum of Rows 1 and 2. In this case, max (Row1, Row 2) = Row 2 = (Ω (0.600, *I*), Ω (0.600, *J*)). This denotes that the primary sequence of 0.600 mm tapped density has a more robust primary sequence over that of the 0.425 mm tapped density. In other words, the tapped density of 0.600 mm OPPs was easily affected by the controllable factors than was the tapped density of 0.425 mm OPPs. This makes the 0.600 mm OPPs tapped density as the more strongly influenced of the two output variables.

Looking through the columns of the matrix, the values of the grey relational grade for the adjustable factors *G*, *H*, *I* and *J* to the physical property of 0.425 and 0.600 mm tapped densities are shown in Cols. 1 and 2, respectively. Again, this provides opportunity to assess the sphere of influence each factor exercises over the output variables. The most important factor was the maximum value of Col 1 and Col 2. In this case, max (Col 1, Col 2) = Col 2 = (Ω (0.425, *H*), Ω (0.600, *J*)) = (0.9612, 0.9541). This indicates that the volume, $\beta_{(B)}^{(0)}(b), \beta_{(D)}^{(0)}(k)$ exhibits the stronger comparison sequence of the tapped density parameters. This implies that the volume has a better correlation to the tapped densities of 0.425 and 0.600 mm OPPs. Therefore, volume was the most important factor to the tapped density of the particulates.

A careful contrast of Row 1 and Row 2, shows that the tapped density of 0.600 mm OPPs as the more influenced of the two output variables. We can know the extent of influence each of the adjustable factors exerts on the tapped density of 0.600 mm OPPs by examining every item in the row carefully. In Row 2, Ω (0.600, *I*) > Ω (0.600, *J*). This implies that the priority of adjustable factors to tapped density of 0.600 mm OPPs is given by the order, *I* and *J* i.e. mass followed by volume. For Row 1, it is Ω (0.425, *H*) > Ω (0.425, *G*). This makes the priority of factors in the order *H* and *G* i.e. volume, then mass. Thus, the priority of factors changed in the two separate tapped densities. The range of influence each of the factors has over the tapped densities of 0.425 and 0.600 mm can be seen clearly through the columns. In Col1, the mass of 0.600 exerts a stronger influence compared with that of the 0.425, while in Col 2, the volume of 0.425 has a superior effect with respect to that of the 0.600 mm OPPs.

Table 8 Grey relational coefficient as well as the grey relational grade for experimental factors of 0.425 mm OPPs tapped density

	G (0.425 mass)	H (0.425 volume)
Grey relational coefficient	1.0000	1.0000
	1.0000	0.9624
	1.0000	0.9465
	1.0000	0.9359
	0.5002	1.0000
	0.5002	0.9624
	0.5002	0.9465
	0.5002	0.9359
	0.5002	1.0000
	0.5002	0.9624
	0.5002	0.9465
	0.5002	0.9359
	0.5002	1.0000
	0.5002	0.9624
	0.5002	0.9465
	0.5002	0.9359
Grey relational grade	0.6251	0.9612

Table 9 Grey relational coefficient as well as the grey relational grade for experimental factors of 0.600 mm OPPs tapped density

	I (0.600 mass)	*J* (0.600 volume)
Grey relational coefficient	1.0000	1.0000
	0.9999	0.9529
	0.9999	0.9392
	0.9999	0.9243
	0.9999	0.9392
	1.0000	0.9243
	0.9999	1.0000
	0.9999	0.9529
	0.9999	0.9243
	0.9999	0.9392
	1.0000	0.9529
	0.9999	1.0000
	0.9999	0.9529
	0.9999	1.0000
	0.9999	0.9243
	1.0000	0.9392
Grey relational grade	0.9999	0.9541

3.4 Taguchi optimisation

Further optimisation was carried out using another variant of the Taguchi method (Taguchi 2*) to obtain new optimal values for the parameters of 0.425 and 0.600 mm OPPs tapped densities. The Taguchi 2* used the mass and volume of the 0.425 mm OPPs as well as the mass and volume of the 0.600 mm OPPs, as factors with their respective levels. This produced an optimal parametric setting of $G_2H_2I_1J_1$ which translates to a tapped density of 3.434 and 3.269 g/cm3, respectively for the 0.425 and 0.600 mm OPPs.

For " lower-the-better" quality characteristics the S/N ratio is given as [34]:

$$\text{S/N } (\eta) = 10 \log 10(\tfrac{\mu^2}{\sigma^2}) \qquad (7)$$

where $\mu = \dfrac{1}{n\sum y_i}$ and $\sigma^2 = \dfrac{1}{(n-1)}\sum (y_i - \mu)^2$

where $y_1, y_2, \ldots, y_\text{n}$ are the individual responses of the tapped density and 'n' is the number of observations.

Table 10a Comparison of optimal setting results (with Taguchi 1* method)

S/N	Particulate size (mm)	Normal results (g/cm^3)	Taguchi 1* Method [33]	Grey method (current work)	Percentage improvement (%)	
					Normal vs. Taguchi1*	Normal vs. Grey
1	0.425	3.431	$A_1B_1C_1$ (4.433 g/cm^3)	G_1H_1 (3.30)	-22.6	3.82
2	0.600	3.423	$A_1B_1C_1$(4.395 g/cm^3)	I_2J_3 (3.495)	-22.11	20.6

Taguchi 1* is based on the use of number of taps, tapped density of 0.425 and 0.600 mm OPPs as factors

Table 10b Comparison of optimal setting results (with Taguchi 2* method)

S/N	Particulate size (mm)	Normal results (g/cm^3)	Taguchi 2* method (current work)	Grey method (current work)	Percentage improvement (%)	
					Normal vs. Taguchi 2*	Taguchi 2* vs. Grey
1	0.425	3.431	G_2H_2 (3.434)	G_1H_1 (3.30)	0.087	3.92
2	0.600	3.423	I_1J_1 (3.269)	I_2J_3 (3.495)	6.466	4.40

Taguchi 2* is based on using the masses and volumes of 0.425 and 0.600 mm OPPs, respectively as factors

Comparatively, the Taguchi 2* produced an improvement of 0.087 over the normal tapped density of 0.425 mm OPPS, while the grey method gave a 3.92 % improvement over the Taguchi 2* optimal results. For the 0.600 mm OPPs, an improvement of 6.466 % was recorded by the Taguchi 2* over the normal tapped density results, while the grey method had an improvement of 4.40 % over the Taguchi optimal results.

Performance analysis

In Table 10a and b, comparisons of the different optimal setting of tapped density parameters obtained from different methods are presented. This was done to have a side-by-side performance analysis of the different methods and their obtained results. This would enable design engineers and composite fabricators to make informed decisions based on the results presented. Thus, three categories of results were presented namely, from the normal, Taguchi and grey methods alongside the performance analysis of the methods.

For the 0.425 mm OPPs, the normal tapped density result was calculated as 3.431 g/cm^3. This was obtained by finding the average of average masses across ten runs and dividing the average of average volumes from ten runs. By so doing, the average masses and volumes of the tapped 0.425 mm OPPs at every successive application of taps was used to calculate the overall average tapped density value of 0.425 mm OPPs, while the same operation was carried out to obtain the average tapped density of 3.423 g/cm^3 for the 0.600 mm OPPs. According to Ajibade et al. [33], the optimal tapped density for the 0.425 and 0.600 mm OPPs were obtained as 4.433 and 4.395 g/cm^3, respectively. The Taguchi 1* method used by Ajibade et al. [33] was carried out using the number of taps, the tapped densities of 0.425 and 0.600 mm OPPs as factors and their bifurcated harmonic means as their respective levels.

In the current work, using the grey relational analysis, the output variables of tapped densities of 0.425 and 0.600 mm OPPs were used as the primary sequence, while the masses and volumes of 0.425 and 0.600 mm OPPs were used as factors with their respective levels. The obtained grey grades were used to evaluate the level of correlation between the two sequences. Thus, the optimal grey grades for 0.425 mm sample (G_1H_1) was used to calculate a tapped density of 3.30 g/cm^3, while the optimal grey grades for 0.600 mm (I_2J_3) was used to obtain a tapped density of 3.495 g/cm^3 for the 0.600 mm OPPs.

A performance analysis was carried out by finding the percentage improvement of the tapped density parameters for the different methods. For the 0.425 mm OPPs, the performance analysis showed that a negative improvement of -22.6 % was obtained by comparing the normal tapped density result to the Taguchi 1* optimal result. However, a positive improvement of 3.82 % was obtained by comparing the normal result to the grey method's results. This signifies improved optimal results for the tapped density of the 0.425 mm OPPs, which can be used to meet improved variety demands. For the 0.600 mm OPPs, a negative improvement of -22.11 % was recorded for the comparison between the normal and Taguchi optimal results, while a positive improvement of 1.832 % was obtained for the normal and grey comparisons.

Further comparison was done by using another variant of the Taguchi method (Taguchi 2*) to obtain new optimal values for the tapped densities of 0.425 and 0.600 mm tapped densities. The Taguchi 2* used the mass and volume of the 0.425 mm OPPs, with the mass and volume of the 0.600 mm OPPs as factors with their respective levels to obtain an optimal parametric setting of $G_2H_2I_1J_1$. This translates to a tapped density 0f 3.434 and 3.269 g/cm^3 respectively, for the 0.425 and 0.600 mm OPPs. Comparatively, the Taguchi 2* produced an improvement of 0.087 % over the normal, while the grey method gave a 3.92 % percentage improvement over the Taguchi 2* 0.425 mm OPPs optimal results. For the 0.600 mm OPPs, an improvement of 6.466 % was recorded by the Taguchi 2* over the normal tapped density results, while the grey method has an improvement of 4.40 % over the Taguchi 2* optimal results.

4. Calculation of the compressibility/compactibility index and associated indices

The compressibility/compactibility (CC) index is obtained from the laboratory data of initial and final volumes, masses and heights of the tapped orange peel particulates (OPPs) with the aid of a 250 ml graduated cylinder, carried out in the Civil Engineering Laboratory of the University of Lagos. The CC_{index} is the ratio of the changes in density to the height changes of the OPPs during the tapping process. The CC_{index} is given by the following:

$$CC_{index} = \left[\mathrm{d_{OPPs}(final)} - \mathrm{d_{OPPs}(initial)}\right] / \left[\text{Initial height} - \text{final height}\ \right] \tag{8}$$

$$CC_{index} = \sum_{i=1}^{N}(M_f/V_f - M_i/V_i)/\sum_{i=1}^{N}(h_f - h_i) \tag{9}$$

where M_i and M_f are the final and initial masses of the OPPs, V_f and V_i are the initial volumes of OPPs, while h_i and h_f are the initial and final heights of the OPPs measured when poured into the graduated 250 ml graduated cylinder. A typical formula for the normal density is

$$\sigma = M/V \tag{10}$$

where σ is the density of the untapped OPPs and the corresponding mass and volume are M and V. For the specific situation, the M and V are M_i and V_i, respectively since it is in an uncompressed and non-compacted state. The argument here is that we could redefine the density formula to incorporate tapped density with respect to the compressibility and compactibility index as

$$\sigma = M/V\,CC_{index} \tag{11}$$

By introducing M_i and V_i as M and V, respectively, and the symbols of CC_{index} in Equation (10) into Equation (11), we have

$$\sigma = \sum_{i=1}^{N}\frac{\mathrm{M_i}}{\mathrm{V_i}}[\sum_{i=1}^{N}(M_f/V_f - M_i/V_i)/\sum_{i=1}^{N}(h_f - h_i)] \tag{12}$$

where σ is the density of the OPPs. Notice that in an uncompressed and non-compacted state, the $\mathrm{CC_{index}}$ component in Equation (12) becomes unity. Table 11 is then developed based on the dependent and independent variables and the behaviour of the functions studied.

The economic tapped density model can be developed by means of applying the inflation and interest factor in a combined form to Equation (12), in which f and α are the interest and inflation factors in an economic period. The new expression is obtained as Equation (13):

$$\sigma = (\sum_{i=1}^{N}\frac{M_i}{V_i}[(M_f/V_f) - (M_i/V_i)]/\sum_{i=1}^{N}(h_f - h_i).\sum_{i=1}^{N}(1+\alpha)/(f+1) \tag{13}$$

The incorporation of inflation and interest rate factors, α and f, respectively, provides a means of studying the economic factors related to the tapped density. In the specific case of tapped density, time is involved, which is the time-frame to do the tapped density experiment. This time is the major issue that makes the application of the inflation and interest rate factors relevant in our analysis by considering the life-cycle cost analysis of the system. However, as an introduction to the conceptualisation, details about cost and life-cycle issues are ignored in the modelling.

Table 11 shows the inter-relationship between different quantities and indices of untapped and tapped OPPs samples. Twelve runs of tapped density experiments were carried out on 0.600 mm OPPs. Each run is made of 48 applied taps to the OPPs in a 250 ml graduated cylinder. Measurements taken before the application of the taps are the initial volume V_i, initial mass and height of the OPPs taken as M_i and h_i, respectively. After the application of the taps, the final volume, mass and height were measured as V_f, M_f and h_f. Therefore, the measurements taken before and after the application of taps completed an experimental run. From the measurements taken, a number of helpful indices were derived which would be used to further analyse and understand the tapped density behaviour of OPPs. First is the initial density denoted by M_i/V_i, final density given by M_f/V_f, difference in height represented by $h_i - h_f$, ratio of final to initial densities $(M_f/V_f)/(M_i/V_i)$, final density to height increase index, initial density to height increase and compressibility/compactibility index.

The first part of the analysis is to compare the final density to the initial density. The initial density expressed by was found to be lesser than the final density across the ten experimental runs. This is because the final mass and volume of the tapped OPPs is lesser than the initial mass and volume of the untapped OPPs. This is caused by the compactness of the grains due to removal of air from the pores and gaps in the OPPs after the tapped density experiment. Thus, dividing the final mass by the final volume gives a higher density value. As a result of this relationship, the ratio of final to initial densities was found to be greater than unity for all the experimental runs studied. This can be explained by the final density being divided by the initial density for all the twelve experimental runs. The difference in height is the gap in-between the initial and final height of the OPPs specimen in the measuring cylinder. For the twelve runs, it was found to be positive because the initial height is greater than the final height. This is because the height of the OPPs drops in the cylinder due to the application of the taps and compactness of the grains.

The final density to increase in height index was also found to be greater than the initial density to increase in height index across the ten runs. These indices show the level of contribution the increase in height has on the density of the OPPs. The initial and final densities to increase in height indices was found to behave in the same way, having the lowest values at run 6 and reaching a peak value at run 8. The compressibility /compactibility index however behaved differently from the afore mentioned indices. This index shows how much the OPPs can be compressed together by the application of taps. The highest value of this index was obtained at run 4, while the smallest value was recorded at run 7. This demonstrates that the compressibility/compactibility index relationship is influenced differently by the increase in height.

5. Conclusions

In this work, the first pursuit was to apply grey relational analysis in a unique way in which the computation of means of factor-levels and S/N responses were defined by harmonic method of computation. A second pursuit of the work was to establish that tapped density has critical inter-relationships with normal density and the economic factors of inflation and interest rates. This mathematical framework was typically represented by factors including masses, volumes and height of the OPPs as well as the inflation and the interest rate factors.

From the foregoing sections and discussion of results, a number of novel findings have been made on the optimisation of tapped density parameters of OPPs using the grey relational analysis. The following conclusions are made:

- The optimal grey setting for the tapped density parameters of 0.425 and 0.600 mm OPPs was obtained as $G_1H_1I_2J_3$. This means that 257.956 g, 78.076 cm^3 as well as 254.939 g and 72.94 cm^3 for the masses and volumes of the 0.425 and 0.600 mm OPPs, respectively.

Table 11 Information on tapped density and economic factors

Description	M_f	V_f	M_f/V_f	M_i	V_i	M_i/V_i	$(M_f/V_f)/(M_i/V_i)$	h_i	h_f	$h_d = (h_i - h_f)$	$(M_f/V_f)/(h_i-h_f)$	$(M_i/V_i)/(h_i-h_f)$	$[(M_f/V_f) - (M_i/V_i))]/(h_i - h_f)$
Run 1	269.50	74	3.642	269.68	80	3.371	1.080	8	6.75	1.25	2.914	2.697	0.217
Run 2	264.42	73	3.622	264.42	80	3.305	1.096	6.1	5.55	0.55	6.586	6.010	0.576
Run 3	264.41	66	4.006	264.44	80	3.306	1.212	6	5.05	0.95	4.217	3.479	0.738
Run 4	264.24	60	4.404	264.3	80	3.304	1.333	6.5	5.9	0.6	7.340	5.506	1.834
Run 5	266.00	68	3.912	266.68	80	3.334	1.173	6.3	5.25	1.05	3.725	3.175	0.551
Run 6	268.26	75	3.577	268.33	80	3.354	1.066	7.6	6.35	1.25	2.861	2.683	0.178
Run 7	267.59	74	3.616	267.62	80	3.345	1.081	7.5	5.55	1.95	1.854	1.716	0.139
Run 8	269.06	74	3.636	269.09	80	3.364	1.081	6.3	6	0.3	12.120	11.212	0.908
Run 9	266.97	72	3.708	266.98	80	3.337	1.111	6.7	5.5	1.2	3.090	2.781	0.309
Run 10	267.03	70	3.815	267.09	80	3.339	1.143	6.2	5.65	0.55	6.936	6.070	0.866
Run 11	268.11	72	3.724	268.15	80	3.352	1.111	6.3	5.75	0.55	6.770	6.094	0.676
Run 12	268.76	74	3.632	268.77	80	3.360	1.081	6.3	5.75	0.55	6.603	6.108	0.495

- The recommended levels for tapped density of the 0.425 and 0.600 mm OPPs which can be used to meet improved composite variety demand which still satisfy the “smaller-the-better” quality characteristic of the primary sequence.
- Since the tapped density of the 0.600 mm OPPs was found to have a more robust primary sequence over the 0.425 mm OPPs, the 0.600 mm OPPs was more affected by the action of the output variables.
- Volume was found to have a stronger correlation to the primary sequences, which makes it the most important factor to the tapped densities of the particulates.
- The final density of the tapped OPPs was found to be greater than the initial density of the untapped OPPs.
- The increase in density is caused by compactness of the grains as a removal of air from the pores and gaps from the OPPs.
- This phenomenon ensures that the difference in the height of the untapped OPPs and tapped OPPs was found positive for the twelve runs.
- The ratio of final density to the initial density was observed to be greater than unity for the twelve experimental runs.
- The final density to increase in height was observed to be greater than initial density to increase in height index. However, both indices were observed to behave in the same manner having their lowest and peak values at runs 6 and 8, respectively.
- The compressibility/compactibility index behaved differently from the afore-mentioned indices, having lowest and peak values at runs 4 and 7, respectively.

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