Availableonline at: http://publikasi.mercubuana.ac.id/index.php/ijiem

IJIEM (Indonesian Journal of Industrial Engineering & Management)

ISSN (Print) : 2614-7327 ISSN (Online) : 2745-9063

A Tapped Density Taguchi Optimization for Orange Peel Particulate Green Fillers

Oluwaseyi Ayodele Ajibade[1], Johnson Olumuyiwa Agunsoye[2], and Sunday Ayoola Oke[3,*]

[1,2]Department of Metallurgical and Materials Engineering, University of Lagos, Lagos, 101017 Nigeria

[3] Department of Mechanical Engineering, University of Lagos, Lagos, 101017 Nigeria

ARTICLE INFORMATION

Article history:

Received: 15 August 2023
Revised: 16 October 2023
Accepted: 10 December 2023

Category: Research paper

Keywords:
Density
Orange peels
Particulates
Mass
Volume
Measurements

DOI: 10.22441/ijiem.v5i2.22415

A B S T R A C T

Transportation of green fillers for composites has serious densification implications due to particulate shape irregularities and size distributions. To date, few scientific studies are available on the tapped density measurements of orange peel particulate fillers. In this work, experiments were conducted on the tapped density of orange peel particulates in gentle and successive taps to the measuring cylinder containing the particulate matter. Taguchi's technique of "smaller-the-better" quality characteristics used in measuring the signal-to-noise (S/N) ratio was applied to determine the optimal setting of the tapped density process parameters. Within a range of taps from 1 to 48 points, all tapped points showed that 0.425mm OPP has a higher average apparent density of 3.22g/cm^2 than 0.600mm (i.e. 3.189g/cm^3) except for points at 8, 28 and 32 taps. Furthermore, for the 0.600mm OPP, its average tapped density improved by 6.97% compared to its average apparent density. Moreover, it was found that the Taguchi optimal setting for the tapped density of OPP given was $A_1B_1C_1$, which reads as 8.727 number of taps, a tapped density of 4.433 and 4.395g/cm^3, respectively, for the 0.425 and 0.600mm OPP samples sizes. This means that the required number of taps to obtain OPPs with light density and structural integrity to meet improved composite variety demands would be 8.727 taps, while a tapped density of 4.433 and 4.395g/cm^3 is required for the 0.425 and 0.600mm OPP sizes. Hence, the number of taps was the tapped density parameter that had the greatest effect on the S/N ratios of the tapped filler materials. The results are of immense benefit to composite design engineers and equipment manufacturers for behavioural simulation and testing purposes.

This is an open access article under the **CC–BY-NC** license.

***Corresponding Author**

Sunday Ayoola Oke
E-mail: sa_oke@yahoo.com

1. INTRODUCTION

With increasing pressure on production systems worldwide towards green manufacturing, it is the need of the hour that the world switched over to non-conventional fillers in composite fabrication, preventing from environmental pollution crisis (Wang et al., 2015; Bradu et al., 2022). The development of the next generation of materials, products and processes should essentially be guided by sustainability, industrial ecology, eco-effectiveness and green chemistry (Abdul-Khalil et al., 2012; La Mantia and Morreale 2011; Mohanty et al., 2002). Considerable efforts need to be devoted to the use of green waste in areas where low-cost composite applications are involved (Jamwal et al., 2023; Baltiet al., 2023; Zhang et al., 2023). In the past few years, emphasis on the cost of composites has been complimented with structural integrity (Ma et al., 2014; Beaumont, 2015; Meriem-Benziane et al., 2015; Gu, 2012). Practically, conventional materials, which are not green, and provide substantial information concerning the structural integrity of composite materials, are being abandoned due to environmental concerns (Baril et al., 2019; Beltran and Pino, 2023; Nath et al., 2023). However, green fillers such as orange peel particulates are at the centre of attention in composite development and practice (Kumar et al., 2012; Aigbodion et al., 2013; Ajibade et al., 2022). It is necessary to ensure the structural integrity of green fillers, relate many of their parameters, formulate and use this information for performance monitoring in orange peel composite development (Ajibade et al., 2015a; 2015b; 2016; 2017; 2021).

Tapped density promises to emerge as a reliable alternative for the evaluation of the densification characteristics of orange peel particulates (Ajibade et al., 2016). Previously, Ajibade et al. (2016) analysed the tapped density of orange peels by adopting the grey relational analysis. Besides, when compared with the conventional density measures, tapped density provides significant information concerning structural integrity measures by way of densification but the conventional density measures fail to achieve this goal (Ajibade et al., 2015a). Very few works regarding tapped density have been reviewed by researchers in the last few years (Ajibade et al., 2016). Tapped density plays a significant role in composite fabrication, design and maintenance since their characteristics (shape, regularity, size distribution, compaction, compressibility, tapping methods such as height, rate) impact the results and performance of composite in which they are made up of (Ajibade et al., 2016). Orange peel particulates are fillers that are increasingly adopted in composite development and maintenance (Ajibade et al., 2015b). Of late, with the development of material science, several new classes of physical properties have been developed and investigated (Xiao et al., 2006; Yang et al., 2012). However, a huge amount of investigations are going on, which are focused on the development of improved physical properties of orange peel and their particulates (Ajibade et al., 2016). These are meant to result in improved mechanical properties of tensile strength, and flexural strength as well as enhanced physical properties of water absorption of the orange peel particulate (Ajibade et al., 2017).

In the beverages, processed foods and the pharmaceutical industry, and by extension, composite fabrication, tapped density measurements are an important physical property evaluation activity (Ojha et al., 2012). It is a preferred measurement approach where huge activities involving transportation and storage of dried forms of products are involved. In this scenario, the input process parameters may be the sizes of the particulates, the number of taps, the volumes and weights corresponding to the progressive no-of-taps measurements, and the surface area of experimental facilities in which the measurements are taken. The output parameter is the tapped density measure. These input parameters are critical factors that dictate the values of the tapped density. The main objective may be to obtain high or low tapped density measurements, as the case may be.

However, due to the unpredictable changes in factors influencing tapped density such as compressibility, and compactness, the prior knowledge of the density of the particulates may change, thereby requiring revisions of measurements. Unfortunately, in the fabrication process, the redesign of a product is very expensive, requiring repetition of simulation steps and forming experiments. Through the implementation of Taguchi techniques in the optimisation of tapped density, the expensive and unnecessary additional design costs could be avoided while the desirable errors in the design process of composite fabrication avoided. This shows the strength of optimisation in the development of a composite structure. In the current situation, Taguchi's design of the experiment is exploited for the benefit of the composite fabrication process. Unfortunately, a common problem that is faced in the composite fabrication industry is to control the density of materials throughout work on the process. Such a process needs to be overcome so that the under or over-design of structures in terms of filler material specification should be avoided. The orange peel particulates, which are evolving as alternative fillers of green origin should be properly investigated for their tapped density.

Although design engineers have been dealing with material density-related issues for several decades, the heightened cost of composite development and the stringent composite manufacturing environment are challenging. They call for the prudent use of scientific principles for the most economic production of composite structures. The tapped density is a principal scientific approach in the determination of the physical properties of orange peel particulates as fillers in composite manufacture. Tapped density research is concerned with the related technical and scientific activities concerned with related compaction of particulate orange peels. Tapped density measurements potentially solve the problem experienced during transportation and movements of powder forms of materials, particularly in the pharmaceutical industry, beverages and food industries, and by extension to composite fillers including orange peel particulates.

Also, despite that some density studies have been performed by Kumar (2012) and Ojha et al. (2012), computations of density by such a unique approach, through tap density measurements, are yet to be considered in the literature. The pursuit of this novel path to analysing density in composite design, using orange peel particulates as fillers, is a necessity for progress in green filler usage campaign. This is because, understanding the tap density characteristics, among other things, cautions on the limits of loads that could be withstood by the fillers thereby planning for the avoidance of failure of structures during the design stage. To the author's knowledge, there is a rare comprehensive analysis of the tap density of orange peel particulates. Therefore, in this paper, experimental investigation relevant to tap density in the development of high physical properties is pursued. Their characteristics are compared and discussed with the direct measurements of mass per unit volume without invoking tappings on the experimental samples. Section 2 is the literature review. In section 3, the details of the materials and experimental procedure are provided. The presentation of results and discussion is made in section 4. Section 5 is the Taguchi optimization technique. In section 6, the major conclusions and prospects towards further research endeavours are summarised.

2. LITERATURE REVIEW

The approach to reviewing the literature adopted in the current study is to survey the tapped density literature and then specifically discuss contributions to orange peels literature. A summary of the literature concerning the first approach follows while that of the other is given afterwards. Wei et al. (2012) investigated the tapped density of $LiFePO_4/C$ microspheres made up of compactly packed nanosheets and found it to attain a peak of 1.5 g cm^{-3}. Xiao et al. (2006) synthesized spherical cobalt carbonate with high tap density, using the measured chemical crystal method. The results of physical properties indicate that the preparation process of the spherical cobalt carbonate with tap density was able to control the pH value and increase the tapped density.

Chevanan et al. (2008) investigated tapped density and observed that the maximum volume reduction ratio was found for switchgrass, wheat straw, and corn stover for fine-chopped samples and coarse-chopped samples. It was also observed that the infinite compressibility was the largest, for chopped switchgrass followed by wheat straw and corn stover. The degree of packing was lowest for chopped wheat straw which shows that the chopped wheat straw particle is closely packed together by tapping compared to chopped switchgrass and corn stover. Hauser ratio, a degree of internal friction, obtained after 50 taps was found to be between 1.114 to 1.321 for switchgrass, 1.105 to 1.309 for chopped wheat straw and 1.06 to 1.239 for chopped corn stover.

Lin et al. (2015) conducted experiments on the tapped density of lithium-ion battery electrode materials. Higher density packing of nanostructures was attained (1.38 gcm^{-3}, pellet form) which produced higher tap density (0.91 gcm^{-3}, powder form). Shah et al. (2015) described the influence of tapped density, compacted density and fluorescent drug concentration on the light-induced fluorescence (LIF) response. They observed that blend concentrations up to 4.00 % w/w API indicated a direct trend in LIF response with rising tapped and compacted density, negative parabolic trend in LIF response. Yang (2012) developed spherical $[Ni_{0.5}MnCo_{0.2}](OH_2)$ with narrow size allocation and high tap density as a forerunner to the preparation of $Li[Ni_{0.5}Mn_{0.3}Co_{0.2}]O_2$ by combining the forerunner with 6 % additional Li_2CO_3 trailed along by calcinations. Close-packing attributes of spherical secondary particles exhibit high-temperature properties and superior rate capacity. Ghosh and Chatterjee (2014) compressed aluminium-alumina compacts with different wt% of alumina within a pressure of about 115 to 290 MPa. Their investigation showed that densification of the compact rises with higher compacting pressure and reduces with higher alumina content.

Bayor et al. (2013) utilised starches from four fresh potato genotypes for tablet diluents, binders and disintegrants; with available maize starch as base. The sweet potato starches also resulted in considerable speedy tablet disintegration and release of paracetamol ($p = 0.005$). The outcome shows the sweet potato starches as better pharmaceutical diluents, binders and disintegrants in comparison to the base maize starch. Govedarica et al. (2011) observed that paracetamol (PAR) crystals were found to have low compressibility and flowability coupled with an inclination of its tablets to cover. The chief benefits of the formulation with coated paracetamol for massive manufacturing are the reduction of its friability, compressibility, faster disintegration and break-down.

Apeji et al. (2011) analysed the tabletting characteristics of microcrystalline starch (MCS) utilised as a direct compression excipient in the preparation of ascorbic acid tablets for comparative purposes with tablets prepared with microcrystalline cellulose (MCC). Their investigation showed that the mechanical properties of tablets prepared using MCS are similar to those of MCC. Minne et al. (2008) determined the effects of formulation excipients on the physical properties of inhalation of dry powders synthesized by spray drying. The particle diameter and powder density were evaluated using laser diffraction and tap density experiments, respectively. They observed that the quality and comparative amount of the excipients influenced the aerosol behaviour of the powders, majorly by changing the powder tap density and the extent of particle aggregation.

Several experimental investigations have been introduced in the literature concerning orange peels, its seed or particulates. Verzera et al. (2004), Nwobi et al. (2006) and Yeoh et al. (2008) are among the frontline articles, carried out in recent years on orange peels and seeds. Their focus was on oil extraction (pectin) from the orange peels and seeds. There were no particulates used in their analyses and no form of density measurements were taken from their experimental analysis. In addition, Pino et al. (2006) investigated the chemical composition of orange oil concentrates. Vora et al. (1983) carried out experiments on the preparation and chemical composition of orange oil concentrate over three decades ago. Yet in another study, Aigbodion et al. (2013) developed a high-density polyethylene/orange peel particulates composite. Ajibade et al. (2022) experimentally studied the moisture loss characteristics of orange peels and concluded that moisture losses could be measured for optimal control of the properties of fillers during the particulate orange peel used for composite manufacturing.

To name a few, Kumar (2012) presented an experimental study of orange peel-reinforced epoxy composite. Ojha et al. (2012) also studied the mechanical behaviour of orange peel-reinforced polymer composite. The last two studies (Kumar, 2012; Ojha et al., 2012) are among the few researches that have recognised the potential of orange peels as fillers for economic-based composite manufacturing. Both indicate that orange peel particulates have a large potential, especially in composite manufacture. However, additional research and development targeted at investigating the physical, chemical, electrical, mechanical and interfacing properties such as physico-mechanical, among others, are needed to prove the potential as critical economic and environmentally-friendly filler for composite fabrication and development. By taking sides on the need for more studies on orange peels and particulates, this research takes a new direction at variance from conducted experiments. The main focus of the research is to consider the tap density measurements of orange peel particulates as fillers for composite fabrications. The pursuit of tap density experimentations is urgently needed given its applications in processes where the advantages of particle size distribution, shape regularity, compaction, and compressibility are to be taken. There is extensive application of this nature in the agricultural produce industries. The operation of silos in which agricultural produce are loaded on another is a good application example. Knowledge of how the aforementioned factor of compatibility, among others is necessary for composite design purposes. Design for extended lifespan of composites is therefore dependent on the information obtained from experimental analysis on tap density.

3. MATERIALS AND EXPERIMENTAL PROCEDURE

3.1 Materials

Orange peel particulates were obtained primarily from waste orange peels collected from sellers of oranges in Bariga, Akoka and Yaba areas of Lagos state, Nigeria. They were processed by sun-drying to remove moisture and oils before being ground into particulate forms. Sieve analysis was carried out using a British standard test sieve (Wykeham Farrance) to obtain 0.075, 0.150, 0.212, 0.300, 0.425 and 0.600 mm particulate sizes. The experiments were performed on 0.425 mm and 0.600 mm sample sizes of OPPs because of their large quantities. Other materials used in this investigation are a British standard 250 ml graduated measuring cylinder (Uniscope) with a plastic base for the measurement of volume. A digital weighing balance (OHAUS Adventurer) having 2-decimal place accuracy, was used for measuring the mass of the OPPs before and after every application of taps.

3.2 Experimental procedure and details

In this section, the flow chart for the research scheme is shown in Figure 1. Furthermore, the tapped experiments were carried out according to the standard test methods B527, D1464 and D4781 for tapped density. This section describes the experimental procedure and the tapped density measurement method adopted to carry out the research. The number of taps, 0.425 mm sample size readings and 0.600 mm sample size readings were chosen as the process parameters. In the result section, the selected process parameters and their levels are displayed. In the entire process, the experiments were carried out at normal room temperature conditions of 25.5^{o}C and an absolute humidity of about 30 g/m^3 respectively. This study was carried out using the steps outlined in Figure 1. A detailed explanation of each of the steps is presented in this section. This work is borne out of the need to characterize the properties of orange peel particulates which are hitherto unknown. Ten experimental runs were performed on both sample sizes of the orange peel particulates for consistency and comparative analysis.

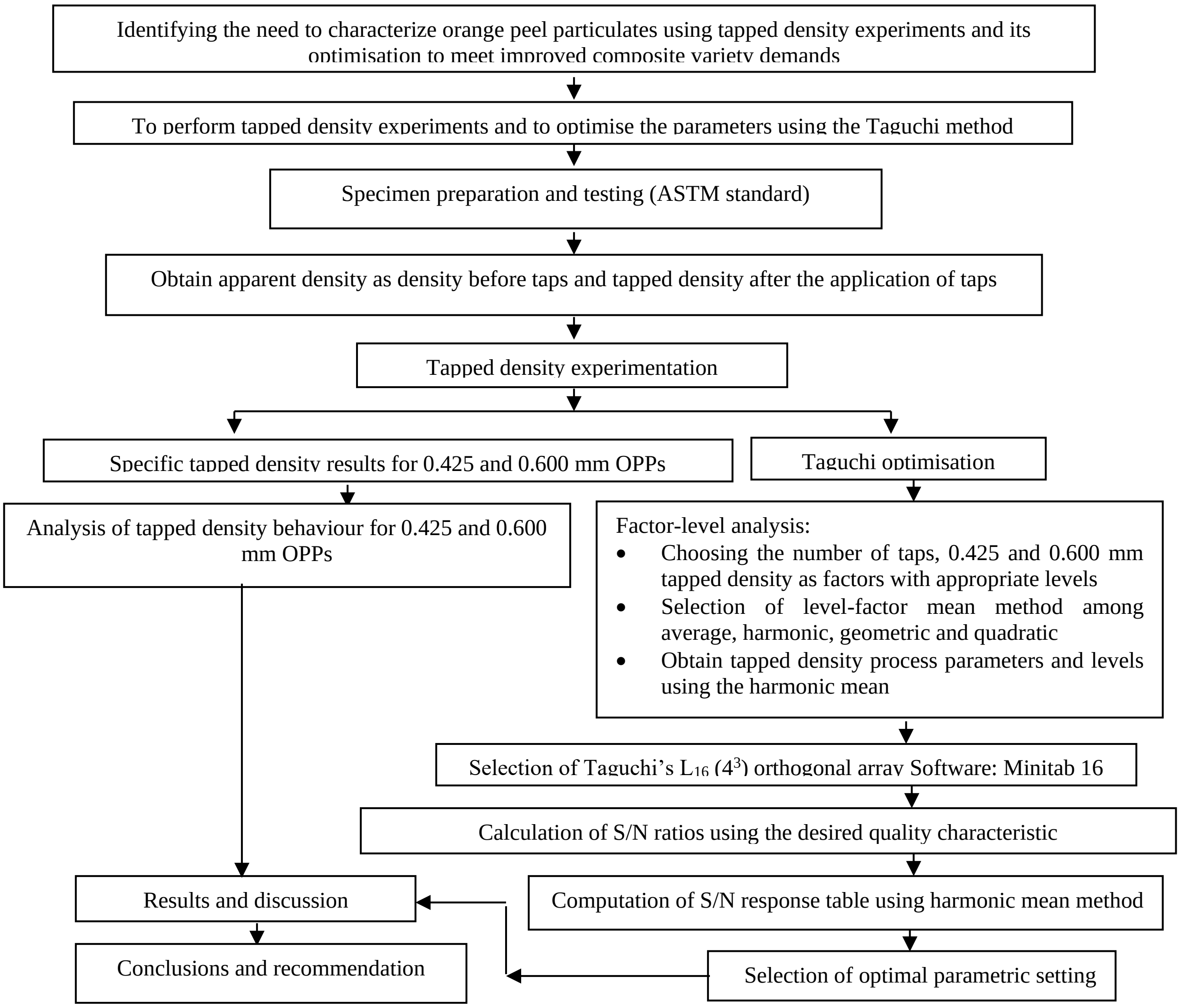

Figure 1: Research scheme for the current study

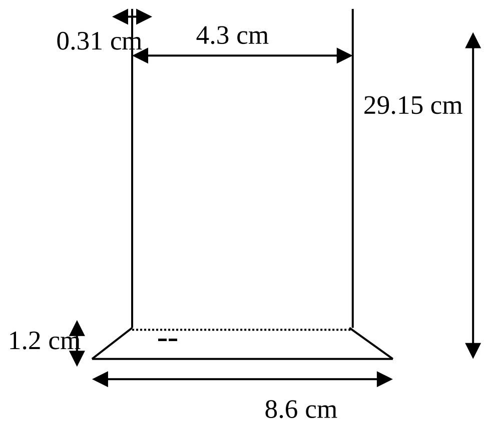

Figure 1. Dimensions of measuring cylinder used for measuring the volume of tapped specimen

Each run comprises 13 measurements of mass, volume and density. A run begins with a '0' number of taps and the corresponding mass and volume measurements are used in obtaining the apparent density ρ_a. This is followed by 12 successive taps in steps of '4' from which the tap density ρ_t measurements are obtained. The large number of experimental runs and extensive number of taps have been carried out to broaden the range of experimental results giving room for more analysis and discussions. The measurements carried in the tapped density experiments are in two categories namely, how to determine the volume and mass of the tapped specimen.

The mass of the tapped specimen was measured using a digital weighing balance (OHAUS Adventurer) with 2 decimal place accuracy. However, the mass of the tapped specimen was not measured directly because it was in the measuring cylinder. Therefore, the mass of the tapped specimen is determined by subtracting the mass of the cylinder from the mass of the cylinder which contains the specimen. This was continued for every successive application of taps to the cylinder. By direct observation from the measuring cylinder (Figure 2), the volume of the tapped OPPs was read at every successive application of taps. For example, at the initial level, the sample was poured into a measuring cylinder to a specific height i.e. 80 cm^3. Then, based on a regular number of taps (say 4) the new height of the specimen is then measured which is expected to be lower than the previous. The next set of taps (4) was applied subsequently and the observation of the new reading on the measuring cylinder was made. This was continued until an insignificant reduction in height was experienced between successive taps. In this case, 48 taps is the reference point. The approach followed is the height method of tapped density.

The particulate orange peels, stored in polyethylene bags were examined for any agglomerates, and if found, were broken up, since it is possible to have such during storage. It was gently done to avoid changing the nature of the particulate orange peels. The particulate orange peels are then gently introduced without compacting, into the measuring cylinder of 250 ml (readable to 2 ml), using weights of approximately equivalent to 20 ml at a time in a small cylinder measured on a weighing scale. The weight was measured with an accuracy of 0.1 percent accuracy. The tapped density is then measured as the filling height reaches say 100 ml. Successive taps are then applied and measurements of volumes and masses are taken again on the cylinder and weighing machine, respectively.

4. RESULTS AND DISCUSSION

The tapped density behaviour of the 0.425 and 0.600 mm OPPs is described in Tables 1 and 2. The tapped density behaviour of the sample sizes will be understood by considering two perspectives. First, is by analysing the mean tapped density of each run and second is by evaluating the mean tapped density along the successive taps.

4.1 Tapped density behaviour 0.425 and 0.600 mm OPPs

The mean tapped density of each run changed as different samples of the 0.425 mm OPPs were used. In run 1, the average tapped density was obtained as 3.412 g/cm^3 which dropped slightly to 3.40 g/cm^3 in run 2. However, runs 3 and 4 produced the same average tapped density of 3.47 g/cm^3. In run 5, the average tapped density dropped slightly to 3.45 g/cm^3 and further undulated between 3.42, 3.47, and 3.37 g/cm^3 respectively, for runs 6, 7 and 8. The average tapped density reached a peak of 3.53 g/cm^3 in run 9 before dropping slightly to 3.43 g/cm^3 in run 10. The changes in the average tapped density may be a result of slight differences in the composition of the 0.425 OPPs, thereby affecting their response to the application of taps. The change could also be attributed to the differences in the intensity of the applied taps. For runs 3 and 4, the combined effect of the intensity of taps and the composition of grains could have been responsible for the same average tapped density of 3.47 g/cm^3.

For the average tapped density along the taps, the values are largely affected by the increasing number of taps in the measuring cylinder. It can be observed that there is a steady rise in the average tapped density of the OPPs as the taps increase. At zero number of taps, the average apparent density is 3.22 g/cm^3. As the number of taps rises in steps of four, the tapped density increases to 3.332, 3.37, 3.401, 3.438, 3.457, 3. 507, 3.51, 3.534, 3.544 and 3.555 g/cm3 for 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44 and 48 number of taps, respectively. This behaviour shows that in all the runs, the number of taps is instrumental to the average tapped density.

Table1. Density measures in several taps for 10 runs (ρ , g/cm^3) considering 0.425 mm orange peel particulates

No. of taps	Runs										
	1	2	3	4	5	6	7	8	9	10	Mean
0	3.22	3.21	3.19	3.20	3.20	3.23	3.22	3.24	3.30	3.19	3.22
4	3.26	3.26	3.27	3.24	3.28	3.27	3.26	3.28	3.39	3.23	3.27
8	3.35	3.30	3.37	3.37	3.37	3.27	3.35	3.28	3.43	3.23	3.33
12	3.38	3.34	3.42	3.42	3.37	3.31	3.35	3.32	3.47	3.32	3.37
16	3.43	3.39	3.42	3.42	3.41	3.35	3.39	3.36	3.47	3.37	3.40
20	3.43	3.39	3.46	3.46	3.46	3.40	3.44	3.41	3.52	3.41	3.44
24	3.43	3.39	3.51	3.51	3.46	3.44	3.44	3.41	3.57	3.41	3.46
28	3.46	3.43	3.51	3.51	3.51	3.49	3.48	3.41	3.57	3.41	3.48
32	3.46	3.48	3.56	3.56	3.55	3.49	3.48	3.41	3.62	3.46	3.51
36	3.48	3.48	3.56	3.56	3.56	3.49	3.48	3.41	3.62	3.46	3.51
40	3.48	3.52	3.61	3.61	3.58	3.49	3.48	3.45	3.62	3.50	3.53
44	3.49	3.52	3.61	3.61	3.58	3.53	3.53	3.45	3.62	3.50	3.54
48	3.49	3.52	3.61	3.61	3.58	3.54	3.53	3.45	3.67	3.55	3.56
$\bar{x}$	3.412	3.40	3.47	3.47	3.45	3.40	3.42	3.37	3.53	3.43	3.44
δ	0.083	0.099	0.128	0.129	0.114	0.105	0.097	0.069	0.104	0.111	0.103
*Min	3.22	3.21	3.19	3.20	3.20	3.23	3.22	3.24	3.30	3.22	3.223
**Max	3.49	3.52	3.61	3.61	3.58	3.54	3.53	3.45	3.67	3.58	3.558

Key: *Min = Minimum, **Max = Maximum

Table 2. Density measures in the number of taps for 10 runs (ρ , g/cm^3) considering 0.600 mm orange peel particulates

No. of Taps	Runs										
	1	2	3	4	5	6	7	8	9	10	Mean
0	3.17	3.18	3.18	3.18	3.17	3.23	3.19	3.20	3.19	3.20	3.189
4	3.19	3.22	3.22	3.26	3.21	3.27	3.23	3.24	3.27	3.24	3.235
8	3.26	3.26	3.34	3.30	3.29	3.39	3.27	3.28	3.36	3.24	3.299
12	3.34	3.34	3.39	3.34	3.33	3.44	3.31	3.37	3.40	3.32	3.358
16	3.39	3.39	3.43	3.43	3.42	3.49	3.36	3.41	3.44	3.46	3.422
20	3.43	3.43	3.43	3.43	3.42	3.54	3.40	3.46	3.44	3.41	3.439
24	3.43	3.48	3.48	3.48	3.47	3.54	3.40	3.46	3.49	3.41	3.464
28	3.43	3.48	3.48	3.48	3.47	3.54	3.45	3.46	3.49	3.41	3.469
32	3.44	3.48	3.48	3.53	3.52	3.58	3.45	3.50	3.49	3.46	3.498
36	3.46	3.53	3.53	3.53	3.57	3.64	3.50	3.50	3.54	3.46	3.526
40	3.48	3.53	3.53	3.58	3.62	3.64	3.50	3.50	3.54	3.50	3.547
44	3.48	3.55	3.55	3.58	3.67	3.64	3.50	3.55	3.59	3.50	3.564
48	3.53	3.58	3.58	3.58	3.67	3.64	3.50	3.60	3.59	3.55	3.582
$\bar{x}$	3.39	3.419	3.43	3.44	3.45	3.50	3.38	3.43	3.45	3.40	3.428
δ	0.108	0.182	0.118	0.131	0.158	0.133	0.105	0.116	0.115	0.108	0.127
*Min	3.175	3.18	3.18	3.18	3.17	3.23	3.19	3.20	3.19	3.20	3.189
**Max	3.53	3.58	3.58	3.58	3.67	3.64	3.50	3.60	3.59	3.55	3.582

Key: *Min = Minimum, **Max = Maximum

For the 0.600 mm OPPs, the mean tapped density of each run as different samples of 0the sample size were used. The average tapped density for run 1 was obtained as 3.39 g/cm3. The average tapped density increased progressively to 3.419, 3.43, 3.44, 3.45 and 3.5 for runs 2, 3, 4, 5 and 6, respectively. However, the average tapped density in run 7 decreased sharply to 3.38 g/cm3. It rises further in runs 8 and 9 to 3.43 and 3.45 before dropping to 3.40 g/cm^3 in run 10. Again, the joint influence of changes in the intensity of taps and slight differences in the composition of grains could be responsible for the different values of the average tapped density from run 1 to 10. The mean tapped density along the taps increased accordingly with a higher number of taps. With zero number of taps, the average apparent density is given as 3.189 g/cm3. Further increase in the number of taps in steps of four, the average tapped density increases to 3.325, 3.299, 3.358, 3.422, 3.439, 3.464, 3.469, 3.498, 3.526 and 3.547 g/cm^3 reaching a peak of 3.582 g/cm^3 at 48 number of taps. This correlates with the tap density behaviour of the 0.425 OPPs, that a higher number of applied taps is responsible for increased tapped density values.

5. TAGUCHI OPTIMISATION TECHNIQUE

Taguchi optimisation is a proven method of obtaining the best or most profitable results from a process or an effective way of putting a process to its best advantage. It has powerful, product quality characteristics improvement, reliability and low-cost attainment potentials. Taguchi's method uses factors and levels to describe each process or experiment. Factors are the parameters involved in the experiment, while the levels describe the conditions of the factors during stages of the experiment. Zareh et al. (2013) observed that the Taguchi method involves three major stages, namely, the system design, parameter design and tolerance design. The system design is used to determine appropriate working levels of the factors, while the parameter design is used to pick the factor levels that can produce the optimum performance of the process under investigation. Lastly, the tolerance design is used to adjust the outcome of the parameter design by guaranteeing that the tolerance factors have a significant effect on the product. These design methods have been used successfully over the years with the arithmetic method of mean to obtain factor levels and S/N ratio response determination.

However, Ajibade et al. (2015) in their work investigated the Taguchi methodological approach by using another method of means to derive factor levels and output responses for the optimisation of moisture loss and drying properties of orange peels. They concluded that the harmonic mean could be used to obtain better optimal results in the face of scarce resources than the conventionally used arithmetic mean. According to this, the same innovation will be applied in the current investigation. In Ajibade et al. (2015), the factors used in the Taguchi optimisation of orange peel moisture loss are the parameters involved directly in the moisture loss and drying experiments such as weights before and after drying, time of drying and density of the dried orange peels. To obtain the best possible combination of parameters that would give the desired light-density composite variety, a novel approach was used to obtain the factors used in the present investigation. The number of taps which starts from 4 and increases in steps of '4' to 48 was bifurcated into four using the harmonic mean to obtain 8.727, 19.459, 31.644 and 43.756. the average tapped densities of the 0.425 mm OPPs obtained at successive application of taps across all the 10 runs were bifurcated using the harmonic mean was obtained as 4.433, 3.431, 3.498 and 3.544 g/cm3, while that of the 0.600 mm OPPs was given as 4.395, 3.441, 3.497 and 3.564 g/cm3. This ensures we have the average tapped density of each sample size at every increase of taps across all 10 runs. Thus, we have a three-factor-four and four-level optimisation problem.

Table 3. Tapped density process parameters and levels obtained using the harmonic mean

Parameters	Level 1	Level 2	Level 3	Level 4
A: No of taps (*n*)	8.727	19.459	31.644	43.756
B: 0.425 mm tapped density (g/cm^3)	4.433	3.431	3.498	3.544
C: 0.600 mm tapped density (g/cm^3)	4.395	3.441	3.497	3.564

For a three-factor-four level combination, the experimental outline was obtained using a commercially available software package (Minitab 16) to generate an L_{16} (4^3) orthogonal array described in Table 4 for the design of experiments. Taguchi method makes use of the signal-to-noise (S/N) ratio to know the degree of performance. The S/N ratio is given by the logarithmic value of the desired response which is the objective function for the optimisation (Roy, 2001). The three major quality characteristics used for measuring S/N ratios in the Taguchi technique are the "lower-the-better" (LB), "higher-the-better" (HB) and "nominal-the-best" (NB). In this investigation, the minimum tapped density of the OPP is required to obtain a low-density composite that can meet improved composite variety demands. Therefore, the (LB) quality characteristics are used as follows

$$S/N(\eta) = 10\log10\left(\frac{\mu^2}{\delta^2}\right) \quad (1)$$

where $\mu = 1/n \sum y_i$,

$\delta^2 = 1/(n-1) \sum (y_i - \mu)^2$

$y_1, y_2, \ldots, y_n$ are the individual responses of tapped density parameters and n denotes the number of observations. Irrespective of the quality characteristic used, a higher S/N ratio denotes a superior quality characteristic (Zareh et al., 2013). Therefore, the factor level combinations with the highest S/N ratio are chosen as the optimal parametric setting for the tapped density experiment.

Table 4. Taguchi's L_{16} (4^3) orthogonal array

Exp. Trial	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	1	4	4
5	2	1	2
6	2	2	1
7	2	3	4
8	2	4	3
9	3	1	3
10	3	2	4
11	3	3	1
12	3	4	2
13	4	1	4
14	4	2	3
15	4	3	2
16	4	4	1

Table 5. Experimental results for tapped density with S/N ratio

Exp. Trial	A	B	C	S/N ratio
1	8.727	4.433	4.395	-6.476
2	8.727	3.431	3.441	-7.045
3	8.727	3.498	3.497	-7.002
4	8.727	3.544	3.564	-6.963
5	19.459	4.433	3.441	-8.713
6	19.459	3.431	4.395	-8.727
7	19.459	3.498	3.564	-8.953
8	19.459	3.544	3.497	-8.960
9	31.664	4.433	3.497	-9.698
10	31.664	3.431	3.564	-9.910
11	31.664	3.498	4.395	-9.706
12	31.664	3.544	3.441	-9.912
13	43.756	4.433	3.564	-10.2
14	43.756	3.431	3.497	-10.392
15	43.756	3.498	3.441	-10.39
16	43.756	3.544	4.395	-10.21

Table 6. S/N response table for tapped density parameters using Harmonic mean

Parameter	Mean S/N ratio			
	Level 1	Level 2	Level 3	Level 4
A	-6.863*	-8.837	-9.805	-10.297
B	-8.504*	-8.817	-8.815	-8.810
C	-8.511*	-8.813	-8.815	-8.806

*Optimal values, A: No of taps (n), B: 0.425 mm tapped density (g/cm^3), C: 0.600 mm tapped density (g/cm^3)

Therefore, the optimal parametric setting for the Taguchi optimisation of OPP tapped density is given as $A_1B_1C_1$. This can be interpreted as 8.727 numbers of taps, a tapped density of 4.433 g/cm^3 for 0.425 mm OPP and a tap density of 4.395 g/cm^3 for the 0.600 mm OPPs. To obtain the optimal tapped density of 0.425 mm OPP to meet improved composite variety demands, 8.727 number of taps would be used to obtain 4.433 g/cm^3. For the 0.600 mm OPP, the required number of taps would be 8.727 while the optimal tapped density would be 4.395 g/cm^3.

The major contribution of this paper is in the experimental investigation of tapped density measurements and the optimisation of the parametric values of the model. A comparison of the current paper with the literature would be helpful to know the differences and characteristics of this experimental work. Comparisons are made on the considerations and methodology of the experiments. Compared with the previous studies, the current paper has several substantial merits and makes the following contributions: (1)

(1) Previous scientific measurements on the density of composite-based fillers have been carried out using direct measurements of mass divided by volumetric measures of powders and the current paper, at variance with previous works has considered tap density instead. This is a new scientific viewpoint on how density is measured;
(2) The optimisation of density measurements on orange peel particulates has not been previously treated and this study has considered using the Taguchi method for the optimisation process of tap density. This is a unique approach to the analysis of the optimisation problem. This approach is particularly interesting as a novel method whereby harmonic mean is utilised to define the factor/level as well as the S/N response. This has not been previously done for tap density measurements.
(3) The Taguchi method offers a cost-reduction approach in experimentation and the application of the Taguchi method in tap density measurements is unique and will save project costs.

5.1 Practical application

In practical composite fabrication, the challenge is how to implement the results of the tapped density of particulate fillers without being lost in the manufacturing process. How can the OPPs which have been tapped for up to 12 runs with a maximum of 48 taps in the final run be used as fillers in composite production, without losing the compacted density obtained by tapped experiments? In the current investigation, a 250 ml measuring cylinder with a diameter opening of 4.3 cm has been used. The limitation of this apparatus is that it does not permit the mixing of its content as a result of its narrow opening. The practical answer would be the use of a beaker with a plastic base which has a wider opening that allows mixing if necessary. The use of a beaker with a wide diameter opening would allow the OPPs to respond better to the application of taps. After the experiment, the tapped density of the OPPs can be preserved using two different approaches. The first approach is by scooping out the desired volume of the OPPs with a measuring spoon directly into a separate beaker containing the desired matrix to be used before mixing and casting into a mould. The second is by carefully scooping out the OPPs and leaving the required volume of the OPPs in the beaker before adding the matrix.

The strength of this work lies in its novelty. This would be the first time the tapped density investigation of OPPs has been carried out in literature to the best of our knowledge. Further, the optimisation of the tapped density was performed using the Taguchi method to have a light-density composite which will meet improved variety demands. The newness of this work also lies in the author's ability to devise simple experiments with easy-to-use apparatus. Lastly, the ingenuity of the authors in providing answers to a practical problem which can limit the use of obtained tapped density in composite fabrication is worthy of mention.

6. CONCLUSIONS

Tap density measurements, which potentially provide some directions on the densification characteristics of green fillers and subsequently hint at the structural integrity of the composites to which they are made up is a promising technique for assuring cost-effective composites of structural integrity through densification information. The purpose of the current work is to investigate the tap density of orange peel particulates.

Based on the analysis of the tapped density behaviour of the 0.425 and 0.600 OPPs sample sizes, the following conclusions are made: In a range of taps from 1 to 48 points, and for ten runs each, all tapped points showed that 0.425mm OPP has a higher average apparent density of 3.22g/cm^2 than 0.600mm (i.e. 3.189g/cm^3) except for points at 8, 28 and 32 taps. This phenomenon can be attributed to the finer grains of the 0.425mm OPP which compacts better and increases in density with the application of taps. Besides, there was an improvement of 6.25% in the average tapped density of the 0.425mm OPP over the average apparent density of the same grade of particulate. Furthermore, for the 0.600mm OPP, its average tapped density improved by 6.97% compared to its average apparent density. This improvement indicates that its grains are loose and not tightly held like the 0.425mm OPP, which gives it a better response to the application of taps and higher improvement. Moreover, the following additional conclusions are relevant. It was found that the Taguchi optimal setting for tapped density of OPP is given was $A_1B_1C_1$, which reads as 8.727 number of taps, a tapped density of 4.433 and 4.395g/cm^3, respectively for the 0.425 and 0.600mm OPP samples sizes. This means that the required number of taps to obtain OPPs with light density and structural integrity to meet improved composite variety demands would be 8.727 taps, while a tapped density of 4.433 and 4.395g/cm^3 is required for the 0.425 and 0.600mm OPP sizes.

REFERENCES

Aigbodion V.S., Atuanya C.U., Igogori E.A. and Ihom P., 2013, Development of high-density polyethylene/ orange peels particulate bio-composite, Gazi University Journal of Science, Vol. 26, No. 1, pp. 107-117.

Ajibade, O.A., Agunsoye, J.O. and Oke, S.A. 2015a, Experimentation and prediction of moisture characteristics and density of sweet orange peels used for epoxy-based composite fabrication, Journal of The Association of Professional Engineers of Trinidad and Tobago, Vol.43, No.2, pp.44-52.

Ajibade, O.A., Agunsoye, J.O. and Oke, S.A., 2015b. Analysis of the free-swell behaviour of orange peel particulates as reinforcement for green composite fabrication, Acta Periodica Technologica, Vol. 46, pp. 131-147

Ajibade, O.A., Agunsoye, J.O. and Oke, S.A., 2016. A grey relational analytical approach to orange peel filler particulates for tapped density experiments of green composite reinforcements, KKU Engineering Journal, Vol. 43, No. 3, pp. 108-119

Ajibade, O.A., Agunsoye, J.O. and Oke, S.A., 2017, Optimisation of water absorption properties of orange peel particulate-based epoxy composite using grey relational analysis, West Indies Journal of Engineering, Vol. 39, No. 2, pp. 25-35

Ajibade O.A., Agunsoye J.O., Oke S.A. 2021, Taguchi method and Taguchi-Pareto scheme to evaluate diffusivity during the development of orange peel epoxy composites, Journal of Applied Science & Process Engineering, Vol. 8, No. 1, pp. 765-785

Ajibade O.A., Agunsoye J.O., Oke S.A. 2022, An optimization of moisture losses and drying properties of orange peel reinforcement for composite fabrication using the Taguchi method, Engineering Access, Vol. 8, No. 1, pp. 84-95. https://doi.org/10.14456/mijet.2022.12

Apeji Y.E., Oyi A.R., and Musa H., 2011. Formulation and evaluation of ascorbic acid tablets by direct compression using microcrystalline starch as a direct compression excipient, International Journal of Health Research, Vol. 4, No. 3, pp. 111-106.

Balti S., Boudenne A., Dammak L., Handi N., 2023, Mechanical and thermophysical characterization of gypsum composites reinforced by different wastes for green building applications, construction and Building Materials, Vol. 372, Article 130840. https://doi.org/10.1016/j.conbuildmat.2023.130840

Barile C. Casavola C., Pappalettera G., Pappalettere C., Vimalathitham P.K., 2019, Investigation of structural Integrity of Composites Materials using wavelet packet transform, Procedia Structural Integrity, vol. 17, pp. 582-588. https://doi.org/10.1016/j.prostr.2019.08.078

Bayor M.T., Tuffour E., and Lambon P.S., 2013. Evaluation of starch from new sweet potato genotypes for use as a pharmaceutical diluent, binder or disintegrant, Journal of Applied Pharmaceutical Science, Vol., 3, pp.

S17-S23. https://doi.org/10.7324/JAPS.2013.38.S4

Beltran J.R., Pino S., 2023, A numerical approach to bound the asymmetrical surface-damage metallic strands response accounting for bending stiffness nonlinearity: Damage and structural integrity evaluation purposes, Structures, Vol. 55, pp. 606-625. https://doi.org/10.1016/j.istruc.2023.06.038

Bradu P., Biswas A., Nair C., Sreevalsakumar S., Patil M., Kannampuzha S., Mukherjee A. G., Wanjari U. R., Renu K., Vellingiri G., Gopalakrishnan A. V., 2022, Recent advances in green technology and industrial revolution 4.0 for a sustainable future, Environmental Science and Pollution Research. https://doi.org/10.1007/S11356-022-20024-4

Chevanan N., Womac A.R., and Bitra V.s., 2008. Loose-filled and tapped densities of chopped switchgrass, corn stover and wheat straw, ASABE Annual International Meeting, Rhode Island Convention Centre, Providence, Rhode Island.

Ghosh A., and Chatterjee S., 2014. Effect of Al_2O_3 content and process variables on structure and properties of Al-Al_2O_3 compacts, Journal of Minerals and Materials Characterization and Engineering, No. 2, pp. 121-128. https://doi.org/10.4236/jmmce.2014.22016

Govedarica B., Injac R., Dreu R., and Srcic S., 2011. Formulation and evaluation of immediate release tablets with different types of paracetamol powders prepared by direct compression, African Journal of Pharmacy and Pharmacology, Vol. 5, No. 1, pp. 31-41. https://doi.org/10.5897/AJPP10.274

Jamwal V., Mittal A., Dhaundival A., 2023, Valorization of agro-industrial waste in composite films for sustainable packaging applications, Materials Today: Proceedings. https://doi.org/10.1016/j.mtpr.2023.08.042

Kumar S.T., 2012. Mechanical behaviour of orange peel reinforced epoxy composite, Unpublished B. Tech Project, Department of Mechanical Engineering, National Institute of Technology, Rourkela, India.

La Mantia F.P. and Morreale M., 2011. Green composites: A brief review, Composites Part A: Applied Science and Manufacturing, Vol. 42, No. 6, pp. 579-588. https://doi.org/10.1016/j.compositesa.2011.01.017

Lin D., Lu Z., Hsu P., Hye R.L., Nian L., Jie Z., Haotian W., Chong L., and Yi C., 2015. A high tap density secondary silicon particle anode fabricated by scalable mechanical pressing for lithium-ion batteries, Royal Society of Chemistry, Energy and Environmental Science, Vol. 8, pp. 2371-2376. https://doi.org/10.1039/C5EE01363A

Mohanty A.K., Misra M., and Drzal L.T., 2002. Sustainable bio-composites from renewable resources: Opportunities and challenges in the green materials world, Journal of Polymers and the Environment, Vol. 10, No. 1/2, pp. 19-26. https://doi.org/10.1023/A:1021013921916

Minne A., Boireau H., Horta M.J., and Vanbeuer R., 2008. Optimisation of the aerosolization properties of an inhalation dry powder based on selection of excipients, European Journal of Pharmaceutics and Biopharmaceutics. Vol. 70, No. 3, pp. 839-844. https://doi.org/10.1016/j.ejpb.2008.06.013

Nath A. Ray A, Ray K. K., 2023, Analyses of the model parameters of kinematic isotropic hardening rule using genetic algorithm approach for predicting cyclic-plasticity of metallic structural materials, Procedia Structural Integrity, Vol. 43, pp. 246-251. https://doi.org/10.1016/j.prostr.2022.12.266

Nwobi B.E., Ofoegbu O., and Adesina O.B., 2006. Extraction and qualitative assessment of African sweet orange seed oil, African Journal of Food Agriculture Nutrition and Development, Vol. 6, No. 2, pp.1-11. https://doi.org/10.4314/ajfand.v6i2.71747

Ojha S., Raghavendra G., Acharya S.K. and Kumar P., 2012. Fabrication and study of mechanical properties of orange peel reinforced polymer composite, Caspian Journal of Applied Sciences Research, Vol.1, No. 13, pp. 190-194.

Pino J., Sanchez M., Sanchez R., and Rocal E., 2006. Chemical composition of orange oil concentrates, Nahrung/Food, Vol. 36, No. 6, pp. 539-542.

Shah I.G., Ely K.J., and Stagner W.C., 2015. Effect of tapped density, compacted density, and drug concentration on light-induced fluorescence response as a process analytical tool, Journal of Pharmaceutical Sciences, Vol. 104, No.5, pp. 1732-1740. https://doi.org/10.1002/jps.24386

Vora J.D., Matthews R. F., Crandall P.G. and Cook R., 1983. Preparation and chemical composition of orange oil concentrates, Journal of Food Science, Vol. 48, No. 4, pp.1197. https://doi.org/10.1111/j.1365-2621.1983.tb09190.x

Verzera A., Trozzi A., Dugo G., Di Bella G., Cotroneo A., 2004. Biological lemon and sweet orange essential oil composition, Flavour and Fragrance Journal, Vol. 19, No. 6, pp. 544-548. https://doi.org/10.1002/ffj.1348

Wang Z., Subramanian N., Gunasekaran A., Abdulrahman M.D., Liu C., 2015 Composite sustainable manufacturing practice and performance framework: Chinese auto-parts suppliers perspective, International Journal of Production Economics, Vol. 170, pp. 219-233. https://doi.org/10.1016/j-ijpe.2015.09.035

Wei W., Dezhi C., Ruining W. and Lin G., 2012. Hierarchical LiFEPO4/C microspheres with high tap density assembled by nanosheets as cathode materials for high-performance Li-ion batteries, Nanotechnology, Vol.23, No. 47. https://doi.org/10.1088/0957-4484/23/47/475401

Xiao J., Wang J., Liu Y., Li J., Li Y., 2006. Preparation of spherical cobalt carbonate powder with high tap density, Journal of Central South University of Technology, Vol. 13, No. 6, pp. 642-646. https://doi.org/10.1007/s11771-006-0008-6

Yang S., Wang X., Yang X., Liu Z., Wei Q., and Shu H., 2012. High tap density spherical $Li[Ni_{0.5}Mn_{0.3}Co_{0.2}]O_2$ cathode material synthesized via continuous hydroxide co-precipitation method for advanced Lithium-ion batteries, International Journal of Electrochemistry, Article ID 323560, https://doi.org/10.1155/2012/323560

Yeoh S., Shi J., Langrish T.A.G., 2008. Comparison between different techniques for water-based extraction of pectin from orange peels, Desalination, Vol. 218, pp. 229-237. https://doi.org/10.1016/j.desal.2007.02.018

Zareh B., Gorji A.H., Bakhshi M., and Nourouzi S., 2012. Study on the effect of forming parameters in sheet hydrodynamic deep drawing using FEM-based Taguchi method, International Journal of Advanced Design and Manufacturing Technology, Vol.6, No. 1, pp. 87-99.

Zhang Y., Shen G., Lam S.S., Ansar S., Jung S.-C., Ge S., Hou L., Fan Z., Wang F., Fan W., 2023, A waste textiles-based multilayer composite fabric with superior electromagnetic shielding, infrared stealth and flame retardance for military applications, Chemical Engineering Journal, Vol. 471, Article 144679. https://doi.org/10.1016/j.ccej.2023.144679