DOI: 10.31276/VJSTE.66(2).61-68

Determination of critical properties of orange peel for a polymer reinforcement material

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

[1]Department of Metallurgical and Materials Engineering, University of Lagos, University Road, Akoka, Yaba Local Government, Lagos, Nigeria
[2]Department of Mechanical Engineering, University of Lagos, University Road, Akoka, Yaba Local Government, Lagos, Nigeria

Received 8 January 2024; revised 31 January 2024; accepted 4 March 2024

Abstract:

Accurately determining the critical properties of orange peels ensures composite engineers can successfully monitor and control in-service composite failures. However, the current approaches to property determination are deficient, lack critical analysis, and are not wide-ranging. Thus, they fail to accurately establish the important properties of orange peels. To overcome this challenge, this article establishes the compressive strength, heat absorption, and electrical conductivity of an orange peel polymer to understand the behaviour of the material in lightweight composite applications. Three experimental sets were used to determine the three mentioned properties. The results obtained showed that the average heat energy absorbed by the samples of collected orange peels in 28 poly bags was 79.32 J. The highest and lowest heat absorbed by the samples was found to be 162.03 and 11.08 J, respectively. The average electrical conductivity was measured at 0.025σ while the average resistance, length, and surface area of 20 orange peel samples were found to be 27.24Ω, 2.92 cm, and 7.02 cm^2, respectively. The resistance of the orange peels had the greatest influence on their electrical conductivity. Lastly, the compressive shear strengths of the 0.300, 0.425, and 0.600-mm orange peel particulates were found to be 41.86, 14.82, and 9.58 kN/m^2, respectively. With this information, composite design engineers using orange peel reinforcements could improve their design accuracies and extend in-service composite lives.

Keywords: **composites, electrical conductivity, heat energy absorption, orange peels, resistance.**

Classification numbers: **2.3, 5.1, 5.3**

1. Introduction

The composite material development industry is governed by the imperative to adhere to carbon neutrality and the peaking policies of governments [1, 2]. Therefore, the development of new green materials, particularly orange peels, which are plentiful and are free at the source, is crucial [3]. In the past, the behaviour of orange peels was evaluated mechanically [3-5]. However, it was recognised that in-service orange peel-based composites absorb infrared radiation and warm up as the waves strike them. The resulting heat stress triggers dehydration, influencing the lifespan of the composites. Moreover, it has been observed that orange peel-based composites can fail in ductility. Additionally, extremes in soil electrical conductivity can impede crop growth. Therefore, considering the importance of heat absorption, electrical conductivity, and compressive strength, incorporating these into a set of mathematical measures is vital for the advancement of property evaluation. As material property assessment progresses, confining evaluations to mechanical, rheological, and chemical properties are increasingly insufficient. Consequently, a method that encompasses heat absorption, electrical conductivity, and compressive strength is necessary to ensure consistent design standards and reliable data for reinforcement materials, such as orange peel.

Despite extensive research on the mechanical properties of orange peels, their potential for heat absorption has been overlooked [3-5]. The literature has also neglected the relevance of compressive strength and the opportunity to enhance the electrical conductivity of orange peel-based composites in design [3-5]. Therefore, despite the abundant knowledge, the heat absorption properties that elucidate the heat transfer rates within orange particles remain underexplored [6-9]. Moreover, the overlooked compressive strength in the literature has implications for structural integrity in designs, and the neglect of electrical conductivity overlooks the durability of structures based on orange peel composites.

However, electrical conductivity measurements, compressive strength, and heat absorption of materials have

---

[*]*Corresponding author: Email: sa_oke@yahoo.com*

been substantial investigation topics in materials science and engineering. Pioneering work on electrical conductivity is attributed to Benjamin Franklin, while Stephen Timoshenko significantly contributed to our understanding of compressive strength. Newton is largely credited for his work on heat transfer in materials.

Recent studies, such as S.M. Jubihulla, et al. (2022) [10], have determined various properties of the *Albizia Julibrissin* plant stem, revealing high cellulose content and low lignin levels. R. Kumar, et al. (2022) [11] presented chemical composition values for *Acacia nilotica* L. fibre, focusing on cellulose, ash content, and lignin. Additionally, R. Vijay, et al. (2022) [12] evaluated the properties and tensile strength of *Vachellia farnesiana* fibre material. J.S.N. Raju, et al. (2022) [13] assessed the thermal, XRD, physical, morphological, and chemical properties of *Symphirema involucratum* stem fibre.

From the literature, there has been a noticeable increase in property evaluation research for green materials, many of which are utilised for polymer reinforcement in composite development. There are also some specific papers tackling the niche aspect of polymer property assessment. O.A. Ajibade, et al. (2016) [14] applied the grey relational analysis for the optimisation of tapped density for particular orange peels. They focused on characterising optimisation information on masses and volumes of the two-grade peels (i.e. 0.425- and 0.600-mm peel particulates) in concept type such that black represents conditions where no information exists and white where perfect information could be obtained. The paper strongly emphasised experimental runs and their conversion of optimal parametric settings. This emphasis is also shown in a comparative attempt of the Taguchi method with the grey relational analysis. However, the optimisation data presented in the results section of the article is limited to only one property, which is tapped density, hence does not represent the major aspects of the much-desired material properties of orange peel particulates. It does not contain information about compressive strength, electrical conductivity, and heat energy absorption. Although tapped density measures the heat effects on particulates after the mobility of the particulates, thus is expensive and not sustainable in a production process. In summary, the paper offers a superior understanding of volumetric and mass changes for orange particulates, but it lacks evaluation of the rise in temperature of the particulate over the experimental period. It has no means of evaluating the applied lead and the gauge's cross-sectional area in a compressive strength evaluation. Again, the orange peel particulate's ability to conduct electricity was not previously determined.

A highly relevant article is also credited to O.A. Ajibade, et al. (2015) [15]. They used the Taguchi method to evaluate the optimisation potentials of coconut shell particulates. In this area and on the aspect considered in this work, the papers offer the most comprehensive range of optimisation methods on free swell for coconut material. However, the heat aspects, information on compressive strength, and details on electrical resistivity are absent. The work only refers to the orthogonal array of $L_{27,}$ which is the foundation for determining the optimal settings for the Taguchi-simplex methods. The study contains substantially relevant information on the properties of green waste for interested stakeholders. Notwithstanding, their study also ignores the ideas of temperature evaluation, applied load, gauge cross-sectional area, and the ability to conduct electricity, which is useful for the determination of compressive strength, electrical conductivity, and heat energy absorption. Overall, to evaluate the most desirable properties of orange peel particulates, the information stated above, which is different in O.A. Ajibade, et al. (2016) [14] and O.A. Ajibade, et al. (2015) [15], is essential. It is thus desirable to evaluate the properties of the compressive strength, electrical conductivity, and heat energy absorption for orange peel particulates.

Furthermore, additional reports on orange peels are as follows: S.V. Aigbodion, et al. (2013) [16] focused on reinforcing high-density polyethylene with orange peels. P. Kumar (2012) [17] and S. Ojha, et al. (2012) [18] both investigated the mechanical properties of an orange peel-based reinforced polymer composite. Preliminary experimental results revealed the vast potential that orange peel particulates have in providing the properties desired in the sporting equipment manufacturing industry. Unfortunately, there exists no significant accessible document that provides information on green reinforcement materials, particularly orange-peel particulates. In addition, investigations into orange peel particulates that gave attention to particulate size considerations and their effects on fabricated material have not been reported in detail. Hence, it is the objective of this work to address the issue of orange peel particulate properties using a systematic approach.

The literature indicates that the utilisation of reinforcement materials for composites has largely been confined to metals and non-metals. In general, these investigations focus more on aluminium alloys than many other materials. However, applications of orange peel particulates in both natural, dried form and carbonised (burnt) form employing various compressive strengths in the formation process and under various viscosity measures in room temperature applications have not yet been documented. By considering the eco-friendliness and cost benefits of using green reinforcement materials for sporting equipment and related facilities, a proposal is undertaken to utilise orange peel particulates as a composite reinforcement material to achieve an economic production of equipment and facilities for the sporting industry. The demonstration of orange peel particulate-based composite through experimental means provides an attractive alternative in composite formulation, fabrication, and development and is a worthwhile endeavour for sporting equipment manufacturers and competitors. The responsibility of exploring the development of new materials and their transfer to industries is expected to be the major benefit of this investigation.

Yet, much research has omitted critical concerns such as heat absorption, electrical conductivity, and compressive strength for orange peel reinforcement materials in composite fabrication. The absence of heat transfer data in the literature restricts the understanding of heat flow duration under sun exposure. Information essential for controlling the rate of heat flow within the material is also lacking. The absence of electrical conductivity data hinders insights into electrostatic industrial coating applications on orange peel composite structures, including implications of conductivity on overspray losses and particle adherence. Furthermore, knowledge of compressive strength is crucial for understanding the load-bearing capacity of orange peels until failure.

Therefore, this study introduces electrical conductivity, heat absorption, and compressive strength measurements for orange peel samples as materials for composite development. The aim is to fundamentally understand the property dimensions of orange peel particulates in terms of electrical, heat, and compressive stress from experimental perspectives. The experimental setup is described, results discussed, and conclusions drawn. The study's principal contributions are:

1. A multi-property evaluation system for orange peels is constructed. This system utilises infrared data to generate compressive strength, electrical conductivity, and heat absorption data for sun-dried orange peel particulates.

2. The experimental approaches are comprehensive. Through theoretical and practical analysis, the efficacy and potential applications of sun-dried orange peel data are explored.

2. Materials and methods

2.1. Materials

Orange peels were collected in polyethylene bags, chosen for their malleability under heat and pressure. Given the irregular shapes and bulk collection, polyethylene bags were suitable for storing and labelling the orange peels. The collected masses were air and sun-dried for approximately two weeks, ensuring adequate drying for grinding and sieving into different grades for compressive testing in the civil engineering laboratory. The experiments employed sieves and a compressive testing machine. A multimeter was used for electrical conductivity and resistivity measurements, while the temperature variations of the orange peels during hot sun-drying were recorded to calculate the heat energy absorbed.

2.2. Procedure for the compressive strength tests

Dried orange peels were milled to fine particles and sieved to different sizes. Each category was treated collectively. Given that orange peel composite reinforcement could be exposed to water in outdoor applications, understanding the compressive strength of the wet samples is essential. A graded set of orange peels mixed with water formed a paste used to fill a cylindrical mould. Known loads were applied to the paste to determine compression extents, with readings taken on compressive testing equipment at the University of Lagos, Nigeria.

2.3. Procedure for the electrical conductivity tests

Orange peel samples were collected from fruit vendors, placed in polyethylene bags, and labelled by category and weight. They were spread out for daily electrical resistivity readings using a multimeter. A Vernier calliper measured sample dimensions, and an equation relating electrical resistivity and temperature was used to determine the relevant electrical conductivity and resistivity.

2.4. Procedure for heat absorption energy tests

Wet orange peels of various shapes such as spherical and needle-like were collected from fruit vendors and subjected to open-sun drying. Open-sun drying is a process that triggers the evaporation of water from the orange peels by the sun's heat. The circulation of air aids the fast evaporation of the water contained in the orange peel waste. The literature suggests that temperatures can reach approximately 98°F during this process. Based on the rise in temperature of the product as the sun's heat falls on it, it is argued that a change in temperature from an initial stage when the orange peels are laid out in the open air when no sun emerges to a final stage when the heat from the sun is the highest, is represented as ΔT where it is T_f-T_i, T_f is the final temperature experienced by the orange peels while T_i is the initial temperature experienced by the orange peels when the sun is not yet active, Eq. (1). This is known as the heat-absorbed energy of the orange peels.

$$\Delta H = C_p m \Delta T \tag{1}$$

The mass of the set of orange peels is represented as m, the specific heat capacity of orange peels, obtained from literature sources, is defined as C_p.

3. Results and discussion

The specified objectives and methods for determining the heat absorption, compressive strength, and electrical conductivity properties of orange peels were previously outlined. Experimental investigations on the collected orange peel samples were conducted and the findings are graphically presented to elucidate the correlations between several parameters and their resultant properties: heat absorbed versus mass of orange peels for heat absorption; electrical conductivity and resistance of orange peels for electrical conductivity; electrical conductivity against surface area and length of orange peels for electrical conductivity; and stress versus strain for compressive strength behaviour.

The electrical conductivity and compressive strength property measurements were divided into two categories (i.e., relationship concerning the surface area and length of orange peels) for electrical conductivity and three categories (i.e., relationship regarding 0.300, 0.425, and 0.600-mm particulates) for compressive strength. To determine the heat-absorbed energy, parameters such as the mass and specific heat capacity of the orange peels were used. During the analysis of the heat absorbed by the orange peels, the specific heat capacity was obtained from W. Zhou, et al. (2008) [19] as 3.77J $kg^{-1}K^{-1}$. This value was used to compute the heat absorbed by the orange peels examined in this work. The details of the analysis and discussion of results are henceforth given.

3.1. Heat absorbed by orange peels

The relationship between the mass of the orange peels and heat absorbed is presented in Fig. 1.

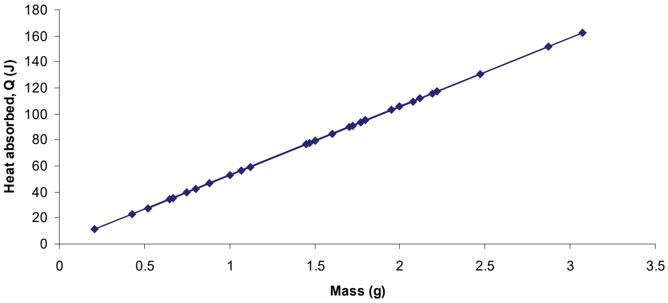

Fig. 1. Relationship between heat absorbed and mass of orange peels.

The mass is taken to be the net loss between the initial and final weights of the orange peels, measured in grams. This figure represents the mass of orange peels that have absorbed heat during the drying process. The calculation for heat absorption involves the product of the mass, the specific heat capacity, and the change in temperature. For this investigation, orange peels were gathered into 28 separate polyethylene bag samples. The relationship between the heat absorbed and the mass is depicted by an upward-sloping curve. It was noted that the amount of heat absorbed, measured in Joules, rose with an increase in sample mass. The minimum energy uptake was observed in sample 6, with a heat absorption of 11.08 J at a mass of 0.21 kg. Samples 2, 3, 5, 6, 13, 17, 18, 23, 24, 27, and 28 displayed similar heat absorption values, ranging from 11.08 to 56.47 J, correlating with their comparable masses. Conversely, samples 1, 4, 7, 8, 9, 10, 12, 15, 16, 19, 20, 25, and 26 showed a heat absorption range of 76.53 to 117.17 J, which is attributed to their greater masses. Samples 14, 28, and 11 exhibited the highest heat absorption at 130.37, 151.48, and 162.03 J, respectively, which is consistent with their larger mass, lying between 2.47 and 3.07 kg. These results clearly demonstrate that the mass of the samples is a primary determinant of the heat energy absorbed. The experiments were conducted under consistent atmospheric conditions of humidity and temperature, assuming a constant specific heat capacity. The findings underscore the significance of mass in the heat energy absorption by the orange peel samples.

This knowledge is particularly relevant in the context of composite material production, where orange peels serve as reinforcement. It becomes crucial when orange peels are integrated into composites for use in thermal storage applications such as heat sinks, storage tanks for volatile substances, and insulation. In such cases, the ratio of orange peel volume/weight to the composite matrix must be optimised to ensure the composite can absorb or dissipate the requisite amount of heat for the application.

3.2. Electrical conductivity of orange peels

The electrical conductance of orange peels depends on three basic quantities, namely, resistance, surface area, and length. The individual relationship of these three quantities will be discussed.

Relationship between electrical conductivity and resistance of orange peels: The resistance of a material is inversely proportional to its electrical conductivity. In this study, the correlation between the resistance and electrical conductivity of selected orange peel samples is depicted by a curve in Fig. 2.

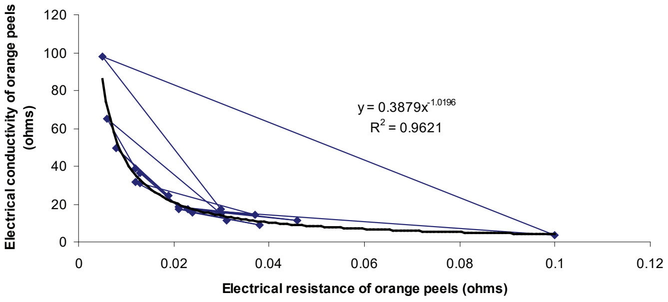

Fig. 2. Relationship between electrical conductivity and resistance of orange peels.

The curve shows a steep decline in conductivity from 98.1 to 38.6 S/m, corresponding to an increase in resistance from 0.005 to 0.012 Ω. This indicates that a higher resistance significantly diminishes electrical conductivity. The high resistance observed in the orange peels may be attributed to their moisture content and fibrous composition. The other samples exhibit closely grouped resistance values, resulting in the scattered data points seen in Fig. 3. Consequently, samples with lower resistance demonstrate higher conductivity. The sample with the utmost conductivity recorded a resistance of 3.6 Ω, possibly due to enhanced drying, reducing the moisture and oil content in the peels.

Relationship between electrical conductivity and surface area of orange peels: Unlike the rapidly descending curve observed between resistance and conductivity, the relationship between the surface area and electrical conductivity is characterised by a series of linearly aligned points in Fig. 3.

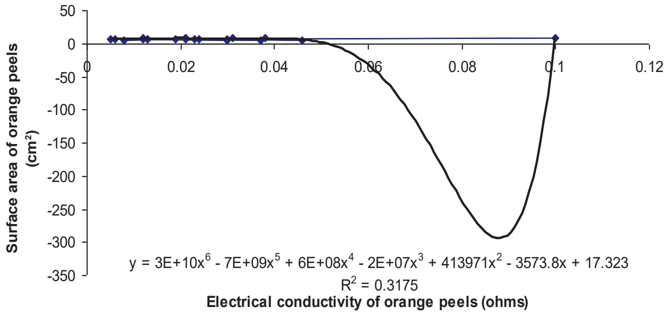

Fig. 3. Relationship between electrical conductivity and surface area of orange peels.

The data from the monitored orange peel samples do not present a consistent pattern regarding the impact of surface area on conductivity. Additionally, the surface area values did not significantly affect electrical conductivity in the same manner as resistance. Thus, certain samples with larger surface areas exhibited lower conductivity, while others with similar dimensions showed higher conductivity. The influence of surface area on conductivity reflects the potential cross-sectional region available for conductance.

Relationship between electrical conductivity and length of orange peels: The length of the individual orange peel samples impacts their conductivity. Specifically, the length denotes the electrode gap which facilitates the travel of electric current through the caps of the orange peels. This correlation is depicted in Fig. 4.

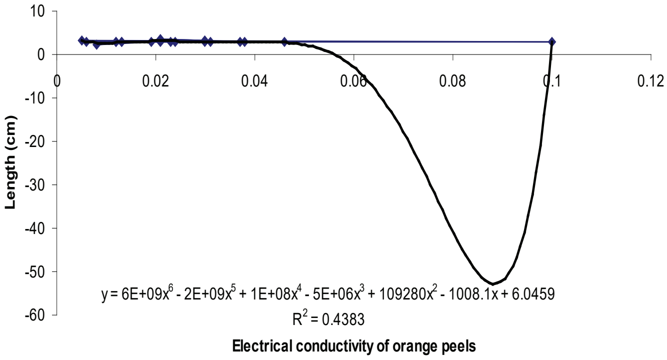

Fig. 4. Relationship between electrical conductivity and length of orange peels.

A longer peel tends to exhibit higher conductance and current flow. However, length is not the sole determinant of conductivity. This is evident as different samples measuring 2.8 cm in length displayed varying conductivities of 0.012, 0.03, 0.031, 0.037, 0.038, and 0.046 S/m, respectively. Therefore, the conductivity of orange peels is the result of a complex interaction of various factors.

3.3. Compression test results

The compression test generated three distinct stress-strain curves for the 0.300, 0.425, and 0.600 mm particulate sizes, as illustrated in Figs. 5, 6, and 7, respectively. Each curve represents unique compressive strength behaviour.

Compression strength behaviour of 0.300-mm orange peel particulates: The compressive strength behaviour for the 0.300-mm particulates is outlined in Fig. 5. The curve appears to be segmented into three distinct phases, reflecting different stress-strain responses. Initially, the material exhibited no strain until the compressive stress reached 8.68 kN/m², causing deformation. The strain then increased to 0.52 as the compressive stress rose from 8.68 to 13.01 kN/m², indicating elastic behaviour. At this juncture, had the stress been removed, the material would likely revert to its original shape without lasting damage. The 0.300 mm sample reached its proportional limit at an applied stress of 13.01 kN/m², which is evident as a straight line on the curve, confirming adherence to Hooke's Law; where stress is directly proportional to strain. Subsequent stress application, from 13.01 to 15.13 kN/m², resulted in an increased strain of 0.78.

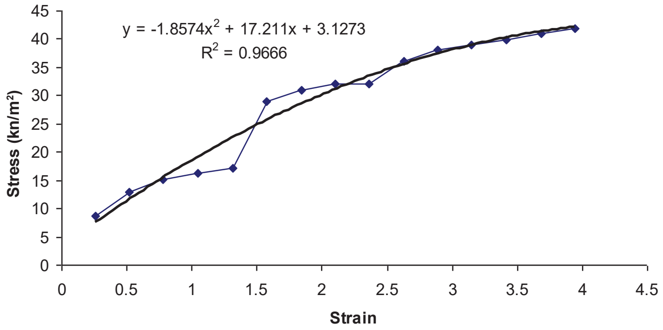

Fig. 5. Relationship between stress and strain for 0.300-mm orange peel particulates.

At this stage, the material is considered to have reached its yield point, with the stress of 15.13 kN/m² acting as the elastic limit or yield strength for the 0.300 mm sample. This marks the transition from elastic to plastic behaviour, with noticeable and significant deformation. The sample's yield strength indicates the elastic and plastic regions. As stress increased further to 16.16 kN/m², the strain escalated to 1.05, indicating plastic deformation. In the plastic region, the material would not revert to its original shape if stress were relieved. The stress continued to rise, correlating with increased strain, until reaching a failure point at 41.86 kN/m², where the strain was 3.94. At this stress level, the material began to bulge and shear, indicating the compressive shear strength of the 0.300 mm orange peel particulates was at 41.86 kN/m².

Compression strength behaviour of 0.425-mm orange peel particulates: Fig. 6 illustrates the stress-strain curve for the 0.425 mm sample. The initial strain of 0.26 was recorded when the compressive strength reached 1.09 kN/m².

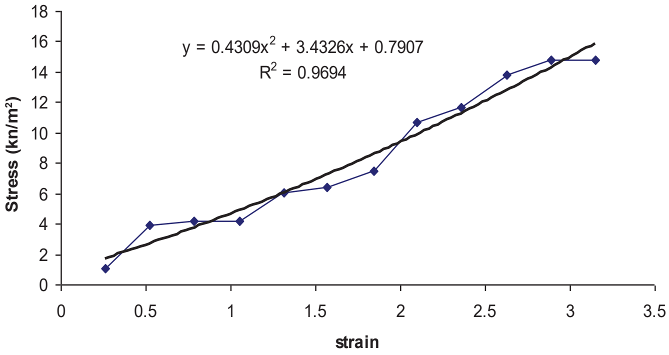

Fig. 6. Relationship between stress and strain for 0.425-mm orange peel particulates.

The stress and strain increase progressively until the material reaches its proportional limit at 4.75 kN/m², where the stress is directly proportional to the strain, signifying compliance with Hooke's law. This is represented by the linear portion of the curve. Within this elastic region, if the stress were removed, the material would revert to its initial state. As the stress increases further, the material reaches its yield point and yield strength at 5.17 kN/m². This transition signifies the end of elastic behaviour and the onset of plastic deformation, characterised by a sharp increase in strain with each increment of stress. At this stage, any removal of stress would not restore the material to its original shape due to plastic deformation. The material ultimately fails at an applied stress of 14.82 kN/m², which corresponds to a strain of 2.89. The compressive strength at which the material begins to bulge, and shear is identified as 14.82 kN/m².

Compression strength behaviour of 0.600-mm orange peel particulates: For the 0.600-mm sample, the stress-strain curve presented in Fig. 7 demonstrates its compressive strength behaviour. An initial strain of 0.26 corresponds with an applied stress of 1.09 kN/m², indicating the material is within its elastic range and would return to its original state if stress was removed.

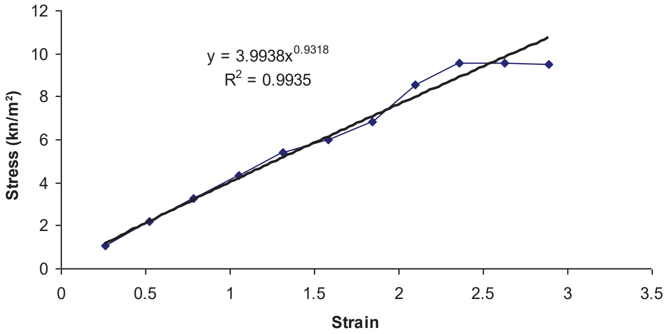

Fig. 7. Relationship between stress and strain for 0.600-mm orange peel particulates.

The material exhibits a proportional limit at a stress of 4.31 kN/m², resulting in a strain of 1.05. This limit is denoted by the straight section of the curve, maintaining a proportional relationship between stress and strain in accordance with Hooke's law. The material's elastic behaviour persists until the stress reaches 5.00 kN/m² with a corresponding strain of 1.20, marking the end of the elastic region and the start of plastic deformation. At this yield point, with a stress of 5.00 kN/m² (the yield strength or elastic limit), the material undergoes permanent deformation. Failure occurs through bulging or shearing at a stress of 9.58 kN/m² and a strain of 2.36. The compressive strength of the 0.600 mm sample is established at 9.58 kN/m².

The varying values of proportional limit, yield strength, and compressive strength across the samples highlight specific characteristics. For instance, the 0.300 mm sample required more stress, 8.86 kN/m², to produce an initial strain of 0.26 compared to the 1.09 kN/m² necessary for both the 0.425 and 0.600 mm samples. Similarly, the yield strength for the 0.300 mm sample is the highest at 15.13 kN/m², while the 0.425 and 0.600-mm samples exhibit lower yield strengths of 5.17 and 5.00 kN/m², respectively. The highest compressive strength recorded was for the 0.300 mm sample at 41.86 kN/m².

4. Conclusions

This study presents the outcomes of three sets of experiments that examine the properties of orange peel and its particulates when used as reinforcement materials in the fabrication of green composites. One of the major challenges addressed by this research is the substantiation of the foundational assumptions in the determination of heat absorption, electrical conductivity, and compressive strength properties, along with methodological considerations. The findings provide design engineers with empirical values to develop composites that exhibit superior in-service performance and extended lifespans [20]. The salient conclusions drawn are as follows:

- The heat energy absorption of the collected samples is primarily dependent on their individual masses.

- The minimum energy absorption was observed in sample 6, with 11.08 J, whereas the maximum was 162.03 J in sample 11.

- The electrical conductivity of orange peel particulates is significantly influenced by their electrical resistance.

- Moisture content within the fibrous structure of orange peels may increase resistance and hinder electrical conductivity.

- No consistent pattern was detected in how surface area affects electrical conductivity, indicating that surface area did not markedly influence conductivity in the studied orange peels.

- The length of orange peel samples was not as determinative of conductivity as other factors; thus, samples of equal length exhibited varying electrical conductivities.

- In essence, the electrical conductivity of orange peel samples is largely dictated by the complex interplay of multiple factors.

- The compressive shear strength for the 0.300 mm orange peel particulate samples is established at 41.86 kN/m².

- The compressive shear strength for the 0.425 mm particulates is determined to be 14.82 kN/m².

- The compressive shear strength for the 0.600 mm particulates is recorded at 9.58 kN/m².

- The varying compressive shear strengths across different samples can be attributed to the strength of cohesive forces between the grains. It was noted that these cohesive forces, and hence compressive strength, decreased as the particulate size increased from 0.300 to 0.600 mm.

- The greater the cohesive forces within the samples, the higher the compressive stress they can endure, which explains the robust compressive strength, exhibited by the 0.300 mm OPP samples.

CRediT author statement

Oluwaseyi Ayodele Ajibade: Methodology, Formal analysis, Original draft preparation, Visualisation; Johnson Olumuyiwa Agunsoye: Conceptualisation, Data curation, Investigation; Sunday Ayoola Oke: Investigation, Visualisation, Formal analysis.

ACKNOWLEDGEMENTS

We extend our gratitude to the support staff of the Department of Civil Engineering at the University of Lagos, Nigeria, for their assistance in this research. Our thanks are particularly owed to the Technologist, Mr. Salami, for his instrumental role in facilitating a conducive environment for our experimental work.

COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

REFERENCES

[1] H.M. Tasdemir, A. Sahin, A.F. Karabulut, et al. (2019), "Production of useful composite particleboard from waste orange peel", *Cellulose Chemistry and Technology*, **53(5-6)**, pp.517-526, DOI: 10.35812/CelluloseChemTechnol.2019.53.52.

[2] N.S. Sambudi, W.Y. Lin, N. Harun, et al. (2022), "Modification of poly(lactic acid) with orange peel powder as biodegradable composite", *Polymer*, **14(19)**, DOI: 10.3390/polym14194126.

[3] A. Awasthi, K.K. Saxena (2019), "Evaluation of mechanical properties of orange peel reinforced epoxy composite", *Materials Today: Proceedings*, **18(7)**, pp.3821-3826, DOI: 10.1016/j.matpr.2019.07.320.

[4] S. Karthikayan, A. Balakumaran, R. Abilesh, et al. (2021), "Mechanical properties of orange peel reinforced epoxy composite", *International Research Journal of Modernization in Engineering Technology and Science*, **3(3)**, pp.1889-1894.

[5] R.U. Abass (2015), "Mechanical behaviour of natural material (orange peel) reinforced polyester composite", *International Journal of Engineering Sciences and Research Technology*, **4(3)**, pp.166-169, DOI: 10.3390/polym14194126.

[6] F.P. La Mantia, M. Morreale (2011), "Green composites: A brief review", *Composites: Applied Science and Manufacturing*, **42(6)**, pp.579-588, DOI: 10.1016/j.compositesa.2011.01.017.

[7] H.P.S.A. Khalil, A.H. Bhat, A.F.I. Yusra (2012), "Green composites from sustainable cellulose nanofibrils: A review", *Carbohydrate Polymer*, **87(2)**, pp.963-979, DOI: 10.1016/j.carbpol.2011.08.078

[8] S.K.N.M. Noor (2011), *Erosive Wear Behaviour of Orange Peel Fibre Reinforced Epoxy Composite*, Department of Mechanical Engineering National Institute of Technology, 41pp.

[9] O.A. Ajibade, J.O. Agunsoye, S.A. Oke (2021), "Taguchi method and taguchi-pareto scheme to evaluate diffusivity during the development of orange peel epoxy composites", *Journal of Applied Science & Process Engineering*, **8(1)**, pp.765-785.

[10] S.M. Jubihulla, S. Madhu, C.K. Sudhi, et al. (2022), "Characterisation of natural cellulose fibres from the stem of *Albizia julibrissin* as reinforcement of polymer composites", *Journal of Natural Fibers*, **19(6)**, pp.2204-2217, DOI: 10.1080/15440478.2020.1807440.

[11] R. Kumar, S. Sivaganesan, P. Senthamaraikannan, et al. (2022), "Characterisation of new cellulosic fibre from the bark of *Acacia nilotica* L. plant", *Journal of Natural Fibers*, **19(1)**, pp.199-208, DOI: 10.1080/15440478.2020.1738305.

[12] R. Vijay, J.D.J. Dhilip, S. Gowtham, et al. (2022), "Characterisation of natural cellulose fibre from the barks of *Vachellia farnesiana*", *Journal of Natural Fibers*, **19(4)**, pp.1343-1352, DOI: 10.1080/5440478.2020.1764457.

[13] J.S.N. Raju, M.V. Depoures, J. Shariff, et al. (2022), "Characterisation of natural cellulose fibres from stem of Symphirema in volucratum plant", *Journal of Natural Fibers*, **19(13)**, pp.5355-5370, DOI: 10.1080/15440478.2021.1875376.

[14] O.A. Ajibade, J.O. Agunsoye, S.A. Oke (2016), "A grey relational analytical approach to orange peel filler particulates for tapped density experiments of green composite reinforcements", *KKU Engineering Journal*, **43(3)**, pp.108-119, DOI: 10.14456/kkuenj.2016.17.

[15] O.A. Ajibade, J.O. Agunsoye, S.A. Oke (2015), "A comparative analysis of three optimisation approaches to free swell characterisation of particulate coconut shell reinforcement composite material", *Engineering Journal*, **19(5)**, pp.167-187, DOI: 10.4186/ej.2015.19.5.167.

[16] A. Victor, C.U. Atuanya, E.A. Igogori, et al. (2013), "Development of high-density polyethylene orange peel particulate bio-composite", *Gazi University Journal of Science*, **26(1)**, pp.107-117.

[17] P. Kumar (2012), *Mechanical Behaviour of Orange Peel Reinforced Epoxy Composite*, Department of Mechanical Engineering, National Institute of Technology, 37pp.

[18] S. Ojha, G. Raghavendra, S.K. Acharya, et al. (2012), "Fabrication and study of mechanical properties of orange peel reinforced polymer composite", *Caspian Journal of Applied Science Research*, **1(13)**, pp.190-192.

[19] W. Zhou, W.W. Widmer, K. Grohmann (2008), "Physical properties of fermented citrus peel", *American Society of Agricultural and Biological Engineers*, DOI: 10.13031/2013.24652.

[20] A. Arbelaiz, B. Fernandez, J.A. Ramos, et al. (2005), "Mechanical properties of short flax fibre bundle/polypropylene composites: Influence of matrix/fibre modification, fibre content, water uptake and recycling", *Composite Science and Technology*, **65(10)**, pp.1582-1592, DOI: 10.1016/j.compscitech.2005.01.008.