International Journal of Advances in Scientific Research and Engineering (ijasre)

E-ISSN : 2454-8006

DOI: 10.31695/IJASRE.2024.4.1

Volume 10, Issue 4
April - 2024

Modelling Water Absorption Index and Compressive Strength of Paving Stone Composites with Polyethylene Terephthalate (PET) as Total Binder Replacement

Kiridi, E. A[1], Mac-Eteli, H. D[2] and Alagba, M. B[1]

[1]Department of Agricultural and Environmental Engineering,

Niger Delta University, Wilberforce Island, Bayelsa State

[2]Department of Civil Engineering,

Niger Delta University, Wilberforce Island, Bayelsa State

Nigeria

ABSTRACT

Polyethylene terephthalate (PET) wastes were melted and mixed with river sand to produce paving stone composites (PSCs) of mix ratio 1:3, labelled (PET: 10, 20, 30, 40, and 50%); and sand-cement mix of 1:3 labelled PET 0% (control). In a mold measuring 50 × 100 × 200mm, three replicates of PSCs of each mix ratio and control, were produced and cured in water at a room temperature of (27 ± 2ºC) for 28 days. The PSCs showed a better water absorption property as it ranges from 6.98 % to 3.59 % as against 11.11 % for the control. Significant compressive strengths were shown by the PSCs; PET 30% had the highest mean value of 20.59 N/mm^2, while the control had the lowest mean value of 8.63 N/mm^2. Using Design Expert tool in analyzing the laboratory data obtained for both water absorption index and compressive strength, the results show that the developed quadratic model for water absorption index (WAI) has an adjusted and predicted coefficient of regressions of 0.9851 and 0.9821 respectively, with an average precision of 98.62% within the research work, allowing for simulation of WAI outcomes at different PET contents. Also, the compressive strength model is a quadratic, with adjusted and predicted coefficients of regressions of 0.9623 and 0.9526 respectively, and shows reduced variation between actual and predicted values, making it useful for design space navigation. The research suggests that utilizing PET waste as a complete binder replacement in paver production is a cost-effective method for managing waste.

Keywords: Compressive Strength, Polyethylene Terephthalate, Paving Stone Composites, Modelling, Water Absorption Index.

1.0 INTRODUCTION

Plastics made of polyethylene terephthalate (PET) are produced in huge quantities for use in packaging and related applications worldwide. These materials become garbage after usage and usually cause a nuisance by clogging canals and drainage systems, particularly in underdeveloped nations, this is made worse after every rainfall. Unlike other organic wastes, these materials cannot be completely decomposed by nature in a short amount of time. Because of this, they continue to accumulate in large numbers, which lowers landfills' carrying capacities and leads to environmental issues. The ability to recycle, repurpose, and use these materials in a positive way is one of their many useful qualities, which also makes them non-biodegradable. This allows for the possibility of putting excesses to good use and also contributes to environmental safety [1].

Several researchers have attempted to manage PET wastes by utilizing it as building materials [2-8]. Paving stone was categorized by [9]. Quality A concrete brick is used for roads; quality B concrete brick is used for parking area; quality C concrete brick is used for pedestrian walkways and quality D concrete brick is used for parks and other uses. By using polyethylene terephthalate waste to produce paving stones, reduces pollution potentials, The aim of this research is to model the water absorption index and compressive strength of pavement stones composite with polyethylene terephthalate as total binder replacement. This validates the possible use of PET waste as binder in paving stone production as it will now be a resource for the building sector.

2.0 Materials and Methods

2.1 Materials/Equipment

The materials used in the production process were; personal protection equipment (PPE), melting bowl, mixing spatula, firewood, PET waste, fine aggregates (sand), spent engine oil.

The equipment used in the production process were; weighing scale, digital gun thermometer, rebound hammer tester and composite molds.

2.2 Methods

2.2.1 Production Process

River sand was collected from the sand dump in Swali, a community in Bayelsa State, Nigeria, while PET wastes (PWs) were manually picked from dumpsites. After giving the PET wastes a thorough wash, they were shred into smaller pieces to speed up the melting process. All of these composite materials were sent to Niger Delta University's Structure Laboratory in the Civil Engineering Department.

The shredded PET waste aggregates were weighed and the required weights were then poured into a melting bowl, and firewood heat was applied until the polyethylene terephthalate waste aggregates melts. Sand was added in the required ratio while stirring to mix as desired. The composite mix was transferred to an oiled mold measuring 50 x 100 x 200mm, and allowed to set. Six samples, control (PET 0%), PET 10, PET 20, PET 30, PET 40 and PET 50% in three (3) replicates, were produced for this study. The control paving stones production were guided by [10] class MX specification for bricks. All samples were well compressed during production and cure for a period of 28 days

2.3 Testing

2.3.1 Water Absorption

The water-absorption test was conducted on pavement stone composite samples in line with [11] standards. The specimens were weighed in dry condition, soaked in water, and weighed after 24 hours. Quality paving stone absorbs less water than building blocks, absorbing no more than 14% of its dry mass when soaked for 24 hours.

The percentage of water absorption is calculated as follows.

$$W = \frac{M_2 - M_1}{M_1} \times 100 \qquad (1)$$

Where:

M_2 = mass of paving stone composite when immerse in water (kg)

M_1 = mass of paving stone composite before immersing in water at room temperature (27 ± 2ºC) (kg).

2.3.2 Compressive Strength

The compressive test measures a unit's capacity to withstand axial loads, in accordance with [12]. The rebound hammer test is used for compressive strength, a non-destructive method complied with [13] requirements. Schmidt hammers are used. Quality paving stone absorbs less water than building blocks, indicating its quality.

3.0 RESULTS AND DISCUSSION

3.1 Water Absorption

Figure 1 shows a plot of mean values of water absorption against PET percentages. The cement-sand had a higher mean value of 11.11% for water absorption, while the PET-sand Specimens ranged from 6.98% to 3.59%. The mean of water absorption reduces with an increase in PET proportion. Plastic repels water molecules and leaves no room for water to flow around. As a result of the reduced voids within the brick, there was no water absorption in plastic sand bricks. These values depict that the use of PET waste materials as binders in the manufacture of paving stone composites, produce pavers with better water absorption properties than the use of portland cement. But it should be

DOI: 10.31695/IJASRE.2024.4.1

noted that the sand-PET mix of 10 % and 20 % gave a water absorption value that is greater than 6%, which is the maximum allowable value according to [14]. The improvement in the water absorption property of the sand-waste plastic paving blocks can be attributed to the hydrophobic nature of the plastic [6]. In addition, the bond between the sand and melted plastic helped in reducing air voids in the aggregate, thereby leading to decreased permeability of the mixture [15].

The present study somehow reiterates the excellent water absorption capacity of PET-sand mix paving stone as observed by [16].

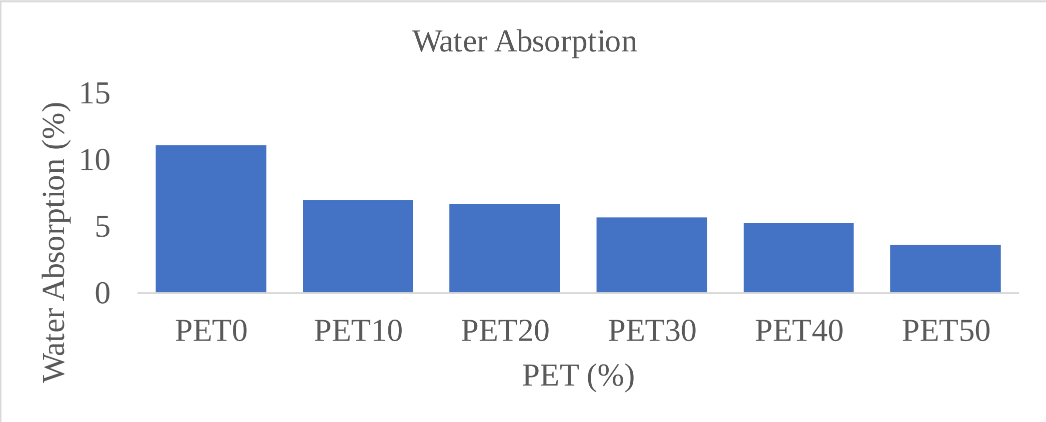

Figure 1: **A bar chart of mean water absorption against PET percentages**

Table 1: Analysis of the water absorption of mean variance (ANOVA) between the control (PET 0%) and PET-mix paving stone composites

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	74.96644	1	74.96644	83.47784	1.66E-05	5.317655
Within Groups	7.18432	8	0.89804			
Total	**82.15076**	**9**				

The results of the ANOVA test between the cement-sand and PET-sand mean water absorption were statistically analyzed using MS Excel and are shown in Table 1. Again, the F(cal) is greater than the F(crit), and the P-value is less than 0.05. It can be concluded that the difference in water absorption between the mean of cement-sand and PET-sand samples were significant. This means that the PET-sand samples have better water absorption quality when compared to conventional paving stones.

3.1.1: Model development and optimization for the water absorption index of PET-sand mix paving stone composites.

Using the Design Expert tool, Surface Response Methodology was adopted in analyzing the laboratory data obtained for the Water absorption index of PET-sand mix paving stones, at a confidence interval of 95%. The design build information inclusive of factors and responses are as shown in Table 2

DOI: 10.31695/IJASRE.2024.4.1

Table 2: Design build information for the water absorption index data analysis of PET-sand mix paving stone composites

File Version	13.0.5.0			
Study Type	Response Surface		**Subtype**	Randomized
Design Type	I-optimal	Coordinate Exchange	**Runs**	13.00
Design Model	Quadratic		**Blocks**	No Blocks
Build Time (ms)	6.00			

The design fit summary as shown in Table 3, shows that the suggested model for analysis is quadratic, having an adjusted and predicted coefficients of regressions of 0.9851 and 0.9821 respectively, at an insignificant lack of fit of 0.0006.

Table 3: Model fit summary of the water absorption index of PET-sand mix paving stone composites

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	< 0.0001		0.9532	0.9394	
Quadratic	**0.0006**		**0.9851**	**0.9821**	**Suggested**
Cubic	0.2351		0.9860	0.9415	
Quartic			1.0000		
Fifth					**Aliased**

The statistical data from the analysis of variance (ANOVA) for the Water absorption index of PET-sand mix paving stone composites are as shown in Table 4.

Table 4: Analysis of variance (ANOVA) for the water absorption index of PET-sand mix paving stone composites

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	20.72	2	10.36	397.69	< 0.0001	significant
A-PET	20.58	1	20.58	789.84	< 0.0001	
A^2	0.6392	1	0.6392	24.54	0.0006	
Residual	0.2605	10	0.0261			
Lack of Fit	0.2605	2	0.1303			
Pure Error	0.0000	8	0.0000			
Cor Total	20.98	12				

DOI: 10.31695/IJASRE.2024.4.1

From Table 4, it is evident that the signal to water absorption ratio as depicted by the F-value is significantly large, necessitating the P-value to be sufficiently within fit and nullifying the null hypothesis.

The Model F-value of 397.69 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to water absorption. P-values less than 0.0500 indicate model terms are significant. In this case A, A^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The summary of fit statistics which is used in depicting the fitness of a model for simulation within and between variables is as shown in Table 5.

Table 5: Summary of fit statistics

Std. Dev.	**0.1614**	R^2	**0.9876**
Mean	5.64	**Adjusted R^2**	0.9851
C.V. %	2.86	**Predicted R^2**	0.9821
		Adeq Precision	43.1320

The Predicted R^2 of 0.9821 is in reasonable agreement with the Adjusted R^2 of 0.9851; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The Adeq Precision of 43.132 indicates an adequate signal. This model can be used to navigate the design space.

The developed model is as shown in equation (2)

$$WAI = 7.22 - 0.0116P - 0.0012P^2 \quad (2)$$

Where;

WAI = Water absorption index of PET-sand mix paving stones (%)
P = percentage of PET in mix (%)
The model expressed as relativity between variables is as shown in Figure 2

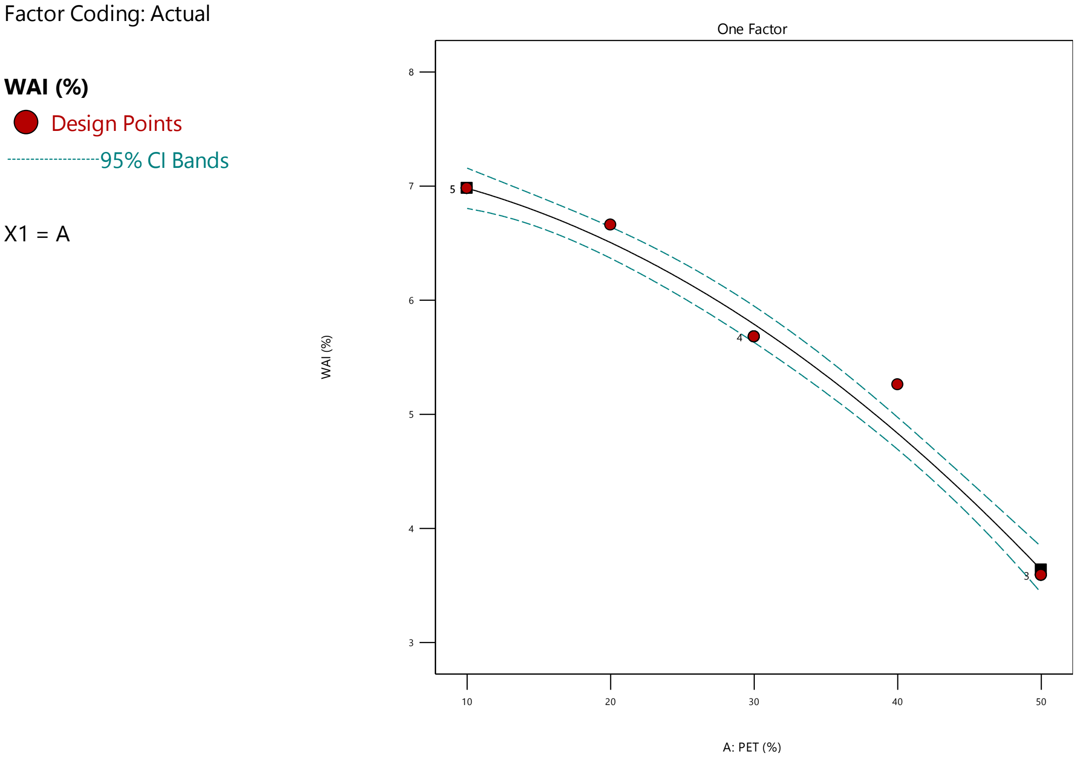

Figure 2: Simulation of model for the Water absorption index of PET-sand mix paving stone composites

DOI: 10.31695/IJASRE.2024.4.1

The model simulation suggests that a quadratic trend is obtainable between the content of plastic as binders and the Water absorption index of PET-sand mix paving stone composites. This trend was seen as a semi- hugging quadratic curve originating at a PET content of 10%, which doubles as the peak concentration for maximum water absorption. Model diagnostics as shown in Figure 3 suggests that the variation between actual values and predicted values greatly reduced at increasing strength values. No significant outlier was observed along the linear slope, as such, the model can be used to circumnavigate the deign space.

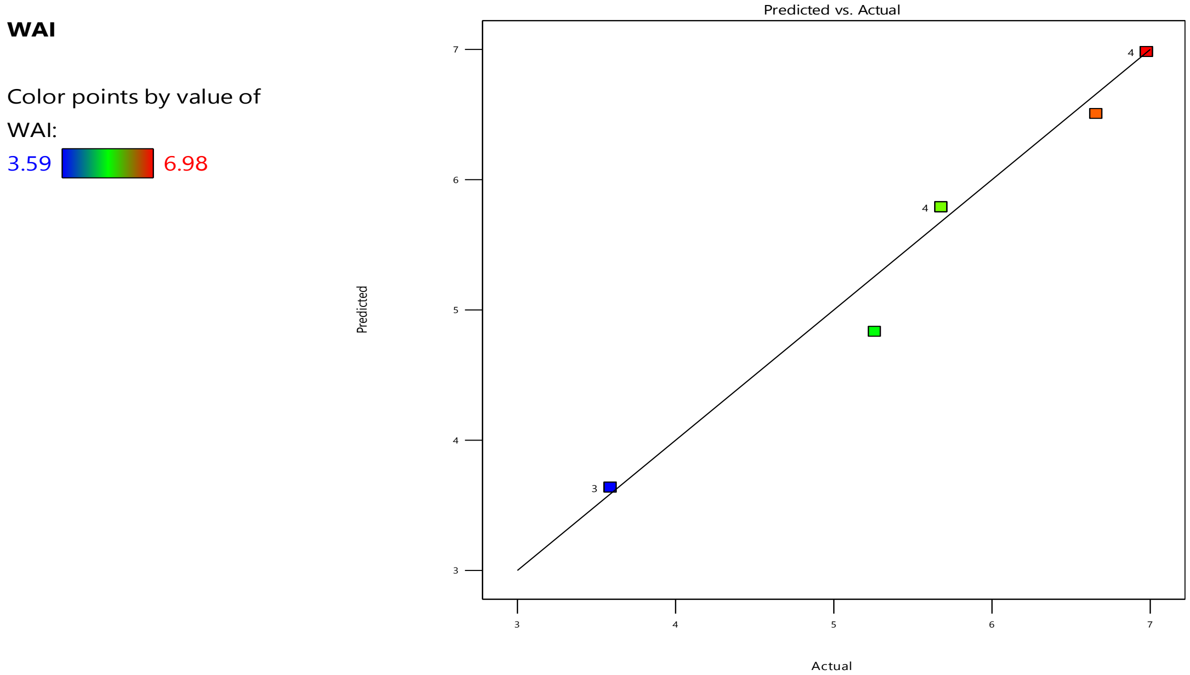

Figure 3: Simulation of model for the water absorption index of PET-sand mix paving stone composites

Table 6. is a validation of the numerical model with the laboratory findings on the Water absorption index of PET-sand mix paving stone composites.

Table 6. Model validation for the water absorption index of PET-sand mix paving stone composites

Specimens	PET (%)	Laboratory WAI (%)	Model WAI (%)	Similarity Index (%)
PET 10	10.00	6.98	6.98	100.06
PET 20	20.00	6.66	6.51	97.72
PET 30	30.00	5.68	5.79	101.97
PET 40	40.00	5.26	4.84	91.94
PET 50	50.00	3.59	3.64	101.39
		Average Similarity Index (%)		98.62

The validated model as tested, have an average precision power of 98.62% within the boundary of the research work, and as such, can be used in simulating WAI outcomes at different PET contents not covered within the scope of this research exercise.

3.2 Compressive Strength

Figure 4 shows a plot of the mean compressive strength of the mixes of cement-sand against percentage PET-sand paving stone composites at 28 days. Surprisingly, all the PET-sand samples showed impressive compressive strengths with PET 30 % having highest mean value of 20.59 N/mm^2 while cement-sand specimen (PET 0 %) had the lowest mean compressive strength of 8.63 N/mm^2. PET 10, PET 20, PET 40, and PET 50 % recorded 12.64, 15.86,

DOI: 10.31695/IJASRE.2024.4.1

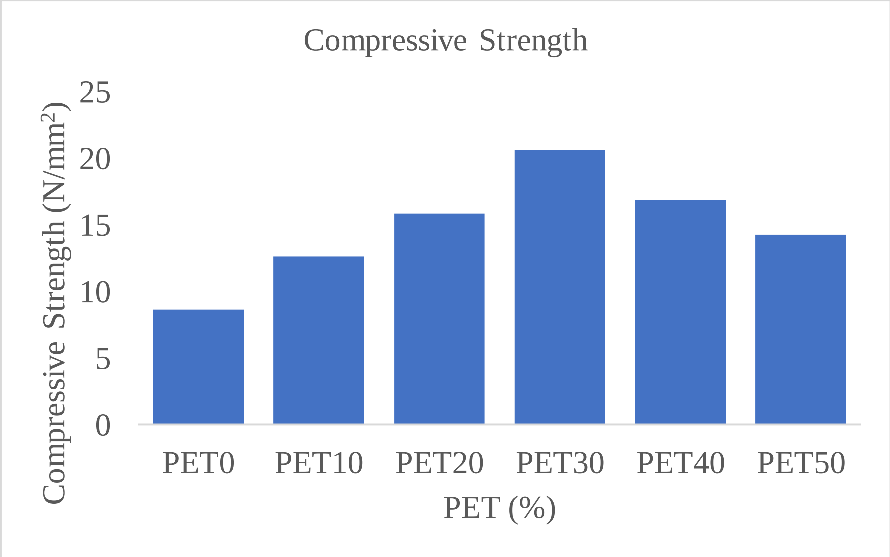

Figure 4: A bar chart of mean compressive strength against PET percentages.

16.89, and 14.26 N/mm^2. This result means that the bond between PET-sand may be better than that of cement-sand thus the improve compressive strength. However, the PET 10 % low performance could be due to the reduction in bonding between plastic and sand as the amount of sand increased substantially compared to the quantity of plastic. The finding of the present study differs from the observation of [17] in which the compressive strength of plastic sand brick of ratio 1 : 4 using 4.75 mm sand was observed to be 9.141 N/mm^2 and that using 600 µm sand was found to be 7.468 N/mm^2 and the observation of [18] in which the average compressive strength of plastic sand brick of ratio 1 : 3 was found to be 9.72 N/mm^2, of 1 : 4 to be 12.28 N/mm^2, and of 1 : 5 to be 3.39 N/mm^2. However, the present study resembles another study by [19] in which a topmost compressive strength of 17N/mm^2 was generated from High Density Polyethylene (HDPE) and river sand with mix ration of 1:2. Finally, the highest compressive strength obtained which is 20.59 N/mm^2 for PET 30 % mix ratio was up to 20 N/mm^2 which is the [20] recommended strength for structural concrete. This shows that the best and/or optimum PET-sand mix is 30 % with 70% river sand. Hence, the utilization of PET waste as binders in the production of paving stones is feasible in terms of compressive strength.

Table 7: Analysis of the mean variance (ANOVA) between the control (PET 0%) and PET-mix paving stone composites.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	137.5668	1	137.5668	30.4137	0.000564	5.317655
Within Groups	36.18548	8	4.523185			
Total	**173.7523**	**9**				

The results of the ANOVA test between the cement-sand and PET-sand mean compressive strength using MS Excel is shown in Table 7. The F(cal) is higher than the F(crit), and the P-value is lower than 0.05. It can be concluded that the difference in compressive strength between the mean of cement-sand and PET-sand samples were significant.

3.2.1: Model development and optimization for the compressive strength of PET-sand mix paving stone composites

Using the Design Expert tool, Surface Response Methodology for adopted in analyzing the laboratory data obtained for the compressive strength of PET-sand mix paving stone composites, at a confidence interval of 95%. The design build information inclusive of factors and responses are as shown in Table 8

DOI: 10.31695/IJASRE.2024.4.1

Table 8: Design build information for the compressive strength data of PET-sand mix paving stone composites

File Version	13.0.5.0			
Study Type	Response Surface		**Subtype**	Randomized
Design Type	I-optimal	Coordinate Exchange	**Runs**	13.00
Design Model	Quadratic		**Blocks**	No Blocks
Build Time (ms)	50.00			

Table 9: Model fit summary of the compressive strength of PET-sand mix paving stones

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	0.0282	< 0.0001	0.3093	0.0429	
Quadratic	**< 0.0001**	**< 0.0001**	**0.9623**	**0.9526**	**Suggested**
Cubic	0.1268	< 0.0001	0.9681	0.9571	
Quartic	0.5516	< 0.0001	0.9658	0.8525	
Fifth	**< 0.0001**		**0.9995**		**Suggested**
Sixth					**Aliased**

The design fit summary as shown in Table 9, shows that the suggested model for analysis is quadratic, having adjusted and predicted coefficients of regressions of 0.9623 and 0.9526 respectively, at an insignificant Lack of Fit of <0.0001.

Table 10: Analysis of variance (ANOVA) for the compressive strength of PET-sand mix paving stone composites

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	519.50	2	259.75	154.22	< 0.0001	significant
A-PET	264.19	1	264.19	156.86	< 0.0001	
A^2	322.73	1	322.73	191.61	< 0.0001	
Residual	16.84	10	1.68			
Lack of Fit	16.69	3	5.56	248.84	< 0.0001	significant
Pure Error	0.1565	7	0.0224			
Cor Total	536.34	12				

The statistical data from the analysis of variance (ANOVA) for the compressive strength of PETcrete are as shown in Table 10, which shows that the signal to noise ratio as depicted by the F-value is significantly large, necessitating the P-value to be sufficiently within fit and nullifying the null hypothesis.

DOI: 10.31695/IJASRE.2024.4.1

The Model F-value of 154.22 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, A^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The summary of fit statistics which is used in depicting the fitness of a model for simulation within and between variables is as shown in Table 11.

Table 11: Summary of fit statistics

Std. Dev.	**1.30**	R^2	**0.9686**
Mean	13.76	**Adjusted R^2**	0.9623
C.V. %	9.43	**Predicted R^2**	0.9526
		Adeq Precision	30.7709

The Predicted R^2 of 0.9526 is in reasonable agreement with the Adjusted R^2 of 0.9623; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The Adeq Precision of 30.771 indicates an adequate signal. This model can be used to navigate the design space.

The developed model is as shown in equation (3)

$$fcm = 0.8 + 1.2P - 0.02P^2 \quad (3)$$

Where;

Fcm = Target compressive strength of PET-mix paving stones (N/mm^2)
P = percentage of PET in mix (%)
The model expressed as relativity between variables is as shown in Figure 5

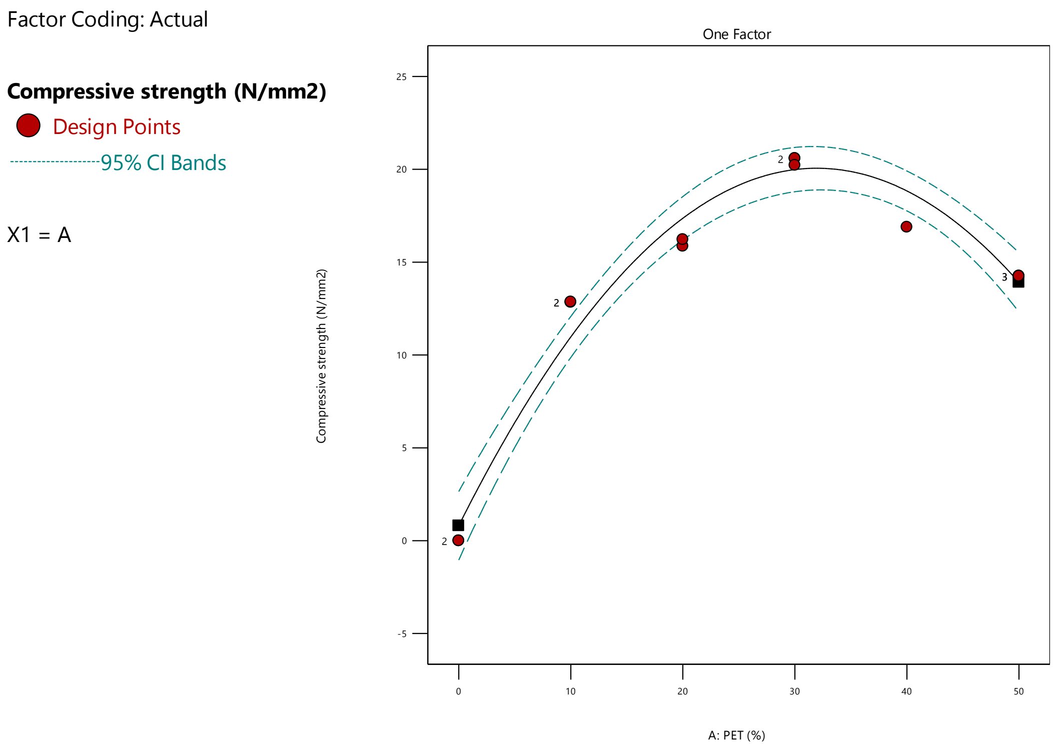

Figure 5: Simulation of model for the compressive strength of PET-sand mix paving stone composites.

DOI: 10.31695/IJASRE.2024.4.1

The model simulation suggests that a quadratic trend is obtainable between the content of plastic as binders and the compressive strength of PET-

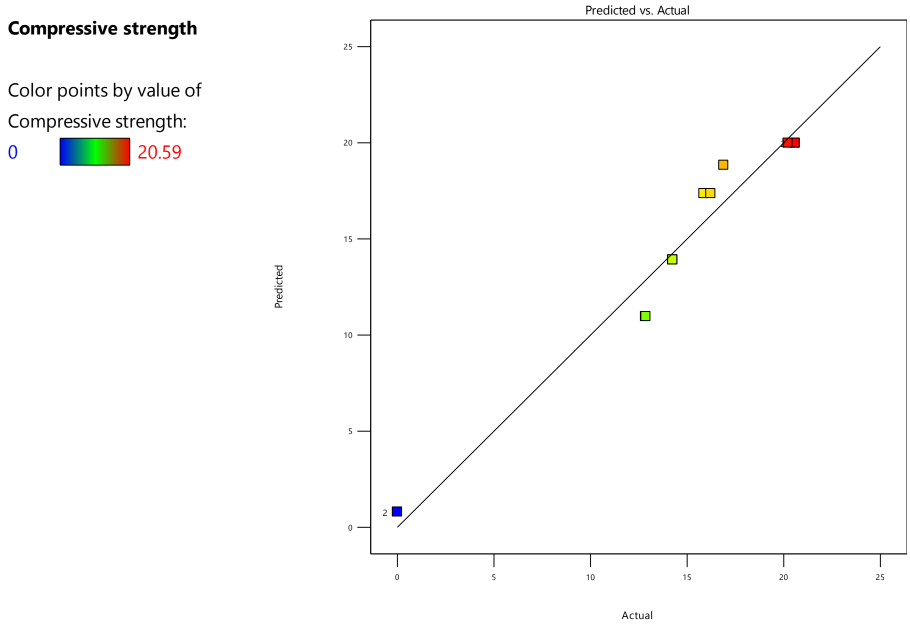

Figure 6: Simulation of model for the compressive strength of PET-sand mix paving stone composites

Table 12: Model validation for the compressive strength of PET-sand mix paving stone composites

Specimens	PET content (%)	Experimental Compressive Strength (N/mm^2)	Model Compressive Strength (N/mm^2)	Similarity Index (%)
PET 0	0	0	0	100
PET 10	10	12.64	10.8	85.44
PET 20	20	15.86	16.8	105.93
PET 30	30	20.59	18.8	91.3
PET 40	40	16.89	16.8	99.47
PET 50	50	14.26	10.8	75.74
		Average Similarity Index		91.58

sand mix paving stone composites. This trend was seen as a hugging quadratic curve peaking between 25 – 35% PET content.

Model diagnostics as shown in Figure 6 suggests that the variation between actual values and predicted values greatly reduced at increasing strength values. No significant outlier was observed along the linear slope, as such, the model can be used to circumnavigate the design space.

Table 12. is a validation of the numerical model with the laboratory findings on the compressive strength of PETcrete paving stones.

4.2 Discussion of Findings

4.2.1 Water Absorption Capacity. Another essential characteristic for building materials is their ability to absorb water. This research study showed that all samples meet the [10] specification, which states that the maximum average of 24 hours of cold-water absorption should not exceed 14%. The control, (PET 0%) recorded 11.11%, followed by a remarkable decrease of 6.98%, 6.66%, 5.68%, 5.26%, and 3.59% for PET 10%, PET 20%, PET 30%, PET 40%, and PET 50%. The trend showed that the water absorption capacity of the paving stone diminishes with increase in PET proportion, and the utilization of PET as sole binders in the manufacturing of paving stone produces pavers with better water absorption properties than cement-sand pavers, as the water absorption rate of PET at 10% recorded a 37%

DOI: 10.31695/IJASRE.2024.4.1

decrease. This result corresponds with the research conducted by [6], which reported that due to their hydrophobic properties, paving blocks made without the use of plastic absorbed more water than paving blocks manufactured with plastic. Thus, the PET pavers can be used mostly in damp and swampy areas.

4.2.2 Compressive Strength

This is a major property used in assessing the load bearing capacity of paving stones. At 28 days, the compressive strength for the reference paving stone composites (control PET 0%) recorded 8.63 N/mm^2, while PET 10%, PET 20%, PET 30%, PET 40%, and PET 50% recorded 12.64 N/mm^2, 15.86 N/mm^2, 20.59 N/mm^2, 16.89 N/mm^2, and 14.26 N/mm^2 respectively. PET mix pavers show a reduction in compressive strength with an increase in PET waste proportion. The control recorded the lowest value, while PET 30% recorded the highest value.

The trend showed an increase in PET by 10% to PET 30% and decrease from PET 30% to PET 50%. The low performance of PET 10% could be because of poor bonding of the PET-sand, leading to possible air voids on the sample, a situation that is likely to reduce the compressive strength. This study shows that the compressive strength reduces as the PET content rises.

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusions

The conclusions from this study are that:

(1) The developed model for water absorption index, $WAI = 7.22 - 0.0116P - 0.0012P^2$ for analysis is quadratic, having an adjusted and predicted coefficients of regressions of 0.9851 and 0.9821 respectively. The validated model as tested, have an average precision of 98.62% within the boundary of the research work, and as such, can be used in simulating WAI outcomes at different PET contents not covered within the scope of this research exercise.

(2) The developed model for compressive strength, $fcm = 0.8 + 1.2P - 0.02P^2$ for analysis is quadratic, having an adjusted and predicted coefficients of regressions of 0.9623 and 0.9526 respectively. Model diagnostics suggests that the variation between actual values and predicted values greatly reduced at increasing strength values. The model can be used to circumnavigate the design space.

(3) The most effective approach to manage PET waste is to use it as total cement replacement when making pavers.

4.2 Recommendation

The recommendations of this study are that:

1. The paving stone composites can be used in swampy areas and also as shore protection materials due to their low water absorption capacity

2. The paving stone composites at 20 – 40 % PET are suitable for use of pedestrian paths and residential parking lots since it meets the minimum strength requirement for pedestrian walkways of 15N/mm^2.

3. The performance of pavers when subjected to attacks from chemicals like sulfate and chloride should be investigated further through further research on their chemical properties.

REFERENCES

1. Kehinde, O., Ramonu, O.J., Babaremu, K.O., and Justin, L.D. (2020). Plastic wastes: environmental hazard and instrument for wealth creation in Nigeria. Published online 2020 Oct 1. doi: 10.1016/j.heliyon. 2020.e05131

2. Zainab, Z.I, and Enas A.A. (2007). "Use of waste plastic in concrete mixture as aggregate replacement." Department of Environmental Engineering, college of Engineering, University of Baghdad, Iraq.

3. Bhogayata, A., Shah, K. D., Vyas, B. A., and Arora N. K. (2012). "Performance of concrete by using non-Recyclable plastic wastes as concrete constituent", International Journal of Engineering Research & Technology (IJERT) vol. 1 issue 4, June-2012.

DOI: 10.31695/IJASRE.2024.4.1

4. Behera, D. (2018). Experimental investigation on recycling of plastic wastes and broken glass into construction material. International Journal of Creative Research Thoughts 6:1659–1667
5. Almeshal, I., Tayeh. B.A., Alyousef, R., Alabduljabbar, H., Mohamed, A.M. (2020) Eco-friendly concrete containing recycled plastic as partial replacement for sand. J Market Res 9(3):4631–4643. https://doi.org/10.1016/j.jmrt.2020.02.090.
6. Agyeman, S., Obeng-Ahenkora, N.K., Assiamah, S., Twumasi, G. (2019) Exploiting recycled plastic waste as an alternative binder for paving blocks production. Case Study: Construction Material. Retri. From https://doi.org/10.1016/j.cscm.2019.e00246.
7. Alexander, K., Richard, G., Silva, M., Zoe, L., and Christopher, C. (2022) Reuse of Waste Plastics in Developing Countries: Properties of Waste Plastic-Sand Composites. Waste and Biomass Valorization (2022) 13:3821–3834. https://doi.org/10.1007/s12649-022-01708-x.
8. Dodo, K., Moussa, T., Antoine, P. D., Mah, F. T., Adama C., Aboubacar, S. T., Mohamed L. O. D., and Kélétigui, D. (2023) Modified Concrete Using Polyethylene Terephthalate Plastic Waste as a Partial Replacement for Coarse Aggregate. J., of Applied Sciences > Vol.13 No.6, June.
9. Standard Nasional Indonesia (SNI) 03-0691-1996. Bata Beton (Paving Block). Badan Standardisasi Nasional. (1996).
10. ASTM C902 (2017). Standard Specification for Pedestrian and Light Traffic Paving Brick.
11. ASTM C 1585 (2006). "Standard Test Method for Measurement of Rate of Absorption of Water.
12. ASTM C109 (2006). Standard Test Method for Compressive Strength
13. ASTM C805/C805M (2018) Standard Test Method for Rebound Number of Hardened Concrete.
14. IS 15658 (2006) Precast concrete blocks for paving. Indian Standard.
15. Ojuri, O.O., and Agbolade, O.C. (2015) "Improvement of Engineering Properties of Igbokoda standard sand with Shredded Polyethylene Waste. "Nigerian Journal of Technology." 34(3), (2015), 443-451. doi: http://dx.doi.org/10.4314/njt.v34i3.3.
16. Singhal, A., and Netula, O. (2018) "Utilization of Plastic Waste in Manufacturing of Plastic SandBricks,"https://www.researchgate.net/publication/325870842_utilization_of_plastic_waste_in_manufacturing_of_plastic_sand_bricks.
17. Salahuddin, S.S.S., and Zambani, S.S. (2020) "Utilisation of waste HDPE plastic in manufacturing plastic sand bricks," *International Research Journal of Engineering and Technology*, vol. 70.
18. Kameshwar, S., Bhesh, R. J., Kabiraj, K., Abiraj, T. M., Sabin, C., and Nabanita, K. (2022). Mechanical Properties of Plastic Sand Brick Containing Plastic Waste. Advances in Civil Engineering | Article ID 8305670 | https://doi.org/10.1155/2022/8305670
19. Chioma, T.G.A., and Samuel, S. (2021) Comparative Study on the Strength Properties of Paving Blocks Produced from Municipal Plastic Waste. Nigerian Journal of Technology 40(5):762 –770. DOI:10.4314/njt. v40i5.1
20. ACI 318-95 (1995) Building Code Requirements for Structural Concrete

Corresponding author: ebizimor.kiridi@ndu.edu.ng

DOI: 10.31695/IJASRE.2024.4.1