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Utilization of Polyethylene Terephthalate (PET) Waste as Total Binder Replacement in Paving Stone Composite for Sustainable Management.

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ABSTRACT

The purpose of this study is to find a sustainable approach to manage polyethylene terephthalate (PET) waste by using it as total binder replacement to producing paving stones. The PET wastes were washed, melted and mixed with river sand to form 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% as the control. In a mold measuring 50mm × 100mm × 200mm,three replicates of PSCs of each mix ratio and control, were casted, cured in water at a room temperature of (27 ± 2ºC) for 28 days. The mean values of the replicates were calculated for density, water absorption, cooling temperature, compressive strength The results show that the control had highest mean value of 2160 kg/m^3 and the mean densities of the PSCs range from 1860 kg/m^3 to 1670 kg/m^3. The PSCs showed a better water absorption property as it ranges from 6.98 % to 3.59 % as against 11.11 % for the control. The control performed better for the cooling temperature with 29 ℃ at 180 minutes compared to the PSCs that ranged from 40 ℃ to 31℃. Unexpectedly, all PSCs demonstrated remarkable compressive strengths, with PET 30% having the greatest mean value of 20.59 N/mm^2 and the control having the lowest mean value of 8.63 N/mm^2. With the exception of mean cooling temperature, analysis of variance reveals that, at a 95 percent confidence level, the differences between the PSCs' mean values for density, water absorption, and compressive strength and the control were significant. This implies that PET can be utilized as total binder replacement in the production of paving stones, reducing the cost of production and a sustainable method of PET management.

Keywords: Paving stone composites, density, water absorption, cooling temperature andcompressive strength

I. INTRODUCTION

Globally, a large quantity of polyethylene terephthalate (PET) materials is produced for packaging and other related uses. These materials end up as waste after use as they are usually discarded. Unlike other organic wastes, these compounds take longer for nature to fully decompose. They consequently continue to accumulate in large amounts, decreasing landfills' carrying capacity and leading to issues with the environment. But these materials' non-biodegradable qualities also make them incredibly useful, allowing for easy recycling, repurposing, and positive application. This allows for the possibility of putting excess materials back to good use while also improving environmental safety [1].

In a bid to manage PET wastes by using it as construction materials, some researchers have used it as partial replacement for fine aggregates [2-7]; for coarse aggregates [8, 9] and for cement [10]. The primary benefit of using plastics is to lower the density of the paving stone composite, which will improve cost, handling, and productivity [11] and also providing a sustainable method of managing PET wastes.

According to [12] paving stone must be able to withstand vehicle loads and have aggravation or resistance to slip, especially at crossroads where traction force due to vehicle wheels, either by braking force or acceleration, so the paving block condition will quickly damage or worn out. [13] classified paving stone based on the class of use as follows: Concrete brick of quality A: used for road; Concrete brick of quality B: used for parking lot; Concrete brick C: used for pedestrians; Concrete brick D: used for parks and other users. This research aims to develop a sustainable, practical approach to managing the pollution potentials of polyethylene terephthalate waste by utilizing it in the production of pavement stones, a practice that will likely help in managing PET waste since it will now serve as a resource in the construction industry. The objectives of this research were to produce paving stone composites of sand and PET wastes total binder replacement in different mix ratios, determine some engineering properties of the composites and statistically compare results with conventional cement-sand paving stone.

II. MATERIALS AND METHODS

2.1 Materials

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

2.2 Equipment

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

2.3 Methods

2.3.1 Production Process

Harvested PET wastes (PWs) from dumpsites were thoroughly washed then shredded into smaller pieces.River sandwas collected from the sand dump on the bank of River Nun, Nigeria. These materials were all transported to the Structure Laboratory in Civil Engineering Department, Niger Delta University.

Appropriate weights of theshredded PET waste were placed in a melting bowl, and firewoodheat was applied until the polyethylene terephthalate waste was melted. Fine aggregates (sand) were then added in the required ratio and mixed. The composite mix was transferred to an oiled mold measuring 50mm x 100mm x 200mm, and allowed to set. Six samples in three (3) replicates i.e, control (PET 0%), PET 10%, PET 20%, PET 30%, PET 40% and PET 50%, were produced for this study. The control paving stones productionwere guided by [14] class MX specification for bricks intended to use as pavers for light vehicles, bikes and pedestrians.The samples were well compressed during production and allowed to cure for a period of 28 days using water at room temperature of (27 ± 2ºC)

2.4Laboratory Analysis

The mean density, water absorption, cooling temperature and compressive strengths of the sample were determined and recordedat 28 days of curing.

III. RESULTS AND DISCUSSIONS

3.1 Density of the Paving Stones

Table 1 shows result of mean densities of the paving stone composites (PSCs) and control (PET 0%) at 28 days. The control had highest mean value of 2160 kg/m^3 and the mean densities of the PSCs range from 1860 kg/m^3 to 1670 kg/m^3. A decreasing trend of PSCs mean densities were observed as the percentage of PET increases and this can be attributed to the fact that cement is denser than PET.

Table 1: Mean densities of the control and paving stone composites.

Samples	PET Mix Percentage (%)	Mean Weight (kg)	Mean Density (kg/m^3)
Control	0	2.16	2160
PET 10	10	1.86	1860
PET 20	20	1.80	1800
PET 30	30	1.76	1760
PET 40	40	1.71	1710
PET 50	50	1.67	1670

The result of the Anova test between the control and PSCs mean densities were statistically analyzed using MS Excel and are shown in Table 2. Since 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 density between the control and PSCs were significant. The implication is that the PSCs are lighter and can be easily transported and better workability, compared to the conventional paving stones. This will cause a reduction of cost of both transportation and paving.

Table 2: Analysis of variance (Anova) between the control and paving stone composites mean densities.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	400000	1	400000	144.1441	2.136E-06	5.317655
Within Groups	22200	8	2775			
Total	422200	9				

3.2 Water Absorption of paving stones

The results of water absorption of the PSCs and control are shown in Table 3. The result shows that the control had a higher mean water absorption of 11.11 % while the PSCs ranges from 6.98% to 3.59 %. The mean water absorption decreases as the quantity of PET increases. This can be attributed to the reduction of void ratio as the percentage of PET increases.

Table 3: Mean water absorption of the control and paving stone composites.

Samples	Mean Dry Weight (kg)	Mean Wet Weight (kg)	Mean Water Absorption (%)
Control	2.16	2.40	11.11
PET 10	1.86	1.99	6.98
PET 20	1.80	1.92	6.66
PET 30	1.76	1.86	5.68
PET 40	1.71	1.80	5.26
PET 50	1.67	1.73	3.59

The Anova test between the control and PSCs mean water absorption were statistically analyzed using MS Excel and are shown in Table 4. 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 mean water absorption between the control and PSCs were significant. This means that the PSCs are of better quality when compared to the conventional paving stones. This is because blocks of good quality are not supposed to absorb more than 14% water of its dry weight when soaked in water for 24hrs [14].

Table 4: Analysis of variance (Anova) between the control and paving stone composites mean water absorption.

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				

3.3 Cooling Temperature

Table 5 shows result of mean cooling temperature of the paving stone composites (PSCs) and control (PET 0%) at 28 days. The mean cooling temperature of the control reduced steadily from 74 ℃ to 29 ℃ while that of the PSCs ranged from 86 ℃ to 40 ℃; 84 ℃ to 38 ℃; 83 ℃ to 35 ℃; 83 ℃ to 33 ℃ and 82 ℃ to 31 ℃, after 3 hours, for PET 10 %, PET 20 %, PET 30 %, PET 40 % and PET 50 %, respectively. An increase in temperature was observed as the percentage of PET increases and also, a decrease in temperatures with time. These show clearly that PSCs are poor conductors and dissipators of heat when compared with conventional paving stones.

Table 5: Mean cooling temperature of the control and paving stone composites.

Samples	Mean Weight (kg)	Mean Initial Temperature (^{0}c)	Temperature (^{0}c) Distribution for 3 hours at 30 minutes interval					
			30	60	90	120	150	180
Control	2.08	27	74	66	58	49	38	29
PET 10	1.80	27	86	80	76	57	48	40
PET 20	1.78	27	84	78	70	56	44	38
PET 30	1.72	26	83	76	68	52	42	35
PET 40	1.67	27	83	75	64	50	40	33
PET 50	1.63	26	82	72	61	49	38	31

The result of the Anova test between the control and PSCs mean cooling temperatures were statistically analyzed using MS Excel and are reported in Table 6. Since the F(cal) is less than the F(crit), and the P-value is greater than 0.05, it can be concluded that the difference in mean cooling temperatures between the control and PSCs were not significant.

Table 6: Analysis of variance (Anova) between the control and paving stone composites mean cooling temperatures after 3 hours at interval of 30 minutes.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	568.4722	5	113.6944	0.317982	0.898222	2.533555
Within Groups	10726.5	30	357.55			
Total	11294.97	35				

3.4 Compressive Strength

Table 7 shows result of mean compressive strength of the paving stone composites (PSCs) and control at 28 days. Surprisingly, all the PSCs showed impressive compressive strengths with PET 30 % having highest mean value of 20.59 N/mm^2 while the control had the least mean compressive strength of 8.63 N/mm^2. This result means that the bond between PET and sand may be better than that of cement with regards to compressive strength.

Table 7: Mean compressive strength of the control and paving stone composites.

Samples	PET Mix Percentage (%)	Mean Weight (kg)	Compressive Strength (N/mm^2)
Control	0	2.16	8.63
PET 10	10	1.86	12.64
PET 20	20	1.80	15.86
PET 30	30	1.76	20.59
PET 40	40	1.71	16.89
PET 50	50	1.67	14.26

Table 8 shows the results of Anova test between the control and PSCs mean compressive strength using MS Excel. 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 mean compressive strength between the control and PSCs were significant. The result of the mean compressive strengths of the control and the PSCs shows that the optimum PET-sand mix is 30 %. Hence, the utilization of PET waste as binders in the production of paving stones is feasible in terms of compressive strength.

Table 8: Analysis of variance (Anova) between the control and paving stone composites mean compressive strength.

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				

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusions

The conclusions from this study are that:

(1) the PSCs were lighter in density, and the density became lighter with an increase in PET ratio.

(2) the PSCs performed better on the water absorption test over the control.

(3) the control, cools off faster than the PSCs when exposed to high temperature.

(4) the PSCs recorded a higher value that the control for the compressive strength test.

(5) It is therefore established that PET waste can be best utilized as total cement replacement in the production of pavers and will now be sustainable way of PET management.

4.2 Recommendation

The recommendations of this study are that:

1. the PSCs can be used in water-logged areas and also as rip rap due to their low water absorption capacity

2. the PSCs produced at 20 – 40 % PETare suitable for the construction of pedestrian paths, landscapes, and residential parking areas because it meets the minimum strength requirement for "class 4", for use of pedestrian walkways of 15N/mm^2.

3. Further study should be conducted on the chemical properties to help determine the performance of pavers when exposed to attacks from chemicals such as sulphate and chloride.

4. Furthermore, tests such as split tensile, flexural, impact resistant, abrasive, and soundness or durability should be conducted.

5. Tamping should be done properly, or a vibrating compressive machine should be used during production, especially when the sample is been discharged into the mold, to avoid the formation of air voids that might lower strength characteristics or aid water retention during the cold soaking for the water absorption test.

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