JOURNAL OF ENGINEERING, EMERGING TECHNOLOGIES AND APPLIED SCIENCES (JEETAS)

A PUBLICATION OF THE FACULTY OF ENGINEERING, NIGER DELTA UNIVERSITY

NOVEMBER 2023 VOLUME 01 ISSUE 02 ISSN: 1116 - 4514

ARTICLES

NIGER DELTA UNIVERSITY

Journal of Engineering, Emerging Technologies and Applied Sciences -– Volume 1 Issue 2, Nov. 2023

Available at ***https://www.ndu.edu.ng/journalofengineering/***

RESEARCH ARTICLE OPEN ACCESS

Strength Properties of Paving Stone Composites with Polyethylene Terephthalate (PET) as Total Cement Replacement

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Abstract:

This study is on the strength properties of paving stone composites with polyethylene terephthalate (PET) waste as total cement replacement. The PET wastes were melted and mixed with river sand to form paving stone composites (PSCs) of PET-sand mix ratio of 1:3, labelled (PET: 10%, 20%, 30%, 40%, and 50%); and sand-cement mix of 1:3 labelled PET 0% as the control. Three replicates of PSCs of each mix ratio and control, were casted in a mold measuring 50mm × 100mm × 200mm, cured for 28 days. Each sample were then tested for density and compressive strength and their mean values were determined. The results showed 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. All the PSCs samples 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. Analysis of variance shows that the inequality observed between PSCs mean values for density and compressive strength and the control were significant at 95 percent confidence level. It can therefore be concluded that PET waste can be used as total cement replacement in the production of paving stones for pedestrian path and residential parking lot.

Keywords — **Polyethylene terephthalate, paving stone composites, density, compressive strength**

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I. INTRODUCTION

Polyethylene terephthalate (PET) materials are used for packaging globally and end up as waste after use. With the remarkable increase in population (urbanization and commercial activities), the waste generation streams have also increased and has become a major challenge to municipal waste managers and other relevant authorities. These bio-nondegradable PET materials like empty plastic bottles, packaged water sachets, empty food packaging packs etc which are discarded by humans, are swept by rain, clogging up drainages and canals. In most cases, these clogged waterways cause flash flooding at the blink of a light downpour (Emeka and Lesley, 2020). Although, PET materials such as water and soft drinks plastic bottles are currently being reused mostly by small and medium-sized enterprises (SME's) owners to package varying local products such as liquid soap, kerosene, zobo drink, palm oil, vegetable oil, etc in developing countries. This practice only offers a temporary solution by taking some of these waste materials off the streets but large volumes are still seen all over the places.

II. RELATED LITERATURES

Puttarajs et al. (2018) manufactured plastic soil-bricks with bitumen, polyethylene terephthalate (PET), polypropylene (PP), and earth quarry debris. In the study, 60% - 80% PET aggregate and 2% - 5% bitumen were used in the manufacturing process and PET shows good resistant properties. The bitumen enhanced the binding property of the PET. The compressive strength was 10 N/mm^2 with 5% bitumen and 70% PET mix ratio. With 2% bitumen and 45% PET waste, the water absorption was 0.9536%. And also, polypropylene has higher compressive strength. Seghiri et al. (2017) reported that floor and roofing tiles were also made from recyclable plastics bottles. Sand and high-density polyethylene (HDPET) with 30-80% mix ratio was used to manufacture floor tiles. Testing for density, impermeability, and flexural breaking stress revealed that as the amount of plastic waste increase, flexural strength increase, and tile density decrease from 1.8 kg/m^3 to 1.379 kg/m^3.Agyeman et al., (2018) utilized plastic waste as binders for paving blocks production along with cement: quarry dust: sand with (1:1:2) mix ratio measured by weight / volume. Composite paving blocks less in plastic (LP) with 1:1:2 mix ratio and high in plastic (HP) with 1:0.5:1 mix ratio measured by weight/volume. The study revealed that paving blocks in HP and LP have compressive strengths of 8.53 N/mm^2 with 0.5% water absorption and 7.31 N/mm^2 with 2.7% water absorption respectively, higher than the control value of 6.07 N/mm^2 with 4.9% water absorption. Almeshal et al., (2020) examined the effects of utilizing recycled poly-ethylene terephthalate (PET) waste as a partial replacement for sand in concrete. They looked at how this substance affected the mechanical and physical characteristics of concrete. Six samples (0%, 10%, 20%, 30%, 40% and 50%) of PET concrete mix were prepared, partially replacing sand. Concrete was cast to determine the behaviour of fresh and hardened concrete in terms of workability, unit weight, compressive strength, flexural strength, tensile strength and pulse velocity. The findings reveal a decrease in unit weight, the concrete's mechanical properties were adversely affected by the replacement of the sand. Youcef et al. (2014) explores the possibility of recycling plastic bags waste to concrete where the variable percent of sand is substituted. The work reveals that plastic bag waste can replace conventional aggregates in concrete without any long-term detrimental effects and with acceptable strength development properties. Zainab and Al-Hashmi (2008) showed the idea of employing various plastic wastes as fine aggregates up to 4.75 mm in concrete, containing roughly 80% polyethylene and 20% polystyrene. The compressive tests revealed that as the plastic waste content in the concrete increased, the compressive strength values of the plastic waste concrete decreased below the reference concrete at each curing age. At 28 days after curing, the concrete containing 10% plastic trash had the lowest compressive strength, nearly 30% lower than the reference concrete mixture. The study also discovered that concrete mixes containing 10%, 15%, and 20% plastic aggregates had densities that were 5%, 7%, and 8.7% lower, respectively. Alaloul et al., (2020) replaces clay and cement with polyethylene terephthalate (PET) and polyurethane (PU) binders while making interlocking bricks. Before mixing the plastic bottles with polyurethane (PU) and polymer, the bottles were finely chopped and grated to a size of 0.75 mm. The interlocking brick machine mold was used to condense the mixer. The highest compressive strength attained using polyethylene terephthalate (PET) and polyurethane (PU) in the ratio of 60:40 was 84.54% (less than the control group), the highest tensile strength was 1.3 MPa, and the maximum impact value was 23.343 J/m. There was a thermal conductivity of 0.15 to 0.3W/m K. These bricks were recommended for usage as a partition wall and were determined to be suitable as non-load-bearing masonry bricks. According to Gharif et al., (2010) 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. Standard Nasional Indonesia (SNI 03-0691-1996), 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 as binder in different mix ratios, determine the compressive strengths of the composites and statistically compare results with conventional cement-sand paving stone.

III. MATERIALS AND METHOD

A. Materials

The materials used in the production process were;

1. Personal Protective Equipment: These are hand gloves, facemasks, cover all, safety boot, These PPEs are to protect various parts of the body from potential hazards
2. Melting Bowl: The melting bowl used was head pan and is needed to melt the PET waste to liquid form before adding sand and stirring to mix
3. Mixing Spatula: A wooden spatula for mixing the molten PET waste and sand during the heating process until desired mix is achieved.
4. Firewood: The source of energy needed to break down the polyethylene terephthalate wastes (PW's) aggregate into molten form before the fine aggregates (sand) are introduced.
5. PET Wastes: Plastic waste of varying sizes collected from dumpsites within the city of Yenagoa was cut into smaller sizes to aid the measurement
6. Fine Aggregates: This is one of the primary constituents involved in the production process. The sand was properly sieved to obtain the same particle as specified by ASTM C33.
7. Spent Engine Oil: This was used to grease the mold to avoid the mixture sticking.

B. Equipment

The equipment used were:

1. Weighing Scale: The scale was used to weigh the quantity of sand, the crushed polyethylene terephthalate waste and the composite paving stones.
2. Rebound Hammer Tester: The rebound hammer tester is a non-destructive concrete testing technique that offers a practical and quick estimate of the concrete's compressive strength. It is a concrete testing technique that adheres to ASTM C805 standards.
3. Mold: The mold was locally fabricated with wood for the purpose of this study. The dimension of the mold is 50 x 100 x 200 mm.

C. Paving Stone Composites Production Process

PET wastes (PWs) were manually harvested from dumpsites while a river sand collected from the sand dump in Swali, a community in Bayelsa State, Nigeria on the bank of River Nun. The PET wastes were thoroughly washed then shredded into smaller pieces to hasten the melting process. These composite materials were all transported to the Structure Laboratory in Civil Engineering Department, Niger Delta University.

The PET wastes were melted and mixed with river sand to form paving stone composites (PSCs) of PET-sand mix ratio of 1:3, labelled (PET: 10, 20, 30, 40 and 50%); and sand-cement mix of 1:3 labelled PET 0% as the control. The composite mix was transferred to an oiled mold and allowed to set. Six samples in three (3) replicates, were produced for this study. The control paving stones production were guided by ASTM C902 class MX specification for bricks intended to use as pavers for light vehicles, bikes and pedestrians. Each sample was well tampered during the casting stage and allowed to cure for a period of 28 days.

D. Laboratory Testing

The paving stone composites and control were taken to the laboratory for testing. The densities and their compressive strengths of the replicates of each sample were determined at 28 days. The mean values were then recorded.

E. Density

The weight and volume of samples measuring 50 x 100 x 200 mm used to determine the densities of each paving stone composites

Mathematically, the bulk density is calculated by the mass paving stone divided by the dimensional volume.

$$\text{Bulk Density} = \frac{\text{Mass (kg)}}{\text{Volum}(\text{m}^3)} \quad (1)$$

where:
M = Mass of paving stone
V = Dimensional volume of the paving stone (length breadth and thickness) in m^3.

F. Compressive Strength

The compressive test is described as the unit's capacity to sustain an axial load that is applied to the bed face, its edge, and/or the proportion of a sample's net area to the crushing load it can withstand and were carried out in accordance with ASTM C109. The rebound hammer test was used for the compressive strength test. It is a quick and efficient method of non-destructively determining the compressive strength of concrete. It is a method of evaluating concrete that complies with ASTM C805 requirements.

IV. RESULTS AND DISCUSSION

A. Density

The results of mean value for density of the paving stone composites at 28 days is shown in Figure 1. The cement-sand (PET 0) had the highest mean value of 2160 kg/m^3, while the mean values of PET-sand mix paving stone composites range from 1860 kg/m^3 to 1670 kg/m^3. The result shows a decreasing trend in the density of PET-sand mix paving stone composites mean values as the percentage of PET increases, and this can be attributed to the fact that cement is denser than PET. The result of the ANOVA test between the cement-sand and PET-sand samples, the mean densities were statistically analyzed using MS Excel and are shown in Table 1. Since the F(cal) is greater than the F(crit), and the P-value is lower than 0.05. It can be concluded that the difference in density between the cement-sand and PET-sand was significant. The implication is that the PET-sand are lighter and can be easily transported and have better workability, compared to the conventional paving stones.

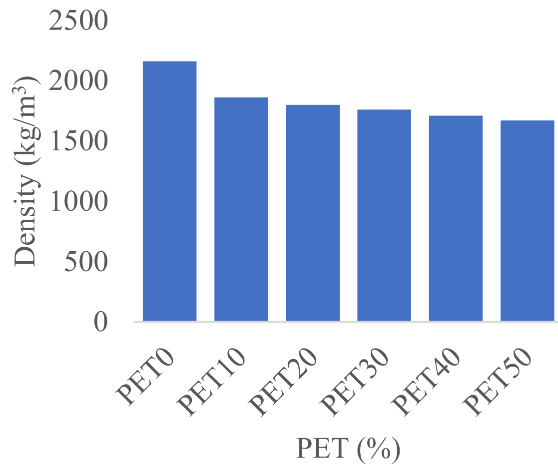

Figure 1: Comparison of PSCs mean densities and control

B. Compressive Strength

Figure 2 shows comparison 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 stronger than that of cement with regards to compressive strength.

Table 2 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. Figure 1 shows a comparison of the mean compressive strengths of the control and the PSCs which indicates 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 1: Analysis of variance (Anova) between the mean densities and control

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**				

Table 2: Analysis of variance (Anova) between the control and paving stone composites 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	36.1855	8	4.5232			
Total	173.7523	9				

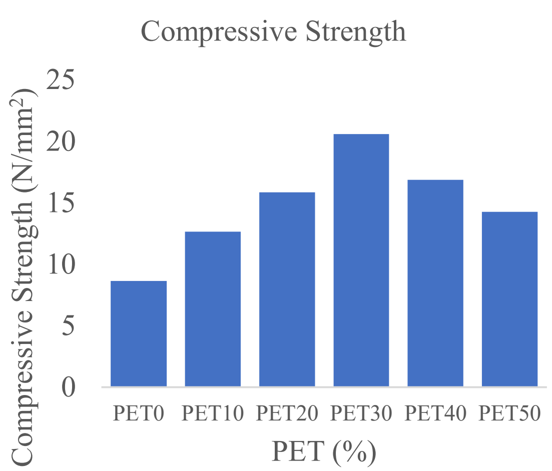

Figure 2**:** Comparison of the mean compressive strengths of the control and the

V. CONCLUSION

A. Conclusions

The conclusions from this study are that:

(1) The density of the control was higher than that of the PSCs and the higher the percentage of PET, the lighter the weight

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

(3) It is therefore established that PET waste can be best used as total cement replacement in the production of pavers.

B. Recommendations

The recommendations of this study are that:

1. the PSCs produced at 20 – 40 % PET are 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.
2. 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.

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

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