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Plastic wastes to pavement blocks: A significant alternative way to reducing plastic wastes generation and accumulation in Ghana

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HIGHLIGHTS

- The compressive strength of the pavement block from the plastic-pit sand exceeded the plastic-sea sand block by 25%.
- The compressive and tensile strength of pit sand, and sea sand blocks was constant at 80% and 90% plastic composition.
- The average penetration of both pit sand and sea sand pavement blocks was constant at 50% plastic composition.

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ABSTRACT

This study explored the conversion of plastic wastes into pavement blocks in Ghana. The physical and chemical properties of the pit sand, sea sand, plastic wastes, and pavement block were determined. The FTIR identified Quartz and Kaoline minerals as the main components of the sand samples, whereas those of the plastic wastes were polyethylene and polypropylene. The SEM showed that the plastic-pit sand pavement block (PPPB) had fibrous surface with smaller pore volume and grain size than the plastic-sea sand pavement block (PSPB). At 20% plastic composition, the water absorptivity of PPPB and PSPB maximized at 3.98% and 4.60%, respectively. Larger quantity of plastic decreased the block water absorptivity but improved the compressive strength. The maximum compressive strengths of the PPPB and PSPB were 36.96 N/mm^2 and 27.81 N/mm^2, respectively. The maximum tensile strength of PPPB (8.2 N/mm^2) exceeded the PSPB (6.1 N/mm^2). Furthermore, increasing the plastic composition improved the average penetration resistance of both pavement blocks. The results suggest that converting plastic wastes into pavement blocks is feasible, and can help reduce the rapid accumulation of plastic wastes in Ghana.

1. Introduction

Waste generation has become a key global issue that has existed persistently in the life of humankind. Many countries in the world have developed various waste management systems to curb this canker. Some of these wastes emanate from plastic industries, cement industries, hospitals, human and animal excretion, food production and consumption [1–3]. Fortunately, some of these wastes are biodegradable and easily re-convertable to other useful products.

Unfortunately, other plastics wastes are difficult to biodegrade, and have increased rapidly over the years. 300 million tonnes of plastics are produced globally each year [4]. From the 1950s to 2018, worldwide production of plastics is about 6 billion tonnes, of which only 9% and 12% have been recycled and incinerated respectively [5], implying that 79% are left untreated in the environment. The rapid annual production of plastics in the world is due to the diverse utilization of plastics in various endeavors such as disposable applications, which contribute 50% of plastic applications [6], and medical and public health applications. In medicine and public health applications, plastics are used in prosthetics, engineered tissues, and micro needle patches for delivery of drugs [7,8].

Africa is one of the continents facing the devastating effects of plastic wastes due to rising per capita consumption, urbanization, growth in population, and insufficient infrastructure to curb the rapid waste generation [9]. In Africa, a total of 4.4 million tonnes

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of plastic wastes were mismanaged in 2010, and the use of plastic in Africa has grown over 150% [10,11]. However, the plastic wastes have associated socio-economic defects, environmental pollution, and public health threat.

The adverse impact of plastic wastes generation is enormous. Some of these include tap water pollution [12], toxicity to humans and animals [13], marine life entanglement [14], blockage of sewage systems and drains, which causes flooding and deadly diseases [15,16].

Ghana is confronted with similar problems concerning plastic wastes (Fig. 1). For example, in Ghana, about 22,000 tonnes of plastic wastes are produced annually with only 2% recycling rate [11]. This has adverse rippling effects on the health and safety of Ghanaians. For instance, in 2014, a total of 1035 cholera cases were recorded in the capital city (Accra), and Brong Ahafo region.

This resulted in fatality rate of 2.4%, which is higher than the <1% WHO recommended rate [17]. From June 2014 to September 2015, IFR, UNICEF and WHO reports indicated that 29,655 cholera cases were recorded in all the regions of Ghana with 0.9% death rate [18]. Massive flooding as results of choked waterways and drains contributed to some of these cases. Typically, in 2015, plastic wastes choked waterways and drains in Accra, which resulted in 150 death cases and damages amounting to millions of dollars [19].

Several solutions have been proposed concerning curbing of plastic wastes. Prominent of them include use of paper or cloth bags, reuse of plastic bags for many times, recycling and incineration of plastics and reduction in the use of plastic wrapped-products [5,15]. However, none of these fully mentions the conversion of plastic wastes into pavement blocks, especially in a developing country like Ghana who have major challenges towards proper plastic waste managements. Meanwhile, 61% of roads in Ghana is classified as poor (Fig. 2) [20]. With only 2% annual plastic wastes recycling rate, the remaining 98% plastic wastes could be converted into pavement blocks.

The use of plastics in road construction is not new. In addition, solid waste materials, including plastics, pavement blocks are known to be versatile, cost effective, functional, aesthetically attractive, and requires little or no maintenance if correctly manufactured and laid [21,22]. The major advantages of using plastics in pavements and road construction include stronger road with increased Marshall Stability, significant reduction in the accumulation of plastic wastes, reduction in the cost of road construction, near zero road maintenance cost, better road resistance towards rainwater and water stagnation, and little or no stripping and little potholes [23]. Despite the adverse effects of plastic wastes, and the key advantages of pavement blocks, the conversion of plastic wastes into pavement blocks to enhance plastic wastes reduction has received little exploration.

Fig. 1. Plastic wastes entering an urban river in Ghana [11].

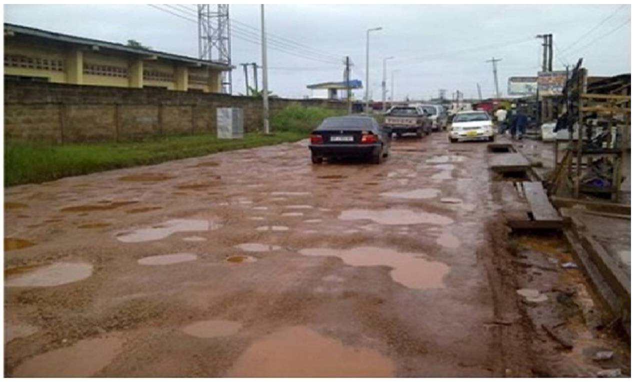

Fig. 2. An image showing one of the poor roads in Ghana Figs 1 and 2 [20].

This work, therefore, focused on the conversion of plastic wastes into pavement blocks for road construction in Ghana. We investigated the effect of pit sand and sea sand on the compressive strength of the plastic pavement blocks, which will be presented and discussed. We used pit sand, and sea sand because these are the abundant sources used for pavement blocks in Ghana. The physical properties and chemical composition of the sand samples were also explored. This work will significantly help reduce the rapid plastic wastes accumulation and improve the poor road system of Ghana.

2. Materials and methods

2.1. Sample collection and treatment

All kinds of thermoplastic solid wastes in any form were collected from Juabin Municipality, geographically located in the Eastern region of Ghana. After collection, the plastic wastes were washed, cleaned and dried to remove all contaminants that would impede the melting process.

2.2. Shredding and melting of the plastic wastes

Shredding is the process of cutting the plastic into small sizes between 2.36 mm and 4.75 mm [24]. The samples were put into the feed hopper of Beston plastic shredder machine (Zhengzhou, China). They were then shredded into 3 mm by the shredder blades. The plastic flakes together with the pit sand or sea sand were placed in an extrusion machine in batches (Fig. 3). The batches were put in an enclosed system of the extrusion machine and melted at 175 °C until no flake was observed.

Fig. 3. An image of the extrusion machine.

2.3. Preparation of plastic and sand mixture

Prior to the preparation of the plastic and sand mixture, the physical and chemical properties of the sand, and the plastic wastes were determined as shown respectively in Tables 1 and 2.

After the flakes had melted completely, varying proportions of the plastic wastes and the sieved sand were mixed and stirred thoroughly to uniformity (Table 3). Thus, the pit sand and the plastics were mixed and labeled as specimen A while the sea sand and plastic mixture was labeled as specimen B.

The molten mixture was transferred into a lubricated 50 × 50 × 50 mm^3 molds and leveled using a hand trowel. It was pressed down using a flat rectangular board to get rid of air gaps, and allowed to cool and harden at room temperature. A total of 20 cubes were made. The cubes were characterized using Fourier Transform Infrared Spectroscopy (FTIR), and Scanning Electron Microscopy (SEM). They were also tested for compressive strength, water absorption, tensile strentgh, and depth of penetration.

2.4. Fourier transform infrared spectroscopy

The pavement block was first characterized by FTIR using attenuated total reflectance ATR, (Bruker Spectrometer IFS 66/SFT-IR instrument, equipped by H-ATR with a ZnSe crystal, USA). The functional groups were checked by analyzing the spectra obtained during the scans.

2.5. Scanning electron microscopy

The samples were oven dried at 60 °C for 48 h to remove entrapped moisture. A sample size required for the SEM was taken and scanned using SEM 6200 (Labgeni, China) with acceleration voltage of 0–35 kV. The SEM 600 was equipped with hair fork tungsten cathode electron gun, and vacuum system. The samples were scanned at 10 KV.

2.6. Water absorption

The dried weight of the plastic block was recorded as (w_1). The blocks were submerged in a water tank for 72 h after which each was reweighed and recorded as (w_2). As expressed in Eq. (1), the water absorption of the specimen was calculated as percent increase in mass resulting from water immersion.

$$Water\ absorption = \frac{w_2 - w_1}{w_1} \times 100 \quad (1)$$

2.7. Determination of the compressive strength of the blocks

This method adopted IS:4031-PART 6-1988 procedure [25]. The compressive strength of the pavement blocks was determined after 28 days, using an ELE compressive strength machine with a load cell of 2500 kN and a loading rate of 24 kN/sec. We waited for the 28 days due to the conventional method applied in the cement industry, though the plastic binder is not like cement.

2.8. Determination of the tensile strength of the blocks

ISO 7500-2:2006 method was applied. The test was carried out using a calibrated 1000 kN, LD-1000 D digital gauge No. 01864 force-proving instrument Dynamometer (Nippon Kaiji Kyokai Research Center, Japan). The operation was carried out taking duplicate readings from each sample, and slowly increasing the trend of the applied force at different load points from which the reference force for each loading were evaluated.

Table 2
Properties of thermoplastic wastes used.

Property	Value
Flash point	350 °C
Melting point range	151–163 °C
Density at 25 °C	0.962 g/ml
Auto-ignition point	341 °C
Tensile strength	26 N/mm^2

Table 3
Proportions of plastic wastes, pit sand and sea sand used.

Specimen A		Specimen B	
Plastic (%)	Pit sand (%)	Plastic (%)	Sea sand (%)
20	80	20	80
25	75	25	75
30	70	30	70
35	65	35	65
40	60	40	60
45	55	45	55
50	50	50	50
55	45	55	45
60	40	60	40
65	35	65	35
70	30	70	30
75	25	75	25
80	20	80	20
90	10	90	10

2.9. Determination of the penetration of the blocks

ASTM C-803 was adopted for the penetration test, using ELE Penetrometer 46-5295 (ELE International, UK) on both plastic-pit sand, and plastic-sea sand pavement blocks [26]. The Penetrometer applied a weight standard of 100 g at 25 °C for 5 s. The samples for both plastic-pit sand, and plastic-sea sand pavement blocks had percentage plastic ranging from 20 to 95. The sand with zero plastic could not bind, making it difficult to ascertain its penetration test. Therefore, relative comparison of blocks was made by varying the plastic composition.

All reproducible methods and measurements were duplicated, and the average value reported. All statistical analyses, calculations, and graphs were done using Microsoft Excel 2010.

3. Results and discussion

This worked explored the conversion of plastic wastes into pavement blocks and the impact of sea sand, and pit sand on the compressive strength.

3.1. FTIR analysis

The FTIR spectra of the PPPB and PSPB show close similarities due to the similar functional groups present in both mixtures

Table 1
Physical and chemical properties of pit sand, and sea sand used.

Material	Blaine fineness (m^2/kg)	Specific gravity (g/cm^3)	Particle size distribution	Chloride (v/w %)	SiO_2 (wt %)	CaO (wt %)	MgO (wt %)
Pit sand	2.671	2.66	63 μm–1.18 mm	0	99.10	0.06	0.01
Sea sand	2.43	2.70	300 μm–2.36 mm	0.145	81.23	0.05	0.11

(Fig. 4). The wavenumbers 1455.20 cm^{-1} and 1375.59 cm^{-1} are assigned to the –CH_2 and –CH_3 bends in the plastic respectively [27]. These bands are extremely weak in the pit sand and attributed to the higher SiO_2 concentration (99.10%) in the pit sand than the 83.23% in the sea sand. The result suggests that polyethylene and polypropylene are the main constituents of the plastic wastes since the –CH_2 and –CH_3 bends are very common in these plastics.

The 1025.49 cm^{-1} and 1073.79 cm^{-1} are attributed to Si-O-Si stretching vibrations, indicating the presence of Kaoline mineral in the sand samples [28,29]. The 796.80 cm^{-1} and 777.27 cm^{-1} are assigned to Si-O symmetrical stretching vibrations. The 692.28 cm^{-1} or 694.08 cm^{-1} is assigned to Si-O symmetrical bending vibration. The 458.97 cm^{-1} or 460.21 cm^{-1} is assigned to Si-O asymmetrical bending vibration. These bands indicate the presence of Quartz mineral in the sand [27,28,30]. The result implies that Quartz mineral forms the main component of the sand, followed by Kaoline mineral.

The SEM portraying another variation in the morphology of both blocks (Fig. 5). The PPPB have fibrous network surface with smaller interparticle voids.

The pit sand grains are rounded and relatively smaller in size. However, the PSPB is rocky surface with wider void stretches. The sea sand grains are lumpy and relatively bigger in size. The PSPB is more porous than PPPB, implying that the PPPB will have higher water resistance than the PSPB.

3.2. Water absorptivity of the plastic pavement blocks

The water absorptivity of PSPB and PPPB maximizes at 4.60%, and 3.98%, sequentially (Fig. 8). The higher water absorptivity of PSPB than PPPB can be attributed to the higher concentration of the $MgSO_4$ and Cl^- ions in the sea sand, which enhanced water transport by means of osmosis. The larger interparticle voids in PSPB, as portrayed in Fig. 6, may also contribute to the higher water absorptivity.

In concrete building, these $MgSO_4$, and Cl^- ions are known for causing set concrete to expand, resulting in spalling, cracking, and finally reducing the concrete strength [31], therefore, this result shows that sea sand is not a good material for building and construction.

Again, the water absorptivity decreases as the percent plastic increases in the block. Thus, the higher concentration of the plastic results in higher water resistance of the pavement block. This is consistent with other literature, which mentions water resistance as one of the advantages of plastic pavement blocks [23].

3.3. Compressive strength of pavement blocks

The compressive strength directly relates to the percent plastic in the block (Fig. 7). Increasing the percent plastic elevates the compressive strengths of the blocks. This may be because of the increasing binding energy induced by the plastic.

Generally, the compressive strength of the PPPB (36.96 N/mm^2) exceeds the PSPB (27.81 N/mm^2). The trend in the compressive strength is similar to that reported in other studies on pavement blocks from plastic wastes and sand with 14–33% plastic [21,32].

The lower trend in compressive strength identified in the PSPB may arise from the $MgSO_4$, and Cl^- ions which caused higher absorptivity [31]. This reflects the results of the previous work which mentions that sea sand prisms or blocks have weak compressive strength, hence not potentially good material for con-

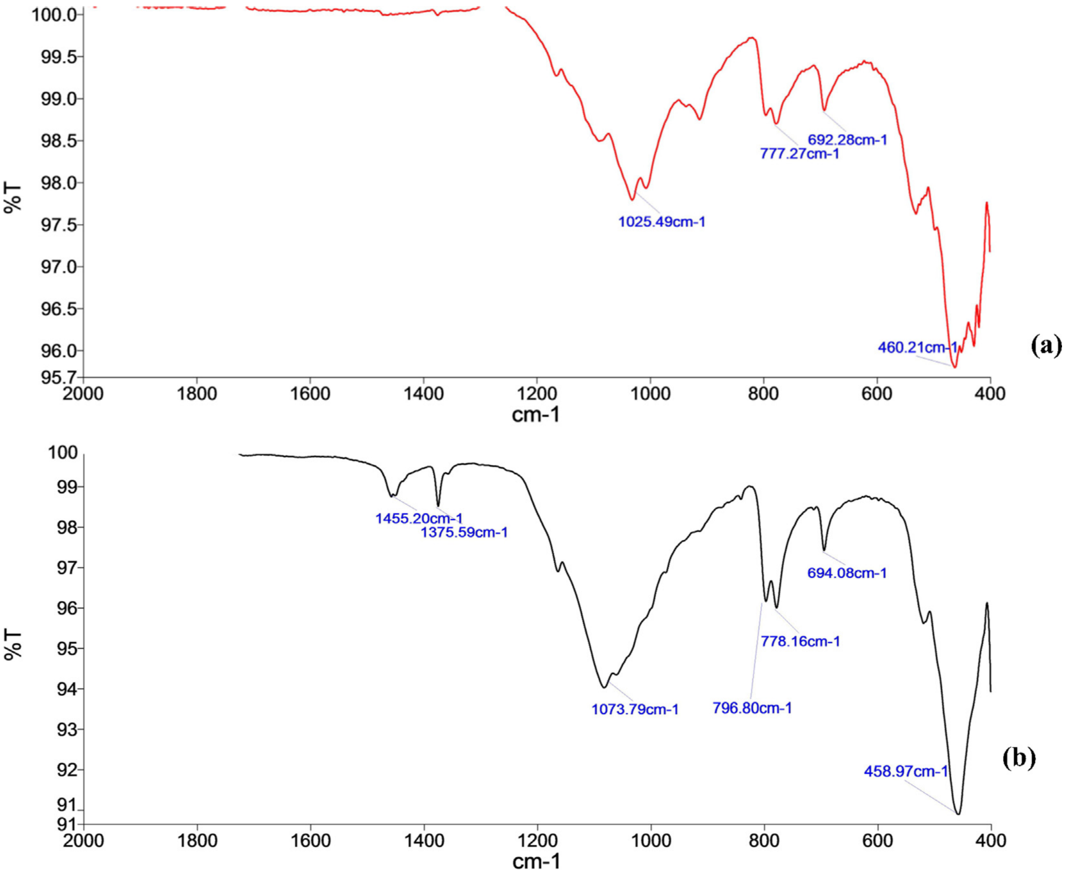

Fig. 4. FTIR of PPPB (a), and PSPB (b).

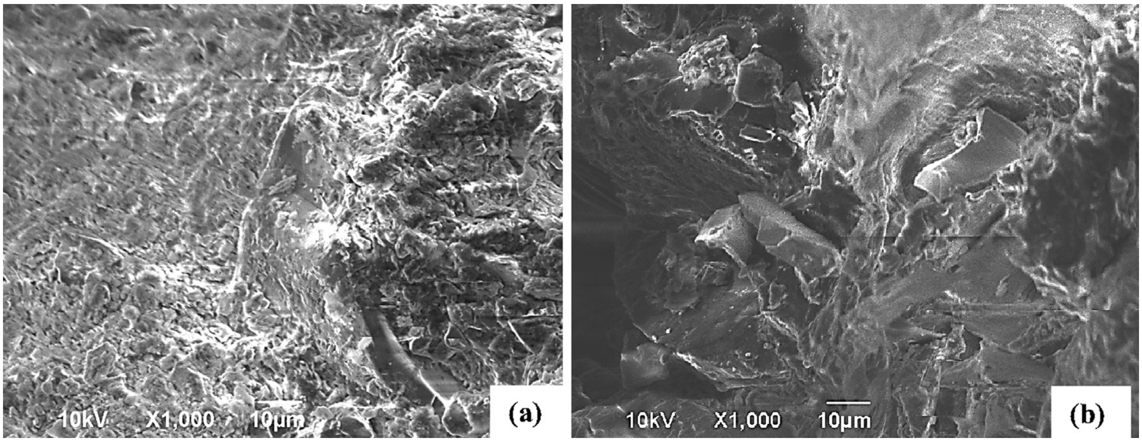

Fig. 5. SEM of PPPB (a), and PSPB (b).

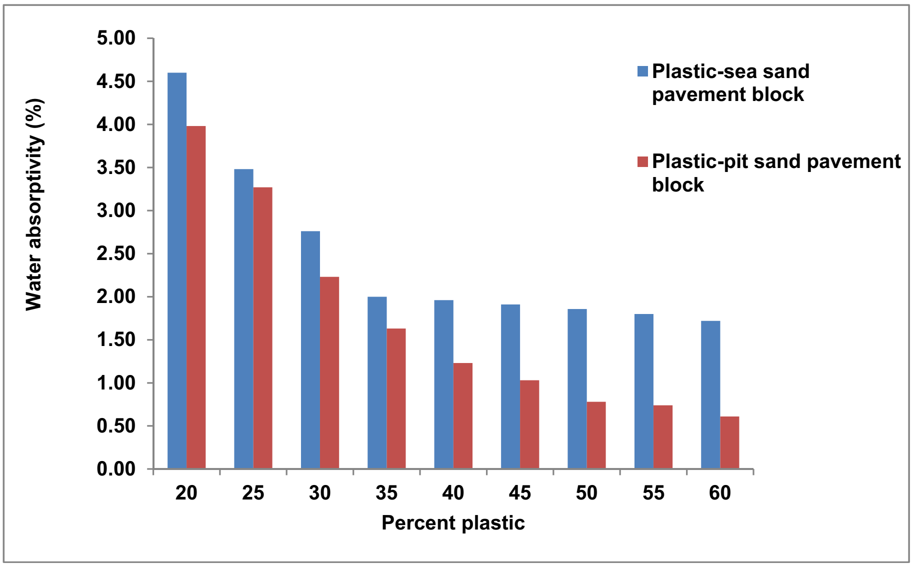

Fig. 6. Percent water absorptivity of PPPB and PSPB.

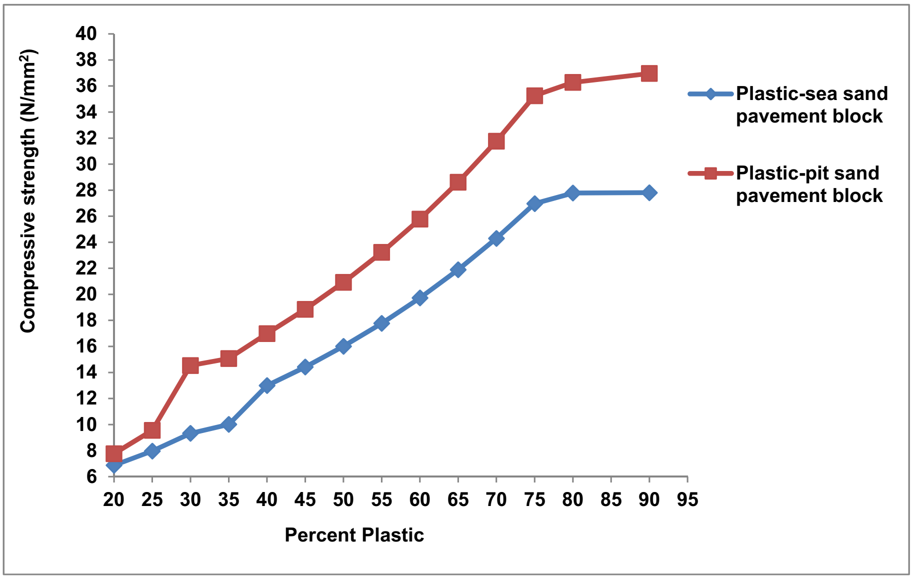

Fig. 7. The compressive strength of plastic-pit sand, and plastic-sea sand pavement blocks.

struction [33]. The compressive strength reaches equilibrium at 80% plastic.

3.4. Tensile strength of the pavement blocks

The tensile strengths for the both the PPPB and the PSPB directly relates the percent plastic in the blocks (Fig. 8). The maximum tensile strengths of PPPB (8.2 N/mm^2) exceeds the PSPB (6.1 N/mm^2). Like the compressive strength, the tensile strength is nearly constant at 90% plastic. The $MgSO_4$, and Cl^- which reduces the compressive strength of PSPB may be the same reason for its lower tensile strength.

3.5. Penetration test on the pavement blocks

The average penetration is inversely proportional to the percent plastic in the blocks (Fig. 9). The sharp decrease in penetration for both PSPB and PPPB is due to the increasing hardness and compressive strength of the pavement blocks as the percent plastic increases. The average penetration of the PSPB was basically higher than that of the PPPB, indicating that PPPB has higher penetrative resistance than PSPB. The average penetrations of both blocks remain almost the same after 50% plastic.

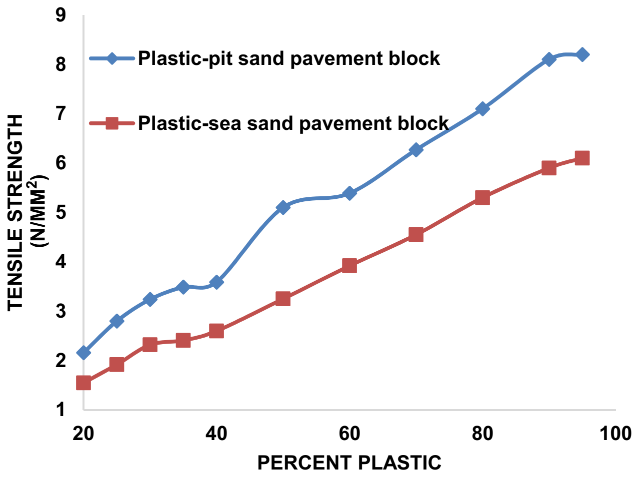

Fig. 8. The tensile strength of plastic-pit sand, and plastic-sea sand pavement blocks.

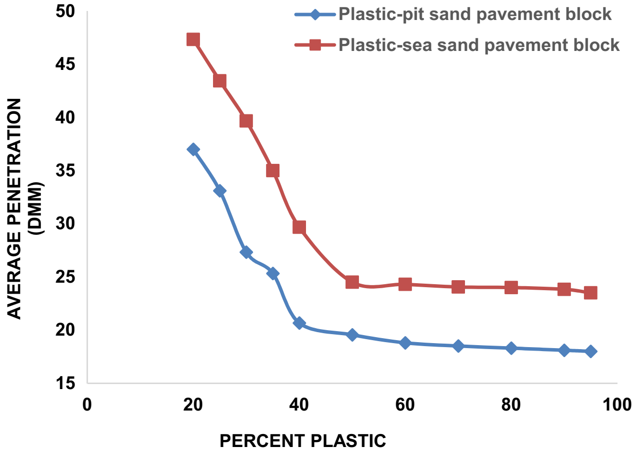

Fig. 9. The Average penetration of plastic-pit sand, and plastic-sea sand pavement blocks.

Thus, considering the compressive strength, tensile strength. For the rising levels of the sea due to global warming, it is crucial to preserve the coastline with the sea sand, which will eventually avert sea erosion. Therefore, it is beneficial to the environment that the PPPB had higher compressive strength and tensile strength compared with PSPB, as this will prevent the usage of sea sand as building material.

4. Conclusions

This study focused on the conversion of plastic wastes into pavement blocks in Ghana. This is aimed at reducing the rapid accumulation of plastic wastes in Ghana. The amount of plastic decreased the water absorptivity of the blocks but increased the compressive strength. The maximum water absorptivity of PSPB was 15.5% higher than the PPPB. This was recorded at 20% plastic composition. From the FTIR, Quartz and Kaoline minerals were the main components of the sand samples, whereas those of the plastic wastes were polyethylene and polypropylene. From the SEM, the PPPB had fibrous surface with smaller pore volume and grain size than the PSPB. The 36.96 N/mm^2 maximum compressive strength of the PPPB exceeded PSPB by 25%. The tensile strengths of PPPB and PSPB peaked at 8.2 N/mm^2 and 6.1 N/mm^2, sequentially. The compressive and tensile strength of both blocks remained nearly constant at 80% and 90% plastic composition, respectively. The average penetration of PPPB (19.55 DMM) and PSPB (24.55 DMM) remained almost unchanged after 50% plastic addition. The overall compressive strength, tensile strength, and penetrative resistance property of PPPB surpassed the PSPB, which make PPPB a superior constructive material to PSPB. The results suggest that it is feasible to combine pit sand with thermoplastic wastes to form pavement blocks, which could be suitable for building and construction of roads in Ghana. This would also reduce congestion of the sea and other river bodies with plastics.

CRediT authorship contribution statement

Samuel Kofi Tulashie: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Supervision. **Enoch Kofi Buadu:** Investigation, Methodology, Project administration. **Francis Kotoka:** Methodology, Resources, Software, Supervision, Writing - original draft, Writing - review & editing. **David Mensah:** Investigation, Methodology, Project administration, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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