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Research

Effect of solvothermal-treated polyethylene on the mechanical properties of sandcrete blocks and concrete

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Abstract
In building construction, seepage and dampness in walls present serious problems since they can cause structural failures and damage in both residential and commercial contexts. Finding more affordable options is necessary as mitigating these problems frequently requires expensive fixes. This study aims to evaluate the effects of solvothermal-treated polyethylene added at concentrations ranging from 0 to 1.0% on the mechanical properties of concrete and sandcrete blocks. In addition to assessing the workability, split tensile strength, and compressive strength of concrete samples at different levels of the polyethylene (PE) inclusion, the study looked into the water absorption capacity, density, and compressive strength of sandcrete blocks. The blocks' compressive strength and water absorption capacity reduced as the amount of polyethylene additives rose, although there was a slight increase in the density. These changes remain well within the Nigerian Industrial Standards' specified limits. Hardened concrete shows a drop in density, compressive strength, and split tensile strength with increasing polyethylene content, while fresh concrete's workability decreases as the percentage increases. 0.4% incorporation of the treated polyethylene achieved the target strength of 20 N/mm^2 while Sandcrete blocks with up to 1% of the solvothermal treated polyethylene had compressive strengths more than the 2.5 N/mm^2 minimum required for non-load-bearing walls. About 61% reduction in water absorption was achieved in 48 h by the blocks, presenting a promising and cost-effective solution for seepage-related issues in building construction.

Keywords Concrete · Dampness · Polyethylene · Sandcrete blocks · Solvothermal

1 Introduction

The most common building material used worldwide is concrete. Concrete is a composite material made up of aggregate and fluid cement that is allowed to solidify over time [1]. A composite material composed of cement, sand, and water that is moulded into various sizes is called a sandcrete block [2]. Sandcrete blocks and concrete are important construction materials. Sandcrete blocks are fundamental in developing countries like Nigeria, where they are often the only option for building due to the limited availability of other materials.

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In Nigeria, sandcrete blocks are a low-cost alternative to more expensive materials, and they can be produced locally with basic machinery. The Nigeria Industrial Standard [3] specifies a minimum strength range of 2.5 N/mm^2 for non-load-bearing walls and 3.45 N/mm^2 for load-bearing walls, along with a maximum water absorption of 12% [4].

A type of waste plastic that is now essential to human production and daily living is polyethylene (PE). It is renowned for being flexible, strong, and long-lasting. It is also reasonably priced, lightweight, and UV-resistant. Reusing garbage has several benefits, including lowering environmental pollution, promoting the recycling and conservation of energy during the production process, and assisting in the preservation of non-renewable natural resources [5]. Plastic's potential usage in concrete has been demonstrated by studies, and in recent years, this kind of material has attracted a lot of attention [6–8]. Finding a different use for waste produced can help reduce the amount of garbage released into the environment, avoiding any pollution risks associated with disposal and opening up a route for lower building costs [9].

Due to their widespread availability and low cost, polyethylene plastics, for example, are being used more frequently as a result of the expanding global population [10, 11]. Plastics are currently employed to cut through materials used in many aspects of life to produce a wide range of items, from cars to household appliances [12]. Concrete mix contains a variety of waste and recycled plastic materials [13].

Polyethylene incorporation into concrete has demonstrated the potential to enhance mechanical qualities. The focus of Zia ul Haq et al.'s study [14] was how using plastic waste affected the mechanical qualities of concrete. In the experimental study, hand-formed serrated plastic fibers are added to the cement weight in ratios ranging from 0 to 20%. Their laboratory testing revealed that adding plastic fibers to concrete increases its modulus of rupture, tensile strength, and compressive strength. Hossain et al. [15] reported that polyethylene fibers or particles can enhance tensile and flexural strength, increasing energy absorption capacity and ductility. Polyethylene-reinforced concrete also exhibits reduced cracking and shear failure, as demonstrated in research by Nkomo et al. [16] and Karimi Pour et al. [17], which enhances the long-term performance and structural integrity of the material. Odeyemi's work [7] investigated the use of polyethylene terephthalate as a coarse aggregate in self-compacting concrete and showed that it could have an impact on the flow characteristics of the material in addition to its mechanical qualities.

Concrete's thermal characteristics can be affected by polyethylene, mostly through lowering heat transport inside the matrix. This feature is very helpful for building situations where thermal insulation is needed. Studies have shown that mass loss in cement-polymer-based materials when subjected to heat is not more than 30% irrespective of the type of polymer, water-cement ratio, and unit polymer content [18]. Flame retardants have also been used in reducing flame propagation in polyethlene concrete matrix by 85% [19].

The research by Basha [20] highlights the potential of polyethylene-based lightweight concrete in enhancing energy efficiency in building designs. Polyethylene's hydrophobic properties make it beneficial for improving concrete's durability. Studies have demonstrated that polyethylene can reduce water absorption, contributing to the mitigation of freeze–thaw damage and corrosion of reinforcing steel [21]. In aggressive environments, such as those with high chloride ion concentrations, the inclusion of polyethylene can lower chloride permeability and extend the service life of concrete structures [22, 23]. Although there are many benefits to using polyethylene in concrete, there are drawbacks as well. To achieve the intended advantages, polyethylene must be properly dispersed and compatible with the concrete mix. For attributes to be optimized, consideration of elements including polyethylene type, form (fibres or particles), and dosage is essential [15]. According to Adeniyi et al. [24], to create a circular economy, product development is currently pushed to incorporate multiple plastic wastes by valuing solid plastic waste and less-exploited solid minerals.

None of the literature that were reviewed used treated polyethylene in concrete or sandcrete blocks. Thus, the purpose of this study is to examine how the mechanical properties of concrete and sandcrete blocks at 0%, 0.4%, 0.6%, 0.8%, and 1.0% polyethylene content are impacted by the solvothermal treatment of polyethylene.

2 Materials

Portland Limestone Cement (PLC) of grade 42.5R (Dangote Cement 3X), which complies with BS EN 196-3 [25], was the type of cement utilized in this study. Natural river sand with a maximum aggregate size of 4.75 mm, specific gravity of 2.7, water absorption capacity of 2.56%, fineness modulus of 4.17, Coefficient of uniformity (C_u) of 3.38 and Coefficient of curvature (C_c) of 1.44 (indicating a well-graded aggregate) and bulk density of 1.59 was utilized as the fine aggregate. The particle size distribution curve for the fine aggregate is presented in Fig. 1. It contains no harmful components.

The coarse aggregate employed in this study is granite chippings that pass through a 25 mm screen and are retained on a 20 mm filter size. The aggregate has a fineness modulus of 6.8%, a specific gravity of 2.69, water absorption capacity

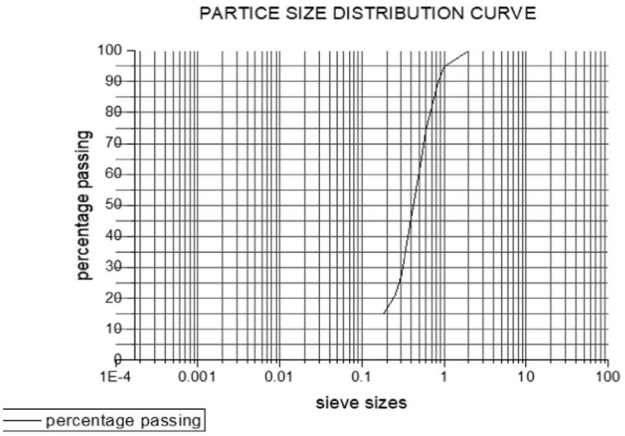


Fig. 1 Particle size distribution curve for the fine aggregate

of 0.2%, and an aggregate crushing value of 21.5%. These values fall within the acceptable limits specified by ACI Committee 363 [26].

The expanded polyethylene used (shown in Fig. 2) was obtained from some commercial electronic stores in Ilorin, Kwara State, Nigeria.

3 Methods

The polyethylene was cleaned and shredded into tiny pieces before it underwent the solvothermal treatment at the Civil Engineering laboratory, at Kwara State University. The solvothermal treatment of the polyethylene involved dissolving the polyethylene in kerosene at about 100 ℃ and stirring it to form a gel-like solution until complete solvent usage. The obtained gel-like solution was allowed to cool overnight and a stable solid paste was obtained as shown in Fig. 3a. The product depicted in Fig. 3b was milled using a milling machine at the material science laboratory at Kwara State University, Malete, following the full desolvent of the stable solid paste. Thereafter, the powdered solvothermal-treated polyethylene was sieved with an 85 µm sieve and presented in Fig. 3c.

Following Reynolds & Steedman's recommendation [27], a 1:2:4 (206 kg/m^3 of cement, 412 kg/m^3 of sand, and 824 kg/m^3 of granite) concrete mix ratio with a 0.5 water-binder ratio and a compressive strength of 20 N/mm^2, was used. For the sandcrete blocks, a mix ratio of 1:4 (288 kg/m^3 of cement and 576 kg/m^3 of sand) as stipulated by Odeyemi et al. [28] and Odeyemi, Anifowose, et al. [29] was adopted. The solvothermal treated polyethylene was added in 0%, 0.4%, 0.6%, 0.8%, and 1.0% of the total volume of cement to both concrete and sandcrete blocks samples.

Thirty (30) concrete cubes measuring 100 mm by 100 mm by 100 mm, thirty (30) concrete cylinders measuring 100 mm in diameter by 200 mm in depth, and thirty (30) samples of nine-inch sandcrete blocks measuring 225 mm by 225 mm × 450 mm were created (6 samples for each being a control experiment and 24 samples for different PE percentages). For seven and twenty-eight days, the specimens were completely submerged in water to cure. According to the



Fig. 2 Expanded polyethylene

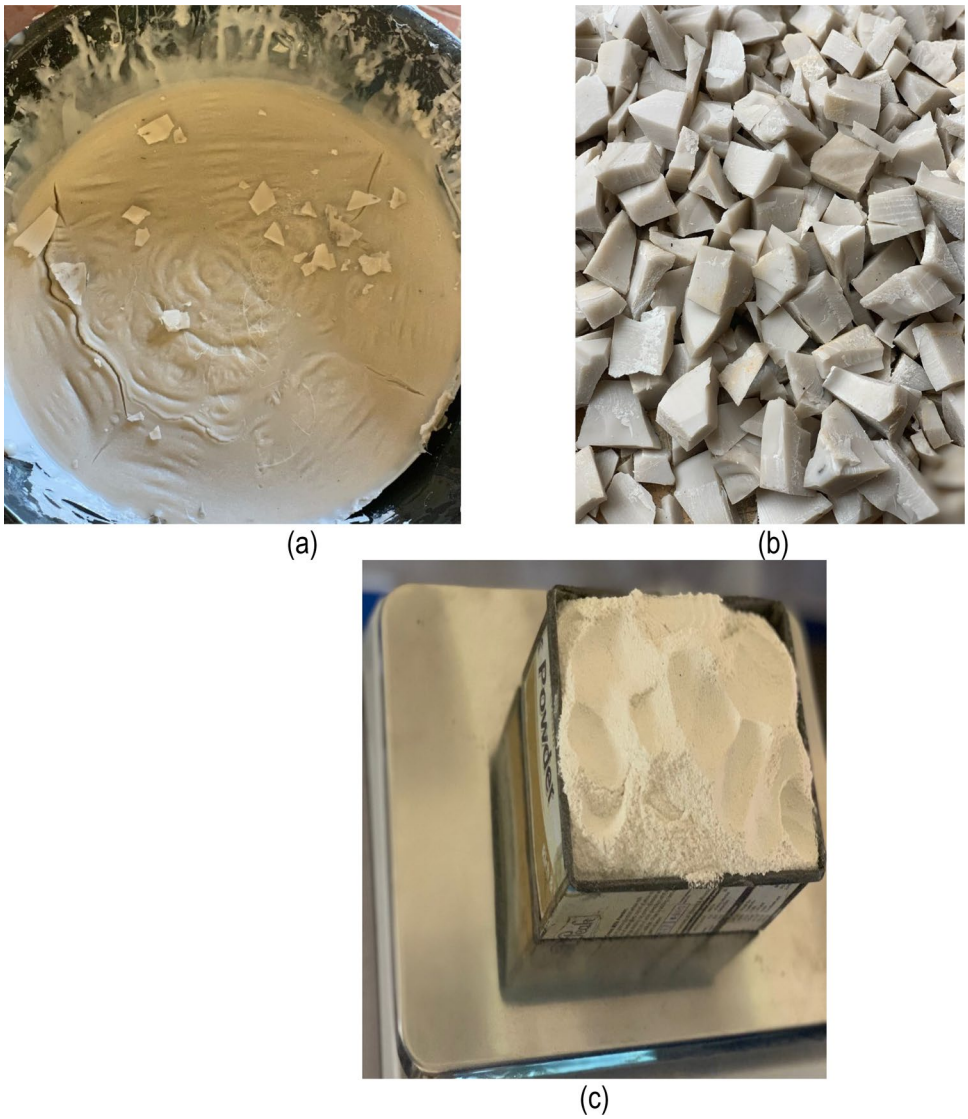


Fig. 3 Polyethylene: **a** Molten form (**b**) Dried form (**c**) Ground form

specifications in BS EN 12390-7 [30], BS EN 12390-3 [31], and BS EN 12390-6 [32], respectively, the hardened concrete was tested for density, compressive strength, and split tensile strength. The fresh concrete was evaluated for workability using a slump cone. Additionally, the sandcrete blocks' compressive strength and water absorption capacity were assessed in compliance with the requirements outlined in the Nigerian Industrial Standard [3]. All the tests were conducted at the concrete laboratory of the Kwara State Ministry of Works, Ilorin, Nigeria. The concrete cubes, and sandcrete blocks after demoulding and when under testing are shown in Fig. 4a, b, and c respectively.

4 Results and discussion

In this section, the study's results are presented.

4.1 Workability test result

Figure 5 illustrates the workability of the concrete batches with varying proportions of solvothermal-treated polyethylene. The result shows that as the percentage of polyethylene increases, the slump height of the concrete decreases. Thus, as the percentage of polyethylene increases, the concrete becomes stiff and less workable. The reduction in the slump height



(a)



(b)



(c)

Fig. 4 Test samples (**a**) Concrete cubes (**b**) Sandcrete blocks after demoulding (**c**) Sandcrete blocks when tested

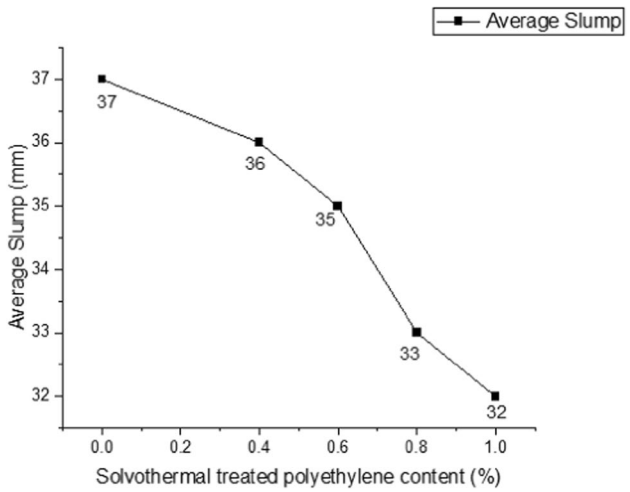


Fig. 5 Slump result for concrete with treated polyethylene

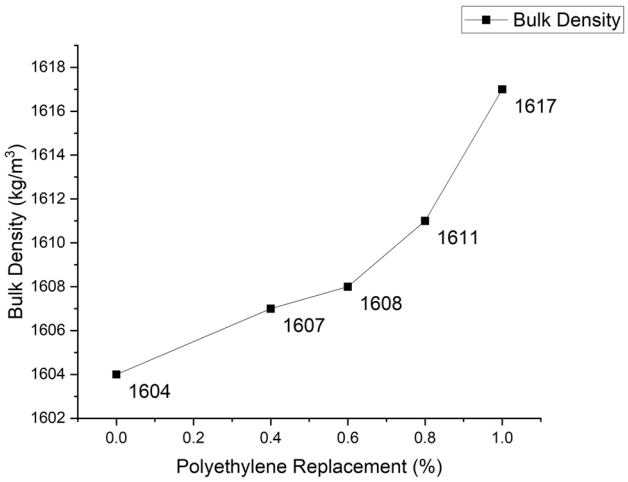


Fig. 6 Density of sandcrete blocks

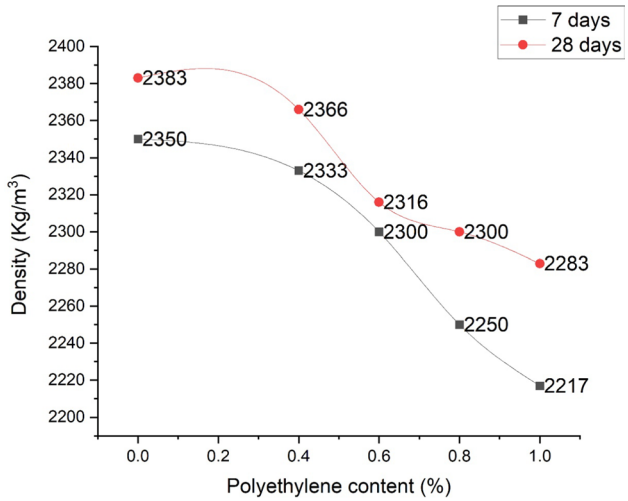


Fig. 7 Density of concrete cubes with solvothermal treated polyethylene content (%) at 7 and 28 days of curing

(workability) could be a result of the particles of the polyethylene absorbing some of the water content needed for the consistency of the concrete mix. This outcome is consistent with the pattern that Meena et al. [22] and Karimi Pour et al. [33] reported.

4.2 Density results for sandcrete blocks

Figures 6 and 7, respectively, show the densities of the concrete samples and sandcrete blocks at days 7 and 28 of their water-curing processes. It is clear from the data that the density of the sandcrete blocks increased marginally (0 to 0.8%) with the increase in the amount of polyethylene in the blocks. This implies a marginal increase in the dead weight of the sandcrete blocks.

The density of the concrete samples was reduced by a maximum of 4.2% at 28 days as the polyethylene replacement increased. This implies a reduction in the self-weight of the concrete when used for construction. These results follow the trend reported in the findings of Punitha et al. [34] and Islam and Shahjalal [35]. The density for all the concrete samples is within the range that is allowable for concrete works [27].

4.3 Compressive strength results

Figures 8 and 9 show the compressive strength of the sandcrete blocks after 28 days of curing in water, as well as the concrete samples after days 7 and 28 of curing in water, respectively. Figure 10 shows the split tensile strength of the concrete.

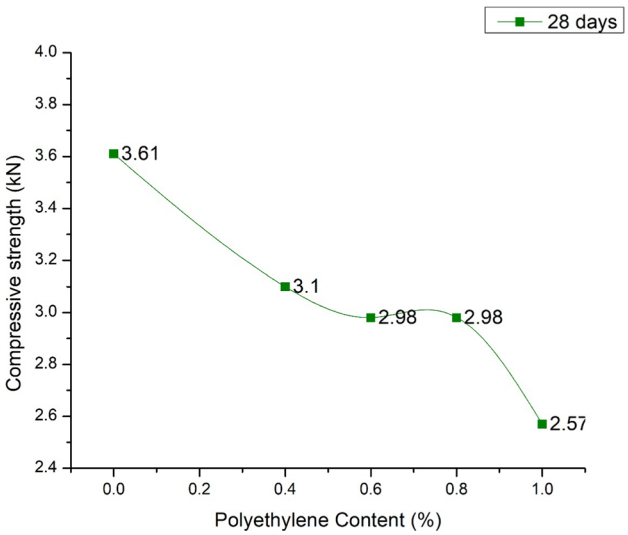


Fig. 8 Compressive strength results on sandcrete blocks after 28 days of curing

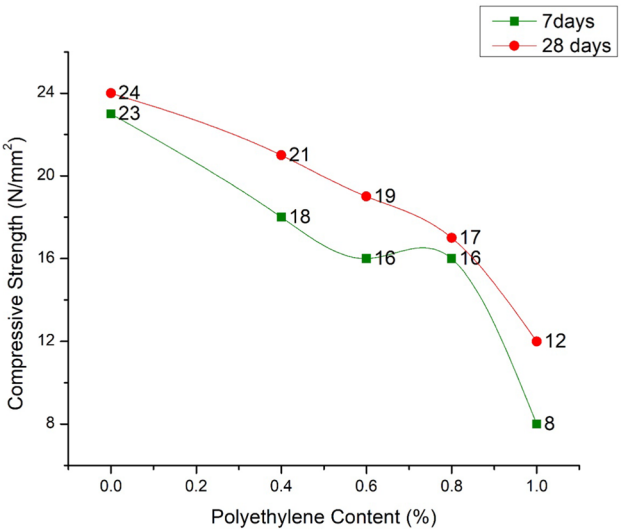


Fig. 9 Compressive strength of concrete cubes with solvothermal treated polyethylene (%) at 7 and 28 days

As the amount of polythene increased the blocks' strength dropped, as shown in Fig. 8. Nonetheless, the blocks' strength exceeds the 2.50 N/mm^2 minimum strength that the Nigerian Industrial Standard [3] specifies for non-load-bearing blocks. The blocks with 0.2% polyethylene content have strengths that are higher than those reported by Odeyemi et al. [4] for manual and machine-compacted sandcrete blocks for the brands of cement considered in their study.

The concrete's compressive and split tensile strengths presented in Figs. 9 and 10 show a similar pattern to that of the sandcrete blocks. The results reveal that concrete containing up to 0.8% treated polyethylene content possesses compressive strengths higher than 15 N/mm^2 and could be used for mass concrete construction [27]. Only concrete samples containing 0.4% of the treated polyethylene content achieved the target strength of 20 N/mm^2 and can be used for reinforced concrete works [27]. The reduction in strength follows the same trend reported by Islam and Shahjalal [15].

The relationship between the compressive and split tensile strength is shown in Figure 11. The Figure reveals that as the compressive strength increases, the split tensile strength also increases. This result follows the same trend as reported by Akinpelu et al. [36] when they studied the relationship between the compressive and split tensile strength for self-compacting concrete. The equation relating the split tensile strength to the compressive strength for solvothermal treated concrete is shown in Equation 1. This model has an R^2 value of 0.98.

$$y = 0.0092x2 - 0.2513x + 3.2969 \quad (1)$$

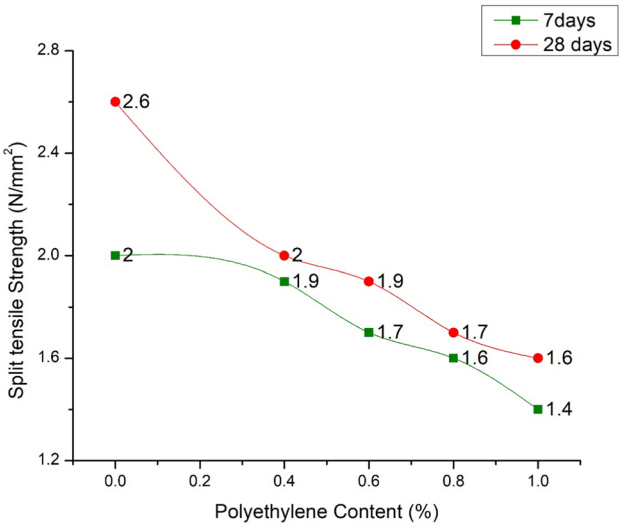


Fig. 10 Split Tensile Strength of concrete

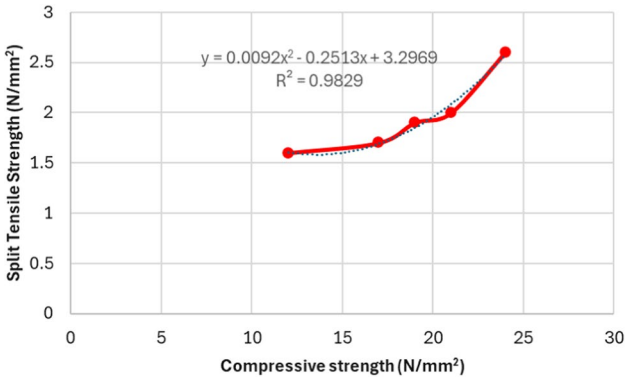


Fig. 11 Relationship between split tensile strength and compressive strength for solvothermal treated concrete

where y = Split tensile strength and x = Compressive strength.

4.4 Water absorption capacity of sandcrete blocks

The water absorption capacity of sandcrete blocks with different percentages of treated polyethylene is shown in Figure 12. When polyethylene was added, the sandcrete blocks' ability to absorb water decreased at all replacement levels examined up to about 61%, indicating that using these blocks could help prevent water from seeping into wall units. The water absorption capacity for the blocks is below the maximum permissible of 12% stipulated by the Nigerian Industrial Standard [3] and the ones produced by the block manufacturing enterprises in Adeta [2]. In line with observations by Ijalana et al. [37], the results suggest that polyethylene decreases the porosity of the blocks, making them less permeable to water.

5 Conclusions

The study's conclusions include the following:

1. As the amount of solvothermal treated polyethylene increased from 0 to 1%, the workability of concrete reduced by 14%.
2. An increase in the percentage of the solvothermal-treated polyethylene caused the density of the sandcrete block specimens to increase by a maximum of 0.8%, whilst the density of the concrete specimens decreased by a maximum of 4.2%.

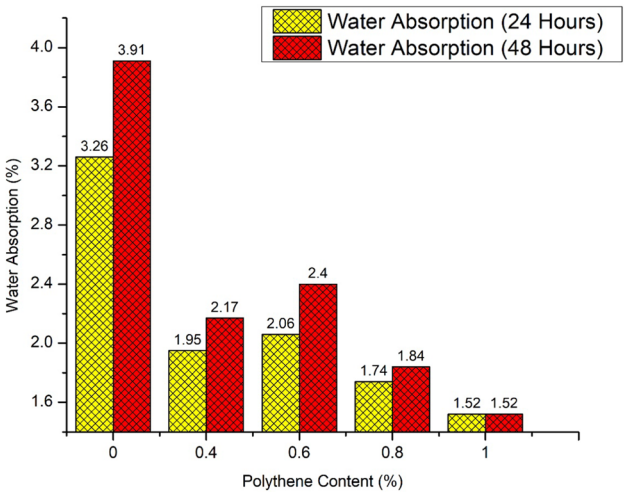


Fig. 12 Water absorption of the sandcrete blocks

3. An addition of 0.4% of the solvothermal-treated polyethylene in concrete achieved the target strength of 20 N/mm^2. The addition of polyethylene up to 0.8% by weight of the cement content can be used for mass concrete production.
4. The inclusion of solvothermal-treated polyethylene in Sandcrete blocks reduced the compressive strengths of the block to a maximum value of 29%. However, all the blocks with up to 1% solvothermal treated polyethylene in them had compressive strengths higher than the 2.5 N/mm^2 minimum required for non-load-bearing walls.
5. The compressive strengths of concrete containing solvothermal-treated polyethylene were reduced by a maximum of 50% at 28 days of testing. The concrete's split tensile strength also decreased by a maximum of 38.5%.
6. The water absorption capacity of blocks containing solvothermal-treated sandcrete blocks was reduced by 61%. Thus, resistance to water permeability can be achieved by adding solvothermal-treated polyethylene to sandcrete blocks.

6 Recommendations

The following are recommended for further studies:

1. The microstructure of blocks and concrete containing solvothermal-treated polyethylene should be examined.
2. The influence of solvothermal-treated polyethylene on mortar should be studied.

Author contributions S.O. and A.G. developed the concept for the work while Z.T., O.D., O.K., B.O., H.O. and A.O. did the laboratory work. S.O. wrote the manuscript and all the authors reviewed it.

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Data availability The data used in this study are presented in Figs. 5, 6, 7, 8, 9, 10, 11 and 12. No other datasets were generated or analyzed in the study.

Declarations

Competing interests All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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