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Effect of Polypropylene Fibre Addition on the Physical and Mechanical Properties of Sandcrete Walling Units

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Abstract
Hollow Sandcrete Blocks are walling units made from a mixture of cement, sand (fine aggregate), and water. However, these blocks are characterized as brittle units, having low tensile strength and therefore highly susceptible to failure. The study focused on evaluating the effect of Polypropylene (PP) fibre on the characteristics of sandcrete walling units with a view to overcoming the shortcomings associated with it. Here, the PP fibre used in the sandcrete mixes was at 0, 0.1, 0.2, 0.3 and 0.4% by weight of dry materials. Properties evaluated were those of flow-ability, compressive and flexural strengths, and density and abrasion resistance. Sandcrete Walling Units specimens were produced; the specimens were 50 × 50 × 50 mm mortar cubes and 160 × 40 × 40 mm mortar beams. Results indicate improvement in flow-ability by 5.6% with 0.2% PP fibre addition. Incorporation of 0.1% PP fibre exhibits an increase in compressive strength by 9% and flexural strength by 3% compared to the control. The density consistently decreases with an increase in fibre content; it was 2066 kg/m^3, 1999 kg/m^3, 1807 kg/m^3, 1688 kg/m^3 and 1573 kg/m^3 for 0, 0.1, 0.2, 0.3 and 0.4% respectively. For abrasion, 0.1% and 0.2% fibred specimen exhibit higher resistance capacity to abrasion, which is 57% and 79% higher compared to the control. While 0.3% and 0.4% fibred specimens demonstrated lower resistance of 121% and 139% compared to the control. As such, the study established that incorporating PP fibre in sandcrete walling units enhance both mechanical and durability properties. Therefore, a polypropylene fibre addition of 0.1 - 0.2% by weight of mortar was recommended for sandcrete walling units' production.

Keywords: Fibre, Polypropylene, Sandcrete and Walling Units.

Introduction
Sandcrete blocks are the common walling units in most developing countries, made from a mixture of cement, fine aggregate, and water. In Nigeria, over 90% of walls are constructed using the conventional sandcrete blocks (Anosike and Oyebade, 2012). These sandcrete blocks offer advantages such as ease of construction, cost-effectiveness, availability, thermal insulation properties and employment of unskilled labour (Arasa, 2018). However, the conventional sandcrete blocks have limitations of low tensile strength and brittleness (Sunil and Kumar, 2018). To overcome these shortcomings, sandcrete blocks can be fibre reinforced using waste steel, jute, flax, and polypropylene. Polypropylene has been used in recent years as fibre in the production of concrete, earth bricks, binders, and other building materials (Khan *et al.*, 2015). Polypropylene (PP), according to Mustafaraj *et al.* (2020) is a synthetic material made up of a thermoplastic polymer produced using a chain-growth polymerization from monomer propylene. Moreover, sandcrete blocks can be manufactured in various sizes and/or shapes. According to Obinna (2022), the choice of size/shape depends on the unit portability or design requirement, such as the Dry-stacking Units.

Dry-stack Walling Units (DWUs) are masonry units stacked/interlocked into a wall or part of a building for mortar-less or dry construction (Martin, 2023). According to Ahmed and Ali (2023), Dry-stack walling units have been used as an alternative to conventional blocks, which is due to less mortar consumption (mortar-less), less construction cost, and time. Dry-stacking units are a new development in most African countries (Arasa, 2018). However, there are few examples of mortar-less units such as the NBRRI interlocking bricks. Moreover, most of the dry-stack/mortar-less units are non-reinforced, and this could be due to the non-availability of standard fibres.
According to Ibrahim *et al.* (2018), the non-availability of standard fibres in developing countries such as Nigeria hinders the growth of sandcrete/concrete technology. Nevertheless, some researchers find means of utilizing locally available fibres to enhance properties of sandcrete or concrete. Adedeji and Ajayi (2008) studied the possibility of using Palm-kernel fibres for composite panel as walling unit or ceiling material. The experiment establishes the possibility of producing particle panel/unit with palm-kernel (after hot water treatment) at a ratio of 2.5:1 palm-kernel fibre to Portland Cement, and a density of 1,200 kg/m^3 was achieved. Esegbuyo *et al.* (2019) used Raffia fibre to reinforce sandcrete block at 0, 1, 2 and 3% fibre content. It was observed that the compressive strength decreases as the fibre volume increases, but the water absorption capacity is within the allowable 12% specified by BS 5628-1 (2005) and NIS: 89 (2000), while the density ranges between 1,954 kg/m^3 and 1,522 kg/m^3. Ibrahim *et al.* (2018) used Waste Gear Inner Wire (WGIW) at 2% in the production of steel fibre-mortar, and results showed that WGIW has the capability of enhancing compressive and tensile strength of mortar. At 28-days of curing, the results reveal an increase of 31% in compressive strength compared to the control. Ibrahim *et al.* (2022) used flax fibre in concrete. The result showed that the flax fibre at 0.2% enhanced both compressive and flexural strength of concrete by 4 and 6%, respectively. Jawad and Al-Haydari (2022) used PP Fibres to reinforce mortar of a 1:3 sand-cement ratio; the reinforcing ratio was in 0, 0.5, 1 and 1.5% by weight of the cement mortar. The results reveal an increase in both compressive and flexural strengths for all the fibre dosages, but a reduction in flow-ability (workability), density and water absorption with all fibre additions.

The availability, lightweight nature and high strength of PP fibre makes it incorporation into sandcrete units cost-effective and less resource/mortar consuming compared to the conventional blocks. According to Ijalana *et al.* (2016), addition of polythene fibre to sandcrete block increases the tensile strength and limits propagation of cracks. Hence, the study aimed at incorporating polypropylene fibre as reinforcement to sandcrete walling unit in order to address limitations of brittleness and low tensile strength associated with conventional sandcrete blocks at same time enhencing the mechanical and durabilty properties.

Materials and Methods
Materials
The constituent materials used for the study are presented as follows:
Fine aggregate: The fine aggregate was river sand passing through standard sieve of 4.75mm in conformity with BS 882 (1992). The sand was sourced within Zaria town of Kaduna state, and it was found to be clean, sharp, and free of organic matter and clay.
Cement: The cement used was a brand of *Dangote* Blended Limestone Cement of grade 43.5N. The cement complied with the requirement of BS EN 197-1:2011.
Water: Potable water (fit for drinking) was use during mixing and curing. The water was sourced from a water storage tank at the Department of Building, Ahmadu Bello University, Zaria. It was free of contaminants both soluble and insoluble.

PP Fibre: The PP fibre used was a brand of *Bagco Sack* (100 kg capacity) inter-woven sack/bag cut to the require size as shown in Plate 1.

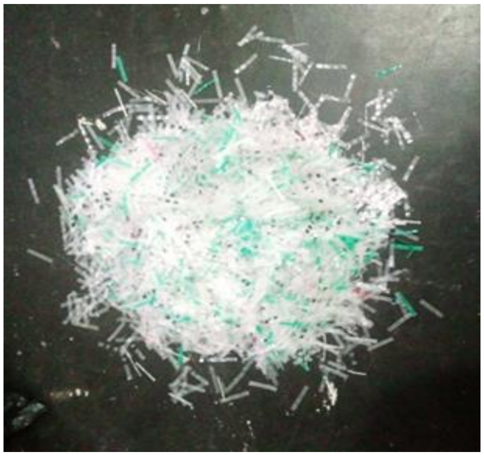


Plate 1: The PP fibre used

Methods

PP fibre preparation: The fibre was added (in terms of percentage of dry-constituent of river-sand and cement) in the sandcrete mixes. Moreover, tensile test was conducted on fibre as shown in Plate 2. The test was conducted using Electronic Universal Testing Machine seen in Plate 3, and the test was carried out at the Department of Metallurgical and Material Engineering Laboratory, Ahmadu Bello University, Zaria.

Plate 2: Tensile Test on PP Fibre

Plate 3: The EUT Machine

Mix Design and Mix Method: Sandcrete mix of 1:6 as specified by Nigerian Industrial Standard (NIS 87, 2000) was adopted. The sandcrete was produced using motorized concrete mixer, the dry constituent first poured in, followed by water then the PP fibre, the mixing continues until uniformity in color and texture was achieved. The water was as minimal as possible to avoid fall after de-moulding, thus 0.5 water-cement ratio adjudged to be optimal. Moreover, the dry constituent materials and water were measured accordingly as summarized in Table 1.

Table 1: Quantity of materials per cubic meter

Materials	Quantity (Kg/m^3)
Cement	274
Fine Aggregate	1824
Water	137

Source: Laboratory work (2024)

The first mix was without fibre content (control), while the mixtures continue with addition of 0.1, 0.2, 0.3and 0.4% PP fibre dosages. The placement process was using scoop and trowel to fill-up the moulds. The compaction was by table vibration of about 3-4 seconds. After compaction, settled spaces were fill, tamped and the surface smoothen. The sandcrete specimens were mortar cubes of 50 × 50 × 50 mm and mortar beams of 160 × 40 × 40 mm. The specimens were covered with nylon sheet and then de-mould after 24-hours. The specimens were cured through immersion in water-tank after which strengths were determined at the ages of 7, 14, 21, and 28 days.
Tests on Fresh Mixes: In order to determine the fresh property of the mixes, a flowability test using the flow-table method was conducted in accordance with ASTM C 1437:2020. The test follow a sequential order of wetting the flow table and the cone, filling the cone with fresh sandcrete mix in two layers. Each layer was tamped 25 times with a tamping rod. The cone was raised and the flow table dropped 15 times as seen in Plate 4, then the diameter flowed was measured.

Plate 4: Dropping PP fibred mix

Hardened Tests on Specimens: The hardened tests were those of Compressive and Flexural Strengths, Dry-Density, Abrasion Resistance and Water Absorption. Plate 5 shows the PP fibred specimens of 160 × 40 × 40 mm beams and 50 × 50 × 50 mm cubes after 24-hour demoulding.


Plate 5: 0.1% PP fibred beams and cubes

Compressive strength: The tests were carried out in accordance with BS EN 12390-3:2019 on specimens using a digital compression-testing machine as shown in Plates 6 at the Department of Building, Ahmadu Bello University, Zaria. The compressive strength (f_{cu}) was calculated using equation 1:

$$f_{cu} = \frac{P}{A} \quad - \quad - \quad - \quad - \quad - (1)$$

Where; f_{cu} = Compressive strength, P = Failure load and A = Area


Plate 6: Compressive Test on Cube

Flexural strength: The flexural test was conducted under three-point load arrangement as shown in Plate 7, in accordance with BS EN 12390-5:2019. The test was to determine the resistance of PP fibred sandcrete walling units to bending and cracks under flexural stresses. The specimens were of 160 × 40 × 40 mm PP fibred and control beams. The flexural strength was calculated using equation 2.

$$\sigma = \frac{3PL}{2bd^2} \quad - \quad - \quad - \quad - \quad - \quad - (2)$$

Where: *P* is the maximum load applied at the midpoint,
L is the span length between the two supports, *b* is the width of the specimen,
d is the depth of the specimen and σ is the flexural strength.

Plate 7: Flexural Test on Fibre Beam

Density: The dry-density was determined to ensure that the walling units meets minimum density of 1500 kg/m^3 specified by BS 6071-1(1989) as reported by (Obinna, 2022) . In Nigeria, the NIS 89: (2000) recommends 1920 kg/m^3 for individual block and 2020 kg/m^3 for an average of three sandcrete blocks. The density was calculated using equation 3

$$D = \frac{M}{V} \qquad - \qquad - \qquad - \qquad - \qquad 3$$

Where, D = Dry Density in kg/m^3, M = Mass of block (kg) and V = Volume of the block (m^3).

Abrasion Resistance: Abrasion test was conducted to determine surface degradation/resistance. After 28 days of curing, three sample of mortar cube (50 × 50 × 50 mm) were randomly selected and weight. The measured weight was recorded and then wire-brushed 50 times on the surface (back and forth) making scratch on the cubes' surface, then weighed again. The percentage abraded was recorded and compared to the control's.

Water Absorption: The test was to determine and relate with the allowable 12% absorption specified by NIS: 89 (2000). The test was conducted in accordance with ASTM C 1585 (2013) at 28 days of curing, the specimen were dried-up for 72 hours in an oven of 105^{o}C temperature. The specimens were removed and left to cool to room temperature, and thereafter weighed. The specimens were immersed in water tank for 30 minutes, removed and dried with a cloth and weighed again. The percentage of water absorption was calculated using equation 4

$$Wa = \frac{W_2 - W_1}{W_2} \times 100 \quad -- \qquad - \qquad - \qquad - (4)$$

Where: W_1= Weight of the sandcrete sample after oven/air dry

W_2= Weight of the saturated surface dry. And Wa = Water absorption capacity

Results and Discussion

The results were driven from the tests conducted on the constituent materials and the sample specimens as presented and discussed.

Constituent Materials Properties

Fine aggregate properties

The Fine-aggregate was found to have Specific gravity of 2.78 kg/m^3, which is within the range of 2.30 kg/m^3 and 2.90 kg/m^3 specified by ACI 201 (2001). Bulk density of 1,596 kg/m^3 that is within the range of 1,280 kg/m^3 and 1,920 kg/m^3 recommended by BS 812: Part 2 (1995). The percentage for moisture content was 2.5% which falls within 0 and 10% acceptable to ACI E1-99.

Portland Blended Limestone Cement Properties

Table 2: Physical Properties of the Cement

Test	**Value**	**ASTM C150 (2005) Recommended Time**
Initial Setting time	140-minutes	Min. 45-minutes
Final Setting time	215-minutes	Max. 435-minutes
Soundness	3 mm	Max. 10 mm

Source: Laboratory Research Work (2024)

Table 2 presents the initial and final setting times as we as the soundness of the cement used for the experiment. The cement was found to have initial and final setting times of 140-minutes and 215-minutes respectively, the times are within the recommended limits of ASTM C150 (2005). The soundness of the cement was found to be within the limit, and indicates that the cement will not experience considerable change in volume if used in the production of sand-concrete blocks as reported by Gambo (2019).

Properties of PP fibre used

PP fibre (PP woven sack) is required to meet certain mechanical and physical properties, Table 3: reported the mechanical properties of breaking force, tensile strength and percentage elongation of the PP fibre used.

Table 3: Mechanical Properties of the PP fibre used

Sample	Breaking Force (N)	Tensile Strength (N/mm^2)	Elongation at break (%)
1	140	566.67	42.92
2	150	633.33	36.97
3	190	783.33	35.66
Mean	160	661.11	38.52

Source: Laboratory Work (2024)

Furthermore, Table 4 presented the physical measurement/properties of the PP fibre used.

Table 4: Physical Properties of the PP fibre used

Measurement	Result/Value
Length	22 mm
Width	3.03 mm
Thickness	0.012 mm
Cross section	0.03636 mm^2
Aspect ratio	1,833.3
Mass	68.92 g/m^2

Source: Laboratory work (2024)

From the result, the fibre meet the minimum Elongation at breaking of 20±5% with 38.52%, width of 3.03 mm and mass of 68.92 g/m^2 which met the minimum requirement of 2.5±1 mm and 67±4,3 g/m^2 respectively as specified by the ISO 23560 (2015).

Fresh Property of the Sandcrete Mixes

Flow-ability test

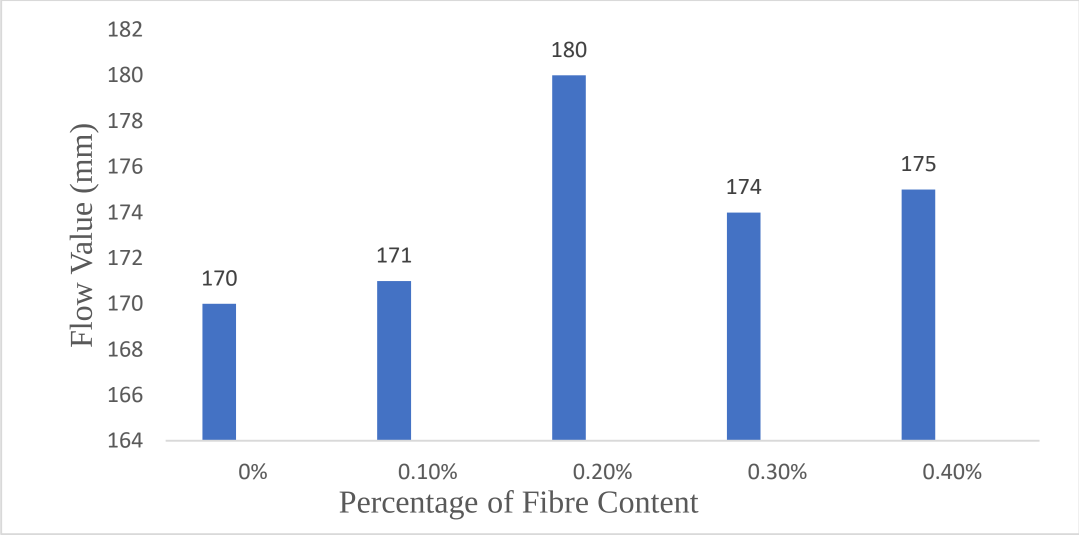
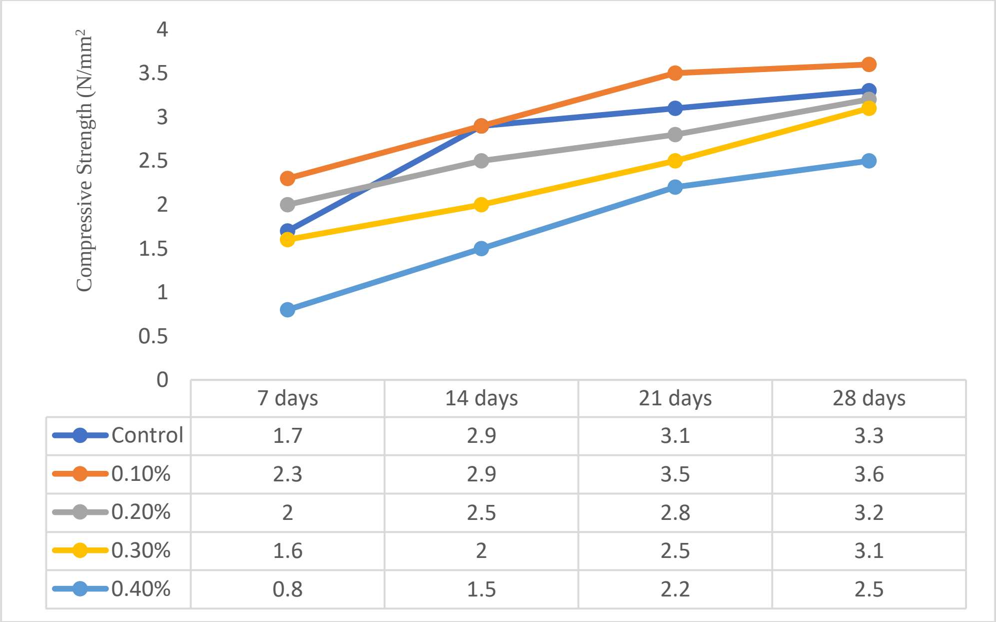


Figure 1: Flow Value of PP fibre Specimens

Figure 1 shows the flow value for the control, 0.1, 0.2, 0.3 and 0.4% PP fibre dosages. The result revealed an increase in workability with PP fibre addition; it is a substantial increase of 5.6 percent for 0.2% fibre dosage compared to the control. It is only 2.4 percent for 0.3% dosage and 2.9 percent for 0.4% dosage. The increase in workability can be attributed to the slippery nature of the fibre. Although this negate Jawad and Al-Hydari (2022) that used PP fibre by Volume-fraction (Vf) and found it to decrease workability. The study established 0.2% PP fibre addition to have positive effect on fresh properties (workability) of sandcrete mixes.

Harden Properties

Compressive Strength

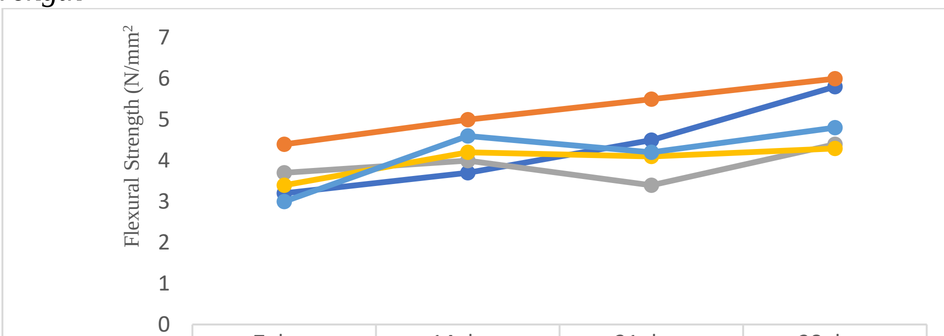


	7 days	14 days	21 days	28 days
Control	1.7	2.9	3.1	3.3
0.10%	2.3	2.9	3.5	3.6
0.20%	2	2.5	2.8	3.2
0.30%	1.6	2	2.5	3.1
0.40%	0.8	1.5	2.2	2.5

Figure 2: Compressive strength of fibre specimens

Figure 2 presents Compressive Strength at the ages of 7, 14, 21 and 28 days. The results revealed an increase in compressive strength as the curing-days progress, a tread in agreement with *Sheikh et al.* (2017). At 28 days, the compressive strength of the control was 3.3 N/mm^2 and that of the 0.1% fibre specimen was 3.6 N/mm^2 while that of 0.2% was 3.2 N/mm^2, this shows the 0.1% PP fibred specimen higher than the control by 9% while 0.2% lower by 3%. Observed also was both the control and the fibred specimens falling within the strength of 2.5 N/mm^2 recommended by NIS: 89 (2000) for load-bearing units. The result established that 0.1% PP fibre could improve compressive strength of sandcrete blocks.

Flexural Strength



	7 days	14 days	21 days	28 days
Control	3.2	3.7	4.5	5.8
0.10%	4.4	5	5.5	6
0.20%	3.7	4	3.4	4.4
0.30%	3.4	4.2	4.1	4.3
0.40%	3	4.6	4.2	4.8

Figure 3: Flexural strength of fibred specimens

Figure 3 shows the Flexural strength of the control 0.1, 0.2, 0.3 and 0.4% PP fibre dosage at the ages 7, 14, 21 and 28 days.

At 28 days, the figure 3 discloses 0.1% fibre addition recording the highest flexural strength of six (6) N/mm^2 compared to the control's 5.8 N/mm^2, which was 3% increase. Jaward and Al-Haydari (2022) reported an increase in flexural strength with 0.5% PP fibre content in 1:3 sand-cement mortar production. Moreover, Ibrahim *et al.* (2022) found 0.2% flax fibre to improve flexural strength of concrete by 5.8%. Nevertheless, 0.1% PP fibre improves flexural strength of sandcrete up to 3%. Therefore, established was that 0.1% PP fibre could have positive effect on sandcrete block's flexural strength.

Bulk-Density

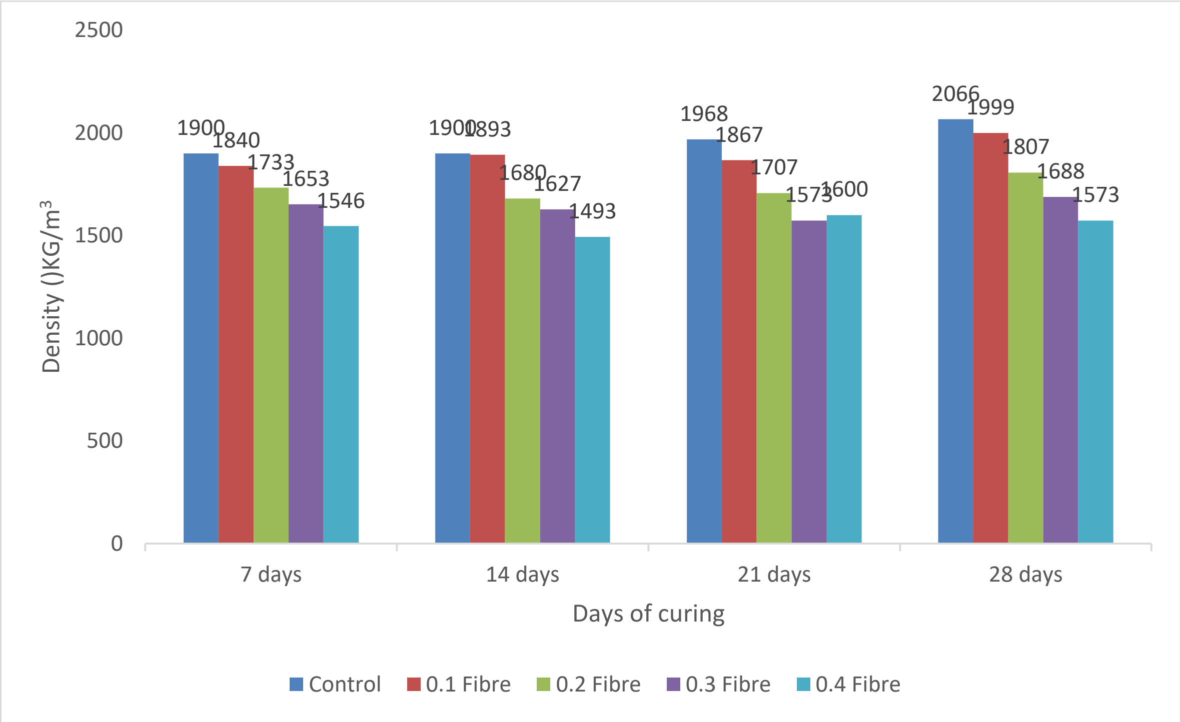


Figure 4: Density of the fibred specimens

Figure 4 shows the density of control and PP fibre reinforced specimens with varying dosages of 0.1, 0.3 and 0.4% at 7, 14, 21 and 28 days of curing.
Observed was decrease in density with increase in PP fibre content, which could be attributed to the lightweight nature and lower density of the fibre (910 kg/m^3) compared to the sandcrete mixture (2000 kg/m^3). The highest density observed was 2066 kg/m^3 for the control at 28days and the lowest density was 1493 kg/m^3 for 0.4% at 14days. At 28days, the result reveals the control, 0.1, 0.2, and 0.3% specimens exceeding the minimum 1,500 kg/m^3 recommended by BS 2028 (1984) by 27%, 25%, 12% and 11% respectively, while the 0.4% at 14days negate the standards by 0.5%. Thus, the study established 0.4% PP fibre to negatively affect density requirement of sandcrete block.

Abrasion/Degradation Resistance

Figure five (5) shows the abrasion percent for the control, 0.1, 0.2, 0.3 and 0.4% PP fibre specimens. The average percentage abraded for the control was 2.8%, the 0.1% and 0.2% fibred specimen abraded by 1.2% and 0.6%, which was less than the control by 57% and 79% respectively. The 0.3% and 0.4% fibred abrasions were 6.2% and 6.7% that is 121% and 139% decrease in abrasion compared to the control. The lower percentage values recorded for 0.1% and 0.2% PP fibred are indicating the high abrasion resistance capability of these dosages compared to other percentage additions. Moreover, Arase (2018) states that lower abrasion value is an indicative of appropriation of a mixture for production of a durable walling units.

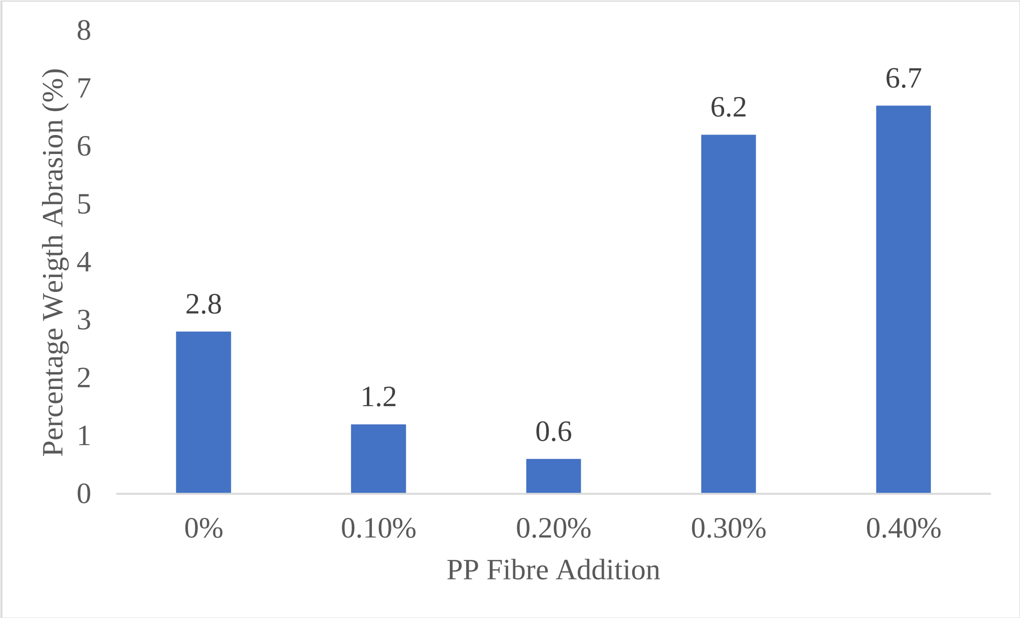


Figure 5: Percentage Abrasion of Specimens

Water Absorption Capacity

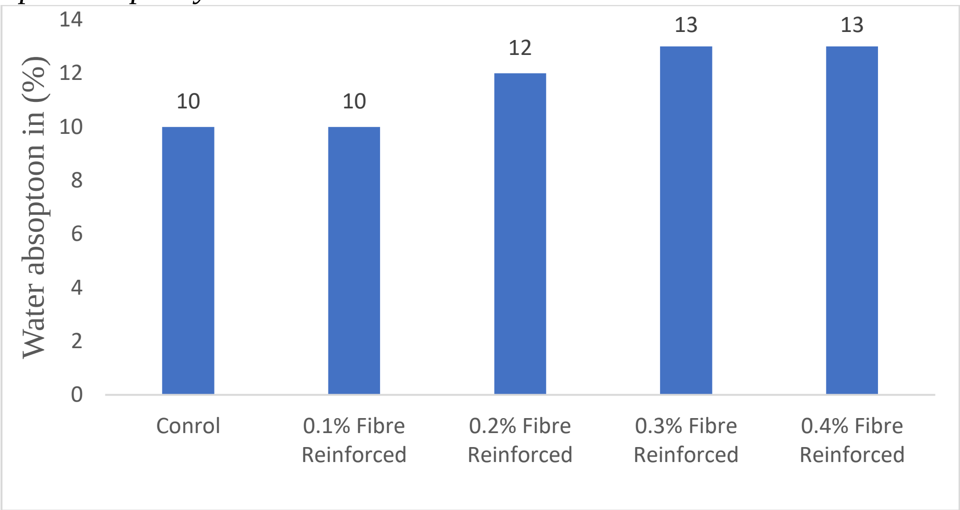


Figure 6: Water Absorption Capacity of specimens

Figure 6 shows the percentage of water absorption for the control and fibre reinforced specimens at 28 days curing. Observed was the control specimen absorbing 10%, 0.1% fibre specimen by 10%, 0.2% fibred specimen by 12%, while 0.3 and 0.4% fibre reinforced specimens absorbed by 13%. The result revealed the control, the 0.1% and 0.2% fibred specimens not exceeding the allowable 12% specified by BS 5628-1 (2005) and NIS: 89 (2000). While, the 0.3 and 0.4% fibred specimens absorbed more than the allowable 12 percent by 8%.
In addition, major researches have reported increase in water absorption with addition of fibres (Jaward and Al-Haydari 2022, Bilal Afridi *et al*, 2019). The increase could be attributed to increase in porosity and permeability. Consequently, the study established addition of only 0.1 and 0.2% be regarded within the allowable water absorption limit.

Conclusion

The study evaluates the effect of Polypropylene fibre addition to sandcrete walling units with a view to reinforcing the conventional sandcrete units. The work demonstrates the potential benefits of incorporating polypropylene PP fibre into sandcrete walling units; and based on the results it could be conclude that:

i. There is improvement of 5.6% in flow-ability of sandcrete mix with 0.2% PP fibre addition.
ii. 0.1% PP fibre have positive effect on both compressive and flexural strengths of sandcrete.
iii. PP fibred specimens of 0.1% and 0.2% have higher abrasion resistance than the control.
iv. 0.1% and 0.2% PP fibred specimens have met density and water absorption requirements.
v. 0.2% PP fibre addition be optimum percent for enhance mechanical and durability properties of sandcrete walling unit.

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