SSRG International Journal of Civil Engineering
ISSN: 2348 – 8352 /doi:10.14445/23488352/IJCE-V8I9P102

Volume 8 Issue 9, 7-13, Sep 2021


*Original Article*

# Effect of Plastic Bottle Arrangement on the Performance in Self-Compacting Concrete Block

Ahmed Omar Robleh[1], David Otieno Koteng[2], Charles Karimi Kabubo[3]

[1] *Graduate student, Institute for Basic Sciences, Technology and, Innovation, Pan African University, Nairobi, Kenya*
[2] *Professor, School of Civil & Resource Engineering, The Technical University of Kenya, Nairobi, Kenya*
[3] *Senior Lecturer, Sustainable Materials Research and Technology Centre, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya*

Received Date: 16 August 2021
Revised Date: 23 September 2021
Accepted Date: 05 October 2021

***Abstract*** - *This study aims to determine the effect of plastic bottle arrangement on self-compacting concrete (SCC) blocks. SCC was adopted because of lack of spacing and fear of damaging the bottles during the compaction. 350 ml plastic bottles were used with four different arrangements inside the SCC blocks. The plastic bottles reduced the volume of concrete needed by 23%. The size of blocks used in the study was 400x150x200 mm. The blocks were tested for compressive strength, density, and absorption according to the ASTM C140 standard. In addition, thermal conductivity and ultrasonic pulse velocity were also conducted. The SCC blocks with bottles satisfied the ASTM C129 requirements for non-load bearing blocks in terms of strength, absorption, and lightweight blocks. This study has also indicated that the thermal conductivity could be reduced by up to 56% compared to the SCC blocks without bottles. Therefore, it is recommended that the construction industry can use these blocks to minimize the dead weight of buildings and provide an avenue for the disposal of plastic waste.*

**Keywords -** *concrete block, plastic bottles, self-compacting concrete, waste management.*

## I. INTRODUCTION

Industrialization, rapid urbanization, and increasing population are some of the greatest challenges the world faces in this century. Most of the products produced for our luxury are responsible for the pollution of the environment, such as plastics that must be disposed of properly or recycled to maintain the beauty of nature [1]. The quantity of plastics consumed has increased annually due to its versatility, lightweight, high strength, corrosion resistance, durability, low maintenance requirements, design flexibility, good vibration damping, and waterproof qualities [2]. Therefore, waste control has become an actual concern for society and is necessary for environmental protection [3], [4].

Self-compacting concrete (SCC) can flow and fill through any obstacle simply by its weight without an external vibration method. Self-compacting concrete varies by the high deformity, good segregation resistance, severe viscosity, and construction quality of conventional concrete [5].

Andreas Froese [6] has proposed the use of plastic bottles to construct concrete buildings where polyethylene terephthalate (PET) bottles are placed in the walls panel with mortar to structure shape. Many attempts have been made to evaluate the compressive strength of concrete blocks with bottles contained. Safinia and Alkalbani [7] conducted a study using plastic bottles in masonry units. Their finding indicated that the average compressive strength was 10.2 MPa at 28 days. The strength was acceptable according to the standard as a concrete block. The author also demonstrated that the plastic bottles in the masonry unit lowered the block's weight and made the block more practical for building construction. The plastic bottle was horizontally positioned in the loading direction, and the bottle was not completely covered.

Wonderlich et al. [8] tested the compressive strength of concrete masonry units with a different brand of plastic water bottle on a single disposition and reported that the compressive strength of the masonry unit with the plastic bottle is reasonable and fulfilled the standard requirements. They also indicated the diameter of the bottles had a significant effect on the strength of the blocks.

Muyen et al. [9] performed a study on the strength properties of a plastic bottle filled with sand in bricks and their suitability as construction material. they found that using the plastic bottle in brick, the strength obtained 19,9 MPa at 28 days, and it was stronger than the concrete block and conventional brick.

Jadhav et al. [10] studied the influence of plastic bottles in the concrete section and observed that the compressive strength of the block relies on the number and size of the bottles. The bottle was placed in a straight and zigzag position.

Plastic has a low electrical and thermal conductivity (TC). Several studies examine the influence of plastic bottles affect thermal conductivity have been performed. Poonyakan et al. [11] studied the potential use of plastic for low TC concrete and found lower TC of 2-31% than plain concrete. Akçaözoğlu et al. [12] enhanced the TC of the cementitious composite containing plastic waste and obtained TC of 58% lower than TC of control concrete (CC). Basha et al. [13] made lightweight recycled plastic aggregate (RPA) concrete and found that TC of RPA to be lower by 35-65% than CC. Fraternali et al. [14] showed that TC of concrete with plastic of 1% volume fraction reduced by up to 21.8% from the conventional concrete. Therefore, in the current global economic situation, using these innovative materials incorporating plastic bottles in the blocks can be effective in reducing TC and help the plastic waste disposal issue in the environment [11], [15].

Viegas et al. (2014) [16] conducted studies where PET bottles were included in a wall, and results indicated a reduction from 29.8 dB and 55.8 dB compared to the wall without bottles. The sound absorption of light-soft-plastic bottles with net capacities ranging from 7 to 2000 mL is impacted by the capacity between 100 and 1000 Hz. Another study conducted by Iwase et al. (2018) [17] found that PET-based materials possess significant sound-absorbing characteristics, especially with high frequencies. Patnaik et al. [18] observed that panels composed of recycled materials had an absorption coefficient of more than 0.7 in the frequency range of 50–5700 Hz, independent of humidity level. All researchers examined the effect of the plastic bottle as an aggregate replacement on insulation properties.

Based on the previous work on the effect of plastic bottles in concrete. In most cases, they used for the investigation a single arrangement of plastic bottles using conventional concrete. The experimental analysis was done in this research to determine the best placement of plastic bottles for usage in masonry units to enhance the strength and thermal conductivity of SCC blocks. The outcomes of compression, density, absorption, ultrasonic pulse velocity, and thermal conductivity tests are discussed in this paper. As a result, SCC blocks are made of plastic bottles.

## II. MATERIALS AND METHODOLOGY

### *A. Materials*

The materials used in this study were Portland Pozzolana Cement CEM II/B-P 42.5N manufactured by Bamburi Cement in Athi River, Kenya, river sand obtained from Meru, Kenya, the coarse aggregate of maximum size 12.5mm procured from a local supplier in Nairobi, plastic bottles of the same shape collected from local dump sites, and Sika Viscocrete-3088 superplasticizer from SIKA Kenya Limited.

### *B. Materials preparation and preliminary tests*

1) ***Cement*****:** The physical properties of cement were conducted following EN 196-1, and the results of the tests are represented in
2) TABLE *I*.
3) ***Fine aggregate:*** Fine aggregate was oven-dried at 105°C for 24 hours to remove the humidity. Sieve analysis, specific gravity, bulk density, silt, and moisture content tests were done. The results of the tests are depicted in TABLE II and Figure 1.
4) ***Coarse aggregate:*** Coarse aggregate was cleaned and oven-dried 24 hours at 105°C to remove entrained moisture. Sieve analysis, specific gravity, bulk density, aggregate crushing value (ACV), and aggregate impact value (AIV) were conducted. The results of the tests are represented in
5) TABLE *III* and Figure 2.

**TABLE I: Properties of Cement**

| Test | Results |
|---|---|
| Specific gravity | 2.85 |
| Normal consistency | 38% |
| Soundness | 8mm |
| Initial setting time | 135 min |
| Final setting time | 258 min |

**TABLE II: Properties of Fine aggregate**

| Test | Results |
|---|---|
| Specific gravity | 2.6 |
| Water absorption | 1.14 |
| Bulk density | 1631 kg/m$^3$ |
| Silt content | 4,83% |
| Moisture content | 0.7 % |

**TABLE III: Properties of Coarse aggregate**

| Test | Results |
|---|---|
| Specific gravity | 2,38 |
| Water absorption | 4.35 |
| Bulk density | 1565 kg/m$^3$ |
| ACV | 19.97 % |
| AIV | 12.83 % |

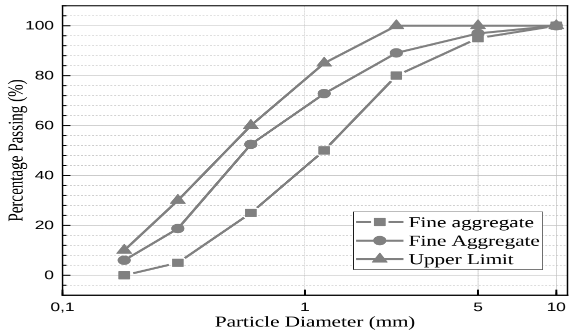



**Figure 1: Particle size distribution of fine aggregate**

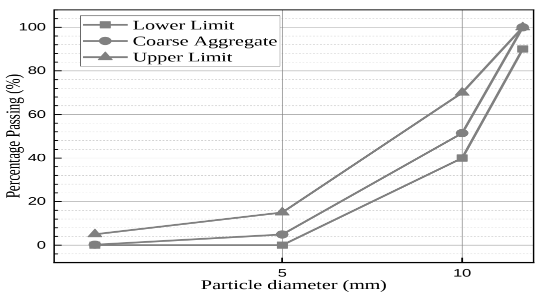



**Figure 2: particle size distribution of coarse aggregate**

### *C. Mix design*

Mix design was carried out by a method proposed by Ashish Kumar & Gaurav Kumar [19]. The target strength of the mix design was 20 MPa at 28 days. The mix proportion for 1m$^3$ of SCC is shown in TABLE IV.

**TABLE IV : Mixture Proportion for 1m$^3$ of SCC**

| Ingredient | Quantity |
|---|---|
| Cement | 400 Kg |
| Water | 180 Litres |
| FA | 863 Kg |
| CA | 678 Kg |
| SP | 4.5 Litres |

### *D. Preparation and curing of test samples*

350 ml plastic bottles having a standard size of 63 mm diameter and 160 mm height were placed in different arrangements to optimize the effective area of concrete and to achieve the minimum spacing requirement for SCC. The bottle arrangement was varied, as shown in Figure 3 dispositions 1 to 4. The self-compacting concrete mix was poured to fill the moulds without any extremal vibration. In this study, the size of blocks was 400×150×200 mm, as shown in Figure 4. 108 blocks were tested for compressive strength; 30 blocks were tested for unit weight, and TC and 10 blocks were tested for Ultrasonic pulse velocity (UPV).

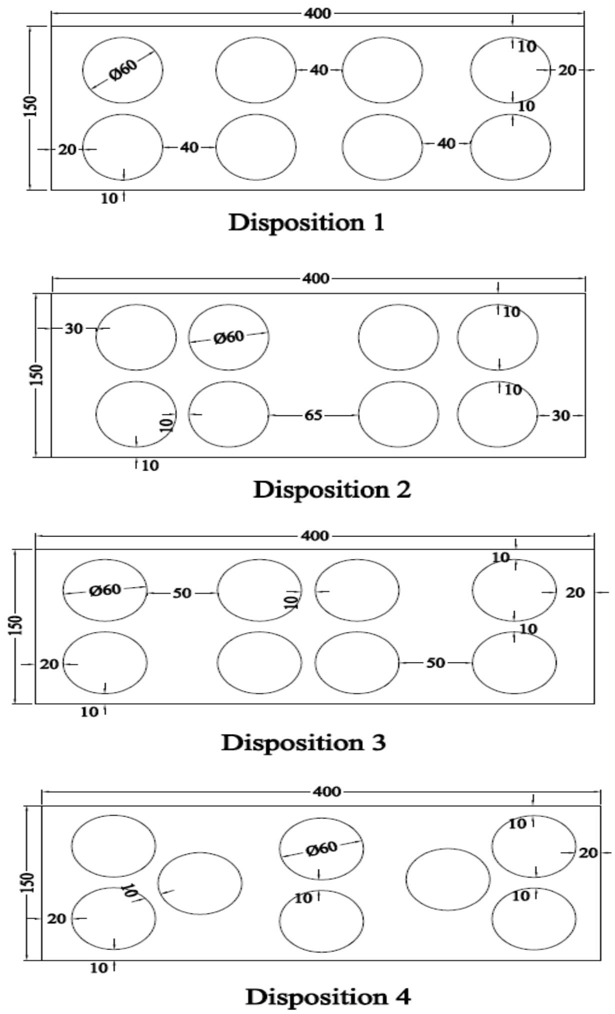



**Figure 3: Disposition of bottles**

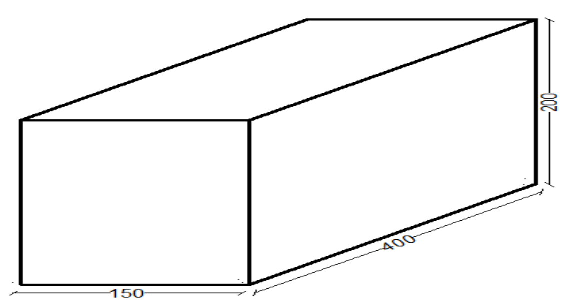



**Figure 4: Block size (mm)**

### *E. Compressive strength testing*

The compressive strength of SCC blocks containing plastic bottles was evaluated using ASTM C140 [20] for up to 90 days. The compressive strength of the specimens was given as an average of three measurements. The load direction was axial to the bottle arrangement, with a constant loading rate of 0.5 MPa/sec. The compressive strength of the blocks was plotted as a function of their age.

### *F. Density and absorption test*

The density and absorption test of SCC blocks were conducted in this study measured at 28 days. First, the SCC blocks were dried for at least 24 h in an oven having the temperature-controlled at 105 ± 5 °C, and the dry weight was determined. Next, the blocks were immersed for at least 24 h in water having a temperature of 15 to 27°C. Finally, the specimens were removed from the water and allowed to drain, any visible surface water was removed with a damp cloth, and the saturated weight was determined. The test was conducted following ASTM C642 [21].

### *G. Thermal Conductivity test*

The thermal conductivity test was carried out by a method used by Al-Tamini et al. (2020) [22]. The heat flow meter apparatus was used to measure the thermal conductivity for SCC blocks under a steady-state with a constant heat flow, according to ASTM C177 [23]. The instrument used in this study is composed of plate assemblies (hot, boiler castable (BC), and cold plate), a cooling system, a data logger, and a control unit for heat flux. The set-up of the heat flow apparatus is presented in Figure 5. The test consists of applying a constant heat flow from power input to the hot plate and using a cooling system to maintain the cooling plate constantly. TDS-630 high-performance data logger was used to recording the temperature of the hot plate, cooling plate, and heat loss. The temperatures were observed until the temperature difference of four intervals of time, indicating that to 0.1%. Thus, the steady-state of the material was accomplished. Heat loss was determined by the temperature difference from the initial temperature of the upper side of BC. The thermal conductivity was determined as follows:

$$Q = V*I \quad (1)$$

$$Q_{lost} = ((K_{BC} * \Delta T_3 * A_{BC}) / h_{BC}) \quad (2)$$

$$\Delta T_3 = (T_1 - T_0) \quad (3)$$

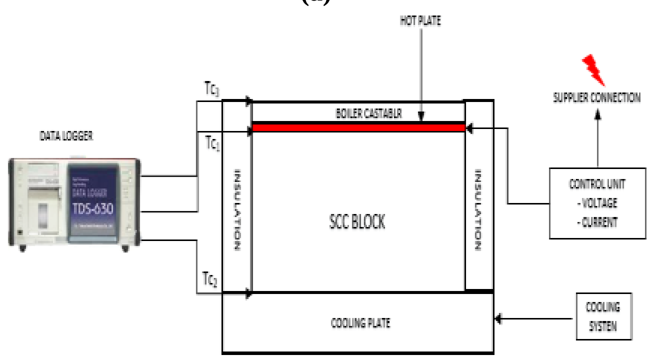
$$Q_f = Q - Q_{lost} \quad (4)$$

$$K = ((Q_f * h) / (A * (T_1 - T_2)) \quad (5)$$

Where:

V: heater voltage (V)
I: heater current (A)
Q: the heat flux from power input (W)
$Q_{lost}$: heat flux lost through the boiler castable (W)
$Q_f$: heat flux through the specimen (W)
A: surface area of the heater ($m^2$)
h: thickness (m)
K: thermal conductivity (W/mK)
$T_1$ : temperature of the hot plate
$T_2$: temperature of the cold plate
$T_3$: temperature through the BC

(a)




(b)

**Figure 5: Thermal Conductivity set-up, (a) original photo and (b) schematic**

### *H. Ultrasonic pulse velocity test*

The Ultrasonic pulse velocity (UPV) test was conducted on the different SCC blocks after 28 days of curing, according to ASTM C597 [24], using the Ultrasonic Nondestructive Tester (UST) and two transducers (transmitter and receiver). According to the direct and semi-direct transmission methods, the UPV test was applied in three directions for the tests. The UPV setup and methods are presented in Figure 6.

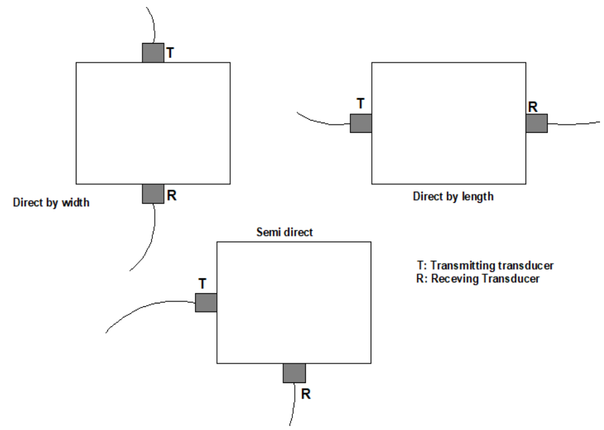



**Figure 6: UPV test**

## III. RESULTS AND DISCUSSIONS

### *A. Compressive strength*

The SCC blocks were tested for compressive strength at 3, 7, 14, 28, 56, and 90 days and the results are shown in Figure 7. The strength of the blocks increased with age. At 28 days, the strength was 20.2 MPa and satisfied the strength requirement of concrete class 20.

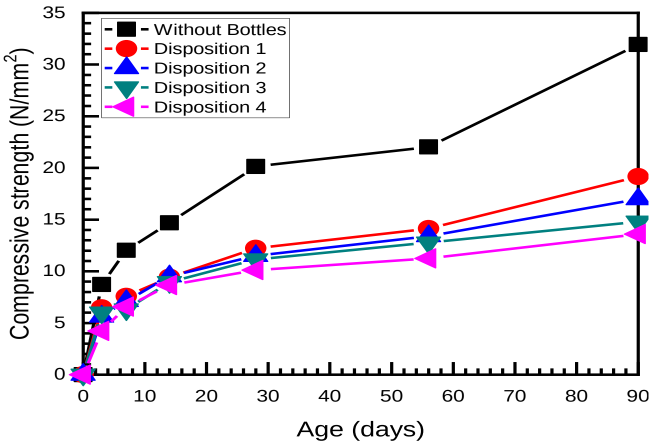



**Figure 7: Compressive strength of SCC blocks**

As expected, the compressive strength of the blocks with bottles achieved a lower value than the control block. The block with D1 and D2 had a value of 13 MPa and 12 MPa, reducing by 68.7% and 71%, respectively. The strength of D3 and D4 was 10 MPa and 9 MPa, indicating the block with the different disposition of bottles satisfied the strength requirement of ASTM C129 for the concrete masonry unit. SCC blocks can be used as non-load-bearing concrete masonry units. The reduction of compressive strength results from the arrangement of bottles was because the effective areas of the concrete section changed. The arrangement of bottles affects the concrete section by the spacing between the bottles. Wonderlich [8] reported that the compressive strength of the block depends on the net area of concrete. Jadhav et al. (2017) [10] showed that the plastic bottle disposition and compressive strength were correlated. The compressive strength of the blocks varied with the disposition of the bottles.

### *B. Density and Water absorption*

The SCC blocks with plastic bottles have a dry density of less than 1680 Kg/m$^{3,}$ and that could be classified the blocks as lightweight block units according to ASTM C90 [25]. TABLE V of column 3 represents the dry density of SCC blocks. The SCC block without plastic bottles has a dry density of 2283 kg/m$^3$ and corresponding to the range of normal weight block unit >2000 kg/m$^3$.

As shown in TABLE V, the weight of the SCC block without bottles (control block) was 27.4 kg, which was lower by 7 or 8 kg compared with SCC blocks with bottles. The reduction of weight is due to the 23% voids created by plastic bottles inside the block. This result of weight reduction agrees with the finds of Safinia & Alkalbani [7].

The water absorption for the SCC block without bottles was 120.1 Kg/m3 (3.18 %), which was slightly higher than the SCC block without bottles. According to ASTM C90, the maximum water absorption of masonry units is 240 kg/m$^3$ for lightweight masonry units. Therefore, the SCC blocks satisfied the absorption limits for the lightweight masonry blocks.

**TABLE V: Weight, Density and Water Absorption of SCC Blocks**

| Specimen | Weight (Kg) | Dry density (Kg/m$^3$) | Water Absorption (Kg/m$^3$) | (%) |
|---|---|---|---|---|
| D0 | 27.4 | 2283.2 | 120.1 | 3.18 |
| D1 | 20.1 | 1675 | 66.7 | 3.82 |
| D2 | 20 | 1666.7 | 66.7. | 3.89 |
| D3 | 19.7 | 1641.7 | 66.6 | 3.89 |
| D4 | 19.6 | 1633.3 | 66.4 | 3.90 |

### *C. Ultrasonic Pulse Velocity (UPV)*

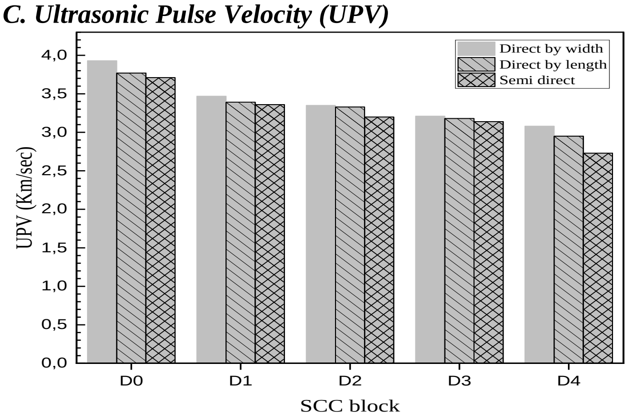



**Figure 8 shows the results of Ultrasonic pulse velocity (UPV) for all the SCC blocks.**

The UPV provides essential information on the pulse transfer rate in SCC blocks. It was worth observing that the value of the UPVs of SCC blocks with bottles decreases as the substitution of bottles. The values are lower by 11, 14, 18, 22 % for the D1, D2, D3, D4, respectively, than the SCC without bottles. The results obtained of UPV values can be attributed to the disposition and spacing between bottles as the number of bottles.

In addition, the UPV is directly related to the porosity of concrete and affects the compressive strength of concrete. The UPV values of all the SCC blocks obtained indicate the same overall significant reduction as compressive strength (cf Figure 7). Furthermore, Abutaha et al. 2016 [26] reported that the voids created between the different constituent materials reduce the pulse velocity. Moreover, according to Chahour et al. 2017 [27] and Cheboub et al. 2019 [28], the UPV values can predict sound insulation. They obtained the value of a lower transmitting wave for the lightweight concrete with plastic compared to the conventional concrete. SCC blocks with bottles may improve the sound insulation of concrete blocks, which agrees with the finding of this other research.

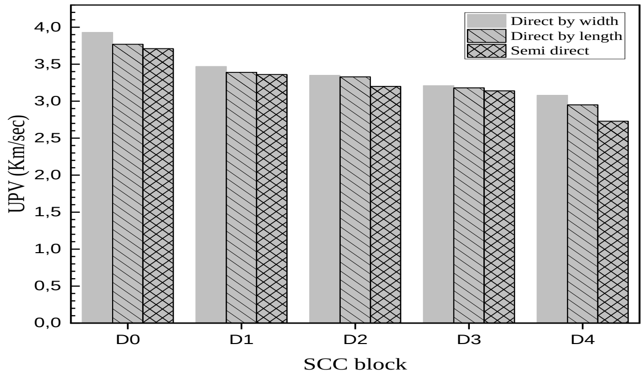



**Figure 8: UPV value of SCC blocks**

### *C. Thermal conductivity*

Figure 9 represents the results of the TC for SCC blocks schematically. The data show the reduction of TC for SCC blocks with bottles (53% D1, 56% D2, 54% D3, and 55% D4) compared with SCC blocks without bottles (D0).

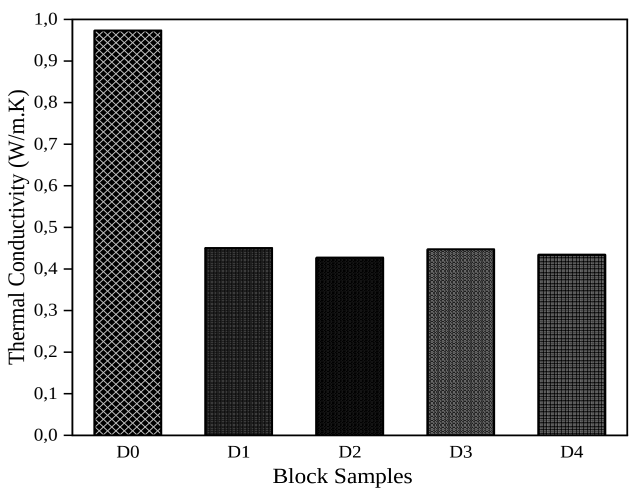



**Figure 9: Thermal conductivity of SCC blocks**

Thus reduction of thermal insulation could explain the incorporation of plastic bottles, and also their arrangement has the cause of the different values obtained according to the different disposition. TC for SCC blocks without bottles was 0.973 W/m.K, which was almost twice the TC of SCC blocks with bottles. Since the heat flow and size of the blocks were the same for the specimen, the reduction of TC on the blocks was caused by the bottle arrangement. For example, D2, which corresponded with the closer arrangement of blocks, gave the TC value K = 0.427 W/m.k. Akçaözoğlu et al. 2013 [12] and Basha et al. 2020 [13] reported that incorporating plastic bottles in concrete reduces the concrete's thermal insulation.

## IV. CONCLUSION

This study finds that incorporating plastic bottles in concrete blocks provides masonry units that meet minimum requirements for non-load bearing walls. Additional advantages are reduced weight, water absorption, sound, and heat transmission. In addition, The blocks produced promote sustainability by reducing the material used and providing an avenue for plastic waste disposal.

The study also finds that the arrangement of plastic bottles in the concrete block impacts the performance. It was found that the D1 arrangement gave the least reduction in strength, while the D4 arrangement gave the best sound insulation. All arrangements gave the same reduction in water absorption and thermal conductivity.

## ACKNOWLEDGMENT

The authors acknowledge and appreciate the financial and administrative support by the Pan African University of Basic Sciences, Technology, and Innovation (PAUSTI). Jomo Kenyatta University of Agriculture and Technology (JKUAT) for the use of the Concrete Laboratory.

## REFERENCES

[1] S. Alsadey, Utilization of Plastic Bottle Waste in Concrete, J. Biol. Environ. Eng., 1(1) ( 2016) 1–5.

[2] M. Jalaluddin, Use of Plastic Waste in Civil Constructions and Innovative Decorative Material ( Eco- Friendly ), MOJ Civ. Eng., 3( 5) (2017).

[3] M. Mokhtar et al., Investigating the Utilisation of Plastic Bottle as Aggregate Replacement for Concrete Block, J. Phys. Conf. Ser., 1049 012093, (2018).

[4] R. B. Kassa, C. Kanali, and N. Ambassah, Flexural performance evaluation of polyethylene terephthalate fiber reinforced concrete with fly ash as a partial cement replacement, Int. J. Eng. Res. Technol., vol. 12( 9) (2019) 1435–1440 .

[5] S. Nagataki and H. Fujiwara, Self-Compacting Property of Highly Flowable Concrete, On-line J., 154(1995) 301–314.

[6] A. Froese, Innovations - Eco-Tec, Andreas Froese Environmental Consultant ( 2018).

[7] S. Safinia and A. Alkalbani, Use of Recycled Plastic Water Bottles in Concrete Blocks, in Procedia Engineering, (2016) 214–221.

[8] S. M. Wonderlich, Strength of Concrete Masonry Units with Plastic Bottle Cores, KANSAS STATE UNIVERSITY, (2014).

[9] Z. Muyen, T. Barna, and M. Hoque, Strength properties of plastic bottle bricks and their suitability as construction materials in Bangladesh, Progress. Agric., 3 362–368 (2016).

[10] K. Jadhav, S. S. Angalekar, and A. A. Taware, Study on Influence of Polyethylene Teraphthalate ( PET ) Bottles in Concrete Section, 06(7) (2017). 1178–1181 .

[11] A. Poonyakan, M. Rachakornkij, M. Wecharatana, and W. Smittakorn, Potential use of plastic wastes for low thermal conductivity concrete, Materials (Basel)., (2018).

[12] S. Akçaözoğlu, K. Akçaözoğlu, and C. D. Atiş, Thermal conductivity, compressive strength and ultrasonic wave velocity of cementitious composite containing waste PET lightweight aggregate (WPLA), Compos. Part B Eng., 45(1) (2013) 721–726,.

[13] S. I. Basha, M. R. Ali, S. U. Al-Dulaijan, and M. Maslehuddin, Mechanical and thermal properties of lightweight recycled plastic aggregate concrete, J. Build. Eng., 32 . 101710 (2020).

[14] F. Fraternali, V. Ciancia, R. Chechile, G. Rizzano, L. Feo, and L. Incarnato, Experimental study of the thermo-mechanical properties of recycled PET fiber-reinforced concrete, Compos. Struct., 93(9) (2011) 2368–2374.

[15] V. S. Mojtaba, V. S. Masoud, and S. B. Azin Investigating the

Application of Plastic Bottle as a Sustainable Material in the Building Construction, Int. J. Sci. Eng. Technol. Res., 2(1) (2013) 2278 – 7798,.

[16] L. S. Viegas, U. T. Bezerra, and N. P. Barbosa, Blocks for Performance of Masonry Using PET Bottle Seal: Thermal, acoustic, and Mechanical and evaluation, Key Eng. Mater., 600 (2014) 753–767 .

[17] T. Iwase, S. Sugie, H. Kurono, M. Abe, Y. Okada, and K. Yoshihisa, Sound absorption characteristic of glass and plastic bottles - Considerations of their dependences on material properties, INTER-NOISE 2018 - 47th Int. Congr. Expo. Noise Control Eng. Impact Noise Control Eng., 2 (2018) 1–10.

[18] A. Patnaik, M. Mvubu, S. Muniyasamy, A. Botha, and R. D. Anandjiwala, Thermal and sound insulation materials from waste wool and recycled polyester fibers and their biodegradation studies, Energy Build., 92 (2015) 161–169.

[19] A. Kumar and G. Kumar, A Mix Design Procedure for Self Compacting Concrete, Int. Res. J. Eng. Technol., 05(2) (2018) 65–70.

[20] ASTM C140, Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units, ASTM Int. West Conshohocken, PAASTM Int., (2020).

[21] ASTM C642., Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, ASTM International, United States., ASTM Int. West Conshohocken, PA, (2006) 1–3.

[22] A. S. Al-Tamimi, O. S. Baghabra Al-Amoudi, M. A. Al-Osta, M. R. Ali, and A. Ahmad, Effect of insulation materials and cavity layout on heat transfer of concrete masonry hollow blocks, Constr. Build. Mater., 254 ( 2020) 119300.

[23] ASTM_Standard, Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus. (2004).

[24] ASTM C597, Standard Test Method for Pulse Velocity Through Concrete, ASTM Stand. B., (2010) 52–55.

[25] ASTM C90, Standard Specification for Loadbearing Concrete Masonry Units, Am. Soc. Test. Mater., 04, ( 2016) 1–4.

[26] F. Abutaha, H. A. Razak, and J. Kanadasan, Effect of palm oil clinker ( POC ) aggregate on fresh and hardened properties of concrete, Constr. Build. Mater., 112 (2016) 416–423.

[27] K. Chahour, D. Aboutaleb, B. Safi, and T. Mazari, Granulated foam glass based on mineral wastes used for building materials, Build. Acoust.,. 1–14, 2017.

[28] T. Cheboub, Y. Senhadji, H. Khelafi, and G. Escadeillas, Investigation of the engineering properties of environmentally-friendly self-compacting lightweight mortar containing olive kernel shells as aggregate, J. Clean. Prod., (2019).