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Utilization of Basaltic Quarry Dust as a Partial Replacement of Cement for Hollow Concrete Block Production

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Abstract

This research was conducted to examine the potential of basaltic crusher dust as a partial replacement for Portland Pozzolana cement in hollow concrete block (HCB) production. Quarry dust is one of the waste materials abundantly available and pozzolanic material in the quarry industry. In doing so, physical tests of cement pastes and hollow concrete blocks of different classes, i.e., A, B, and C, were produced by partially replacing the cement content with 10%, 20%, 30%, and 40% by weight of basaltic crusher dust using vibrating block molding machine. The units without basaltic crusher dust (0%) serve as a control variable. The cement pastes were examined for consistency and setting time, and the blocks produced were tested to determine their compressive strength, water absorption rate, and density. Furthermore, the possible cost advantages of using basaltic crusher dust as a partial replacement of cement in the hollow concrete block were analyzed. The result indicates that the experimental HCB of classes A and C surpassed the required standard of compressive strength, water absorption, and density specified by the Ethiopian standard ES 596:2001; whereas, the compressive strength of class B fails at 40% cement replacement. It was concluded that hollow concrete blocks of classes A and C with up to 40% replacement and class B with up to 30% replacement can be used for load-bearing walls and save the e cost of hollow concrete blocks with comparable properties.

Keywords: basaltic crusher dust, blended cement paste, hollow concrete block, wall

1 Introduction

The basic necessity of human beings after food and water is shelter. One of the major components of any kind of shelter is its walling material (Raheem & Sulaiman, 2013). Walling material of different types, the most common in Ethiopia; especially in an urban areas, is hollow concrete blocks (HCB). Hollow concrete blocks, which are made out of a mixture of cement, sand, and stone aggregates, are the major construction materials used in the construction of residential buildings, factories, and multi-storied buildings. Hollow concrete blocks are more useful due to their lightweight and ease of ventilation. The economy of the structure is one of the basic aspects upon which any design is based. Stability plays an important role but the best designer is one who comes out with a design that gives a stable and economic structure (Negesse, 2018). Hollow concrete block is an important addition to the types of masonry units available to the builders and its use for masonry is constantly increasing, which saves cement in masonry work, bringing down the cost of construction considerably. Additionally, its construction provides facilities for concealing electrical conduits, water, and soil pipes. In Ethiopia, different classes of hollow concrete blocks are produced with a variety of strengths. One of the reasons for its popularity is its incorporation of locally available materials (GTZ, 2003).

Cement, as a binder, is the most expensive input in the production of hollow concrete blocks. In addition, the

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production of cement, relative to other constituents, is an environmentally unfriendly process due to the release of CO_2 gases into the atmosphere. One of the methods to reduce the cement content in the concrete mixes is the use of waste as a pozzolanic material (Adebakin et al., 2012).

The most common blending materials used in cement production added in plants or sites are industrial wastes. This is because recycling industrial wastes as blending materials has technical, economic, and environmental benefits besides the reduction of CO_2 emissions from cement production. Environmentally, when industrial wastes are recycled not only the CO_2 emissions are reduced but residual products from other industries are reused and therefore less material is dumped as a landfill and more natural resources are saved. Fly ash, blast furnace slag, and silica fume are the most widely used industrial wastes in place of cement for concrete production attributed to their reactive nature called pozzolanic behavior (Fennis et al., 2009).

Pozzolana is a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (ASTM, 2003). Pozzolana's main function is to improve durability and strength of hardened concrete, whereas the fineness of Pozzolana determines their effect on workability of fresh concrete. Pozzolans and supplementary cementitious materials (SCMs) either natural or artificial are often used as cement replacement or as an improvement in concrete. The physical or chemical properties of the materials determine their pozzolanic or cementation properties. The hydration of tri-calcium silicate and di-calcium silicate with water gives calcium silicate hydrate and calcium hydroxide. Finely divided pozzolans and amorphous silicates result a better pozzolanic reaction. The principal reaction taking place is as shown in Eq. 1 (Sidney et al., 2002):

$$\text{Pozzolan} + \text{calcium hydroxide} + \text{water} \rightarrow \text{calcium silicate hydrate (gel)} \tag{1}$$

If these pozzolanic materials were not reacted with the calcium hydroxide, free calcium hydroxide would have been present in the concrete resulting in higher permeability of the concrete and susceptibility to other attacks. The pozzolanic reaction reduces the porosity of the concrete by producing a cementitious compound (Kosmatka et al., 2003).

Different researches have been done to replace cement with pozzolanic materials. Chu et al., (2022) studied recycling of waste glass powder as paste replacement in green UHPFRC. In this study, a series of ultra-high performance concrete (UHPC) and high-performance fiber-reinforced concrete (UHPFRC) mixes with waste glass powder (WGP) volume ranged from 0%, 5%, 10% to 15%, and the respective cementitious paste volume ranged from 80%, 75%, 70% to 65%, the sum of which equals to 80% were used. Meanwhile, the waste glass cullet (WGC) used as fine aggregate volume was also fixed at 20% in terms of the total mixture volume. According to Chu et al. (2022) study findings, the addition of WGP as paste replacement could improve the microstructure of the hardened UHPC and UHPFRC, whereas the inclusion of WGP as cement replacement may cause deterioration of the microstructure. The substitution of WGP as paste replacement would significantly reduce the cement content of UHPC and UHPFRC mixtures by up to 18.80%, without sacrificing the workability and strength. Instead, the 28-day compressive strength was increased by up to 67%.

Chu et al. (2021) studied the effect of natural and recycled aggregate packing on the properties of concrete blocks. To overcome the lower strength and lower dimensional stability impacts of use of recycled aggregate (RA) as partial or full replacement of natural aggregate (NA) in concrete, increasing the cement content has been taken as an alternative solution. But, these attempts are prone to elevate the production cost and decrease the sustainability. Particle packing was introduced into recycled aggregate concrete (RAC) with the aim of improving the performance of concrete paving blocks made with RAC to a higher level using the packing optimization concept.

From the Chu et al. (2021) study finding, the packing density of the RA particle system could be significantly increased by up to 31% after appropriate aggregate proportioning. In addition, the packing density of an RA particle system could be optimized to approach that of an NA particle system, despite the presence of adhered old paste or mortar for RA. With appropriate packing optimization, the compressive strength of concrete paving blocks made with only RA could be increased by 156% from 30.90 to 79.20 MPa, approaching the maximum compressive strength of 84.80 MPa obtained for concrete paving blocks made with only NA. The packing density was found to be a key factor that governs the properties of concrete paving blocks, regardless of the aggregate type.

Some studies had been done to investigate the effect of partially replacing cement with SCMs on durability of concrete. In this regard (Chen et al., 2020) studied coupling effect of γ-dicalcium silicate and slag on carbonation resistance of low-carbon materials. They studied to maximize the durability and minimize the environmental impact, the possible coupling effect arising from the combined use of γ-C_2S and slag was systematically investigated. γ-C_2S exhibits low hydraulic but high carbonation reactivity and γ-C_2S generates less CO_2 and capture more CO_2 compared to ordinary Portland cement. On the other hand, the partial replacement of cement by SCMs could lower down the cement consumption but might render the concrete more vulnerable to carbonation. The combined use of γ-C_2S and slag has great potential to give rise to unprecedented properties than their individual. From the research findings of Chen et al. (2020), the accelerated carbonation favored by the coupling effect of γ-C_2S and slag was evidenced by the shallower carbonation depth, finer pore size and reduced pore volume at an optimum combination.

The utilization of by-products and waste materials, which can be used as partial cement replacement materials, has been increasing tremendously in the construction industry. Blast furnace slag, silica fume, fly ash and rice husk can be cited as an example (Kartini et al., 2014). Crusher dust as a by-product from crushing of coarse aggregate during quarrying activities has also received considerable attention to enhance the properties of concrete and it is found to have such pozzolanic properties. Fillers are micro-fine materials passing 75 μm and have a beneficial effect on properties of concrete, such as workability, density, permeability, capillarity, and bleeding. Usually, fillers are chemically inert but there is no disadvantage if they have some hydraulic properties or if they enter into harmless reactions with the products of hydration in the hydrated cement paste (Neville, 2011).

Quarry dust is one of the waste materials abundantly available and unused in the quarry industry. It is a by-product that is produced as a result of crushing operation, containing many fine materials that pass 150 μm sieve. The dust may be dry screenings collected from below the last screen deck in a dry or semi-dry state or pond screenings, obtained from washing aggregates, collected from settling ponds (Doraiswamy & Hudson, 1992). In recent years; this by-product of the aggregate crushing process has been tested in some parts of the world for its pozzolanic property to replace cement partially and has been found to improve some of the properties of the paste, mortar, and concrete. However, a specific investigation is needed as the property of crusher dust varies depending on the locality and type of the parent material.

Crusher dust, as defined by the BS EN standard, is the inherent fraction of an aggregate passing 63 μm. Many quarries also refer to their fine aggregate finer than 4 mm as quarry fines (Alp et al., 2009). The term is used here, in this research, to denote a fine by-product passing 150-μm sieve which are produced during the aggregate extraction process and it is the most common and widely produced stone by-product (Doraiswamy & Hudson, 1992). These materials are left as fine dust and considered to be a waste. According to Shah et al. (2017), the amount of by-products and fines produced could be different based on the size of aggregate to be produced, rock type and type of primary and secondary crusher.

The production of coarse aggregate is increasing as the construction industry develops rapidly. Following this, a by-product (passing 4.75-mm sieve) of coarse aggregate production is also increasing. About 15 to 25% of these fine by-products pass 150 μm sieve size, which is pulverized rock (Doraiswamy & Hudson, 1992). At the same time, most of the specifications limit the maximum percent of fine aggregate passing 150 μm for construction as 10%. This means the material cannot be used as manufactured sand. In addition, crusher dust can be discovered in a separated form which is collected naturally by wind around the crusher site. The dust found in this way is generally considered as waste material. Even though it is difficult to determine the amount produced, currently the amount wasted is increasing as more companies join the industry. So, disposal of this waste material gets concerns since it might cause environmental problems such as; poor permeability of top soil, contamination of surface and groundwater, and air pollution.

Despite the difficulty of determining the amount of crusher dust produced in Ethiopia, it is possible to make an estimation based on the report organized by the Ministry of Urban Development, Housing and Construction in 2014/2015 (Bureau, 2014). The report was organized based on the coarse aggregate demand of the Addis Ababa housing development office to conduct government building construction projects. The average annual crusher dust produced and contained in the crusher by-product was estimated to be more than 110,000 m^3, which can be an indication of a high potential of crusher dust due to coarse aggregate production.

Some research that had been conducted on the use of crusher dust as a partial cement replacement material shows that crusher dust can improve the cement and concrete properties in different effective replacement proportions. Venkata et al. (2013) studied partial replacement of quarry dust as cement in concrete by 10%, 15%, 20%, 25%, 30%, 35%, and 40% by weight of cement, and the optimum replacement percentage of quarry dust was found to be 25%. El-Didamony et al. (2015) revealed that replacing cement with 20% basalt powder provides optimum strength of concrete and can be used as pozzolanic material. Ebrahim (2018) studied the mechanical behavior of C25 and C30 grade of concrete by partially replacing cement with quarry dust by 5%, 10% 15% and 20% (PPC and OPC). The optimum replacement of cement by quarry dust recorded from the findings was 5% and 10% for PPC and OPC, respectively.

Based on the identification of the literature gaps, the specific objectives of this research are: to examine the effect of partial replacement of basaltic crusher dust on consistency and setting time of blended cement paste and to investigate the effect of quarry dust on the performance of load-bearing hollow concrete blocks in terms of compressive strength, water absorption, and apparent density.

2 Materials and Methods

2.1 Materials

2.1.1 Basaltic Crusher Dust

Throughout the experiment, crusher dust obtained from the quarry site found in Addis Ababa (Bole-Bulbula and Akaki Kality) areas was used. The crusher dust from these plants could be different in their chemical composition, clay content and fineness due to the type of parent rock, location of crushing sites and the type of crusher used. The selection was done based on the geological map of Addis Ababa and the population of production plants. Fineness is usually measured by the Blaine air-permeability test that indirectly measures the surface area of the cement particles per unit mass. Cements with finer particles have more surface area in square meters per kilogram of cement (Neville, 2011).

2.1.2 Cement

In this study, Portland Pozzolana Cement (PPC) from Habesha cement factory with a grade of 32.5 N, which is manufactured to satisfy Ethiopian standard (Standard, 2005) and European standard EN 197-1:2011, were used in the production of all HCB specimens for the experimental study.

2.1.3 Aggregates

Throughout the experiment, river sand as fine aggregate, crushed basaltic rock and pumice as a coarse aggregate from Kality Construction Material Production Factory (KCMPF) aggregate stockpile, with the physical properties shown in Tables 1 and 2 were used.

Table 1 Properties of fine aggregate.

Properties	Standard	Test result
Silt content (%)	ASTM C 117	4.50
Fineness modulus	ASTM C 33	2.90
Moisture content (%)	ASTM C 566	4.17
Absorption capacity (%)	ASTM C 29	14.41
Unit weight (kg/m^3)	ASTM C 29	1294

Table 2 Properties of coarse aggregates.

No.	Test description	Test result	
		Pumice	01 Aggregate
1	Maximum size (mm)	19.00	9.50
2	Minimum size (mm)	2.36	1.18
3	Moisture content (%)	8.65	1.90
4	Unit weight (kg/m^3)	640	1519
5	Absorption capacity (%)	60.60	2.00
6	Specific gravity (SSD)	1.05	2.71

2.1.4 Water

In this research, tap water supplied for the Kality Construction Material Production Factory (KCMPF) was used in producing, curing, and soaking hollow concrete blocks. On other hand, to test the consistency of blended cement, drinking water supplied to Hawassa University from Hawassa water and the sewerage authority was utilized.

2.2 Methods

2.2.1 Standards Used

The materials used in this are described in terms of their physical and chemical properties. The laboratory activities on the properties of fine and coarse aggregate, pumice, and the HCB made by incorporation of quarry dust are carried out in the Kality Construction Material Production Factory (KCMPF). The test for the fineness of the crusher dust and cement was conducted in the Addis Ababa University Chemical Engineering laboratory, whereas the properties of cement and blended cement pastes were studied in the Hawassa University construction materials laboratory. On other hand, the chemical composition of quarry dust, and the specific gravity of cement and quarry dust were determined in Ethiopian Geological Survey. The fineness of the cement, as measured in the chemical laboratory of Addis Ababa University, was conducted by using a Blaine air permeability meter according to the test procedure recommended by (ASTM, 2018). Furthermore, the clayey property of the basaltic crusher dust was studied in the IFH Engineering soil laboratory. HCB test was done as per ASTM C-90 (Table 3). The fineness of basaltic crusher dust was done by ASTM C 204 (Table 4).

The fine aggregate size distribution is consistent from 0.15 to 9.50 mm. The coarse aggregate used for this research was crushed basaltic rock and pumice. A crushed basaltic rock with a maximum size of 10 mm

Table 3 Mix proportion for hollow concrete block work.

Mix code	Cement type	Cement (kg)	Crusher dust (kg)	W/Cm	Water	Amount (No. of the box)		
						Sand	01 aggregate	Pumice
Class A								
A0	Habesha PPC	50	0	0.30	15	2	4	2
A10	Habesha PPC	45	5	0.30	15	2	4	2
A20	Habesha PPC	40	10	0.30	15	2	4	2
A30	Habesha PPC	35	15	0.30	15	2	4	2
A40	Habesha PPC	30	20	0.30	15	2	4	2
Class B								
B0	Habesha PPC	50	0	0.34	17	2	4	3
B10	Habesha PPC	45	5	0.34	17	2	4	3
B20	Habesha PPC	40	10	0.34	17	2	4	3
B30	Habesha PPC	35	15	0.34	17	2	4	3
B40	Habesha PPC	30	20	0.34	17	2	4	3
Class C								
C0	Habesha PPC	50	0	0.40	20	2	5	4
C10	Habesha PPC	45	5	0.40	20	2	5	4
C20	Habesha PPC	40	10	0.40	20	2	5	4
C30	Habesha PPC	35	15	0.40	20	2	5	4
C40	Habesha PPC	30	20	0.40	20	2	5	4

Table 4 Naming and proportioning of cement pastes.

No.	Code	Percentage by weight*	
		Crusher dust (%)	Portland Pozzolana cement (%)
1	P-0	0	100
2	P-10	10	90
3	P-20	20	80
4	P-30	30	70
5	P-40	40	60

(01 aggregate) was utilized for the production of all HCB samples. Furthermore, the pumice size distribution is consistent from size 2.36 mm to 19.00 mm on its limit. The sieve analysis test is performed per the procedure of ASTM C 136 to fulfill the grading requirement of lightweight aggregate for concrete masonry units specified on ASTM C 331.

2.2.2 *Preparation of Basaltic Crusher Dust Sample*

The crusher dust was originally found at the crushed aggregate production plant area blended with other grades of aggregate as a by-product and is located near the secondary and tertiary crusher by the action of natural wind. These by-products were collected, packed in a sack, and transported to the construction material laboratory of KCMPF for further processing. The intended basaltic quarry dust passing sieve with an aperture opening of 150 μm (Table 5). Therefore, the originally collected crusher dust was sieved and its fineness and chemical composition were determined before blending it with cement.

2.2.3 *Mix Design Preparation*

Proportioning of materials for hollow concrete blocks requires careful adjustment of water to cement ratio unless the mix could be easily crumbled when the water content in it is too little or it may cause difficulty of immediate withdrawal from mold as the water content became too high. Because of this controlling the water–cement ratio of a mix between 0.30 to 0.40 is recommended; in which the quantity of water required for one cubic meter of the mix can be calculated (Negesse, 2018).

Partial replacement of cement with BCD was done in the way of BCD added to the mixture to replace an equal volume of paste cement without disturbing the fine and coarse aggregates, and cementitious paste proportions. The replacement is done in such a way that 1 kg of crusher dust replaces 1 kg of cement.

The replacement method can replace large quantities of cement without adversely affecting the strength, and

Table 5 Mix code and their description for HCB samples.

Mix code	PPC (%)	Crusher dust (%)	Test days			Number of samples	Remark
Class A							
A0	100	0	3	7	28	18	Control mix
A10	90	10	3	7	28	18	Experimental mixes
A20	80	20	3	7	28	18	
A30	70	30	3	7	28	18	
A40	60	40	3	7	28	18	
Class B							
B0	100	0	3	7	28	18	Control mix
B10	90	10	3	7	28	18	Experimental mixes
B20	80	20	3	7	28	18	
B30	70	30	3	7	28	18	
B40	60	40	3	7	28	18	
Class C							
C0	100	0	3	7	28	18	Control mix
C10	90	10	3	7	28	18	Experimental mixes
C20	80	20	3	7	28	18	
C30	70	30	3	7	28	18	
C40	60	40	3	7	28	18	
Total samples						270	

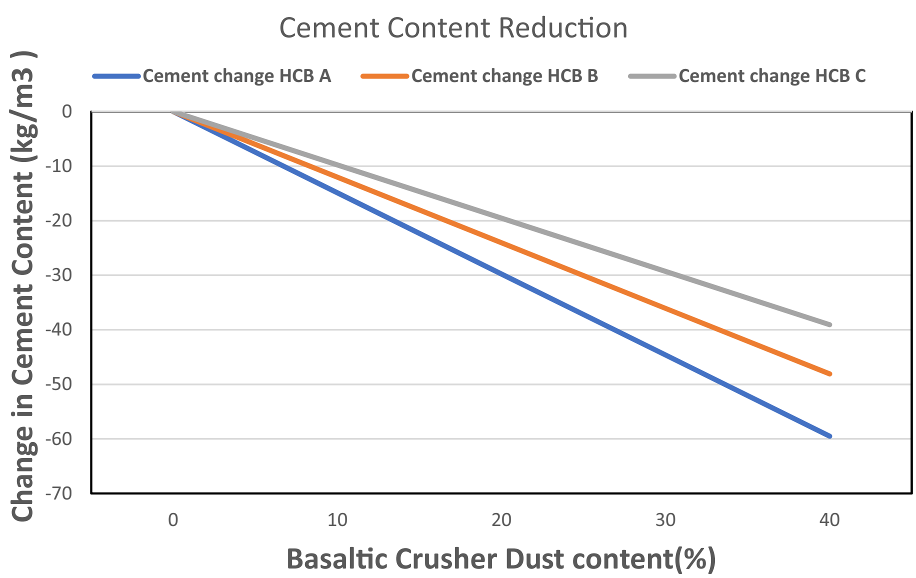

Fig. 1 Cement reduction as replacement of BCD in paste.

reusing a larger amount of BCD would improve the concrete performance. The cement content decreased from 148.79 to 89.27, 120.21 to 72.13, 97.66 to 58.59 kg/m^3 for HCB A, B, and C, respectively, accounting for 40 of by mass of cement and BCD content increased from 0 to 40% with the corresponding decrement of cement content as shown in Fig. 1.

2.2.4 Preparation of Hollow Concrete Block Specimens and Mixing Procedure

For the preparation of constituents, both volume batching and weight measurement were used. After determining the relative amounts of materials to be used for the specimens' production, the aggregates and the cement (hydraulic and blended) were dry mixed for approximately 1 min.

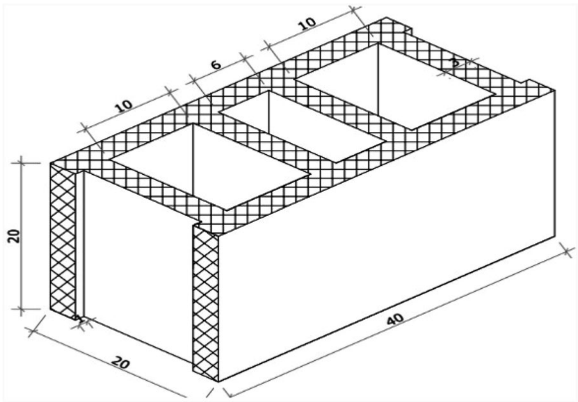

Fig. 2 Dimension details for hollow concrete blocks produced in the research (cm).

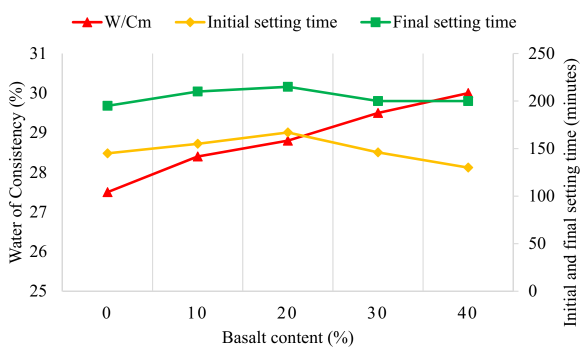

Fig. 3 Water of consistency, initial and final setting time of PPC and basaltic crusher dust.

The mixing process continued for another 1 min after the addition of water. As the mixing process is completed, the mixture is transported into the mold with the help of a conveyer belt and compacted for about one minute using a mechanical vibrator. Finally, the specimen after compacted thoroughly, was demolded and transported to the curing area. The specimen was cured on a wooden pallet being covered by a plastic sheet for 24 h after which they were released from the pallet and stored on a flat surface in a honeycomb fashion with horizontal voids until the test period.

2.2.5 *Compressive Strength of Hollow Concrete Block*

In this study, more than two hundred seventy (270) 20-cm-thick full units of HCB samples, in which each class consisting of 90 samples of the block, with three holes were prepared by blending PPC of 32.50 N and crusher dust in different percentages and tested for compressive strength test at the ages of 3, 7 and 28 curing days.

Specimen size and shape, method of pore formation, the direction of loading, amount and rate of loading, degree of compaction, characteristics of ingredients, cement content, size and number of holes, and method of curing can affect the strength of HCB (ASTM, 2011) (Fig 2).

2.2.6 *Water Absorption and Density of Hollow Concrete Block*

In this study, more than 45 full units of HCB blocks (45), 15 for each class, were prepared by blending PPC and crusher dust in different percentages (Fig 3). The samples were then tested for water absorption at the age of 28 curing days. The HCB samples of water absorption were used for testing the density. Three units from each of the oven-dried samples were measured for their dimensions and weights. Considering the dimensions of the HCB, the overall volume was computed in cubic centimeter and the density of each unit were calculated.

3 Results and Discussion

3.1 Fineness and Chemical Composition of Crusher Dust and Cement

The Blaine fineness of the selected basaltic crusher dust (BCD) was 2870.31 cm^2/g, which is less than the fineness of cement which was measured to have a specific surface area of 3675.74 cm^2/g. This finding shows that the crusher dust passing 150-µm sieve openings, from which it is 20% are less than 75 µm, cannot be used as a filler material in concrete unless further processing or grinding is considered to enhance the fineness of the dust. The specific gravity of the crusher dust measured in the Ethiopian geological laboratory was found to be 2.59. This indicates that the crusher dust is less dense than the cement used in this research which has a specific gravity value of 3.14.

The combined chemical composition of major oxides were found in percentage to be $SiO_2 + Al_2O_3 + Fe_2O_3 = (58.40 + 15.99 + 8.10)\% = 82.49\%$. According to ASTM C 618, the chemical composition of class N Pozzolana

Table 6 Chemical composition of crushed dust.

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O	LOI
BCD (composition)	58.40	15.99	8.10	3.42	1.98	4.14	2.82	1.21	2.13

should contain at least 70% by mass of major oxides as shown in Table 6. Based on this prescription the crusher dust can be classified as raw natural (or class N Pozzolana).

The experimental value of moisture content for the crusher dust was obtained to be 1.21% by mass. This result is less than the maximum limits of water content, i.e., 3%, for class N pozzolana as stated on ASTM C 618. The basaltic crusher dust was found to have an alkalis content, equivalent Na_2O, more than the requirement specified on ASTM C 618; which specify as less or equal to 1.50% by mass. The standard specifies a maximum of 10% loss of mass on ignition for class N pozzolans, hence, the dust satisfies this chemical requirement.

3.2 Consistency of Cement and Blended Cement Pastes

It had been conducted by the use of Vicat apparatus to observe the changes in water requirement of pastes due to crusher dust powder. The control paste, i.e., P-0 had a normal consistency of 27.50%. All the pastes containing crusher dust showed consistency higher than the control paste. The consistency of pastes increased by 0.90% initially as the replacement of the crusher dust is 10%, then after the water requirement showed an increment of 0.40% and 0.70% for 20% and 30% replacement, respectively; which are relatively slow increments in water requirement. As the replacement percent increased to 40%, the consistency attained 30%.

As given in Table 7, despite the coarseness of the crusher dust, the water requirements of the blended cement pastes increased as the percent of replacement increased. This might be due to the clay content of the dust. Clay by its nature consumes more water, therefore, it needs more water for gauging and then the water consistency increased with the basalt content. The blended cement pastes, i.e., P-10, P-20, P-30, and P-40 had a water requirement that is 103.30%, 104.70%, 107.30%, and 109.10% of the control paste, P-0. Moreover, ASTM C 618 limits the maximum water consistency for class N pozzolana blended cement relative to the controls to be 115%. Based on this prescription, the results of all the blended pastes satisfy the requirement.

3.3 Setting Time of Cement and Blended Cement Pastes

The Ethiopian standard specifies the minimum limit of initial setting time and maximum limits of final setting time for Portland Pozzolana Cement as 45 min and 600 min, respectively. ASTM C 150, on other hand, specifies the corresponding limits to be 45 min and 375 min. The consensus is that the less pozzolanic property of the pozzolans in PPC cement at an early age compared with the basaltic crusher dust (Ebrahim, 2018). For these particular basaltic crusher dust, the result showed that the addition of crusher dust has an increasing effect on initial setting time up to 30% of crusher dust replacement than the control paste.

The addition of the crusher dust powder has also increased the final setting time compared to the control paste. The increasing rate of both the initial and final setting time with the addition of crusher dust increased up to 20% replacement; whereas, the rate is slow as the cement is replaced with 30% crusher dust. The trend of increment of the initial, as well as the final setting time with the percentage increment of crusher dust, is not uniform. These increment in initial and final setting time is observed due to the less involvement of the pozzolans in the PPC during the initial hydration compared with the basaltic crusher dust (Ebrahim, 2018), which results in retarded hydration than the control paste. The initial and final setting times of blended cement paste of this research are within the limit specified by both the Ethiopian standard and ASTM.

3.4 Compressive Strength of PPC Crusher Dust Hollow Concrete Blocks

In this study, Agency (2012) specification for concrete masonry units is used as a compliance criterion for checking the suitability of crusher dust blended cement in the production of hollow concrete blocks. At 3 days, controlled HCB of class A, i.e., A0, achieved 4.24 MPa; whereas, concrete mix with 10%, 20%, 30%, and 40% of crusher dust, i.e., A10, A20, A30, and A40, achieved 5.21, 4.49, 3.45, and 3.37 MPa, respectively. An increase of 22.88% and 5.90% in compression with the strength of A0 is achieved for A10 and A20 concrete mixes. For A30 and A40 compressive strength at 3 days is 81.37% and 79.50% of A0. At 7 days, A0 achieved a compressive strength of 4.72 MPa.

Compressive strengths of A10 and A20 concretes are increased by 22.25% and 1.06%, respectively, when compared with A0. For A30 and A40 compressive strengths at 7 days achieved 98.50% and 79.45% of A0. Similarly, the compressive strength of A0 achieved at 28 days is 7.73 MPa. The compressive strength of A10 was increased by 3.36% when compared with A0. At 20%, 30%, and 40% of crusher dust in the HCB at 28 days, a reduction in compressive strength of 7.50%, 17.08%, and 22.38% was observed when compared with A0.

Table 7 Normal consistency of cement and blended cement pastes.

S. no.	1	2	3	4	5
Code	P-0	P-10	P-20	P-30	P-40
Consistency (%)	27.50	28.40	28.80	29.50	30.00

The 3-day compressive strength of class B hollow concrete block with 10% crusher dust, i.e., B10 increased by 2.41% when compared with the controlled mix, i.e., B0, which achieved 3.74 MPa in compression; whereas, B20, B30, and B40 concrete mix achieved 3.37, 3.37 and, 2.42 MPa, respectively, which are 90.10% and 64.70% of B0 at 7 days, B0 achieved a compressive strength of 4.65 MPa. The compressive strength of B10 is increased by 3.23% when compared with B0; whereas, the compressive strength of B20, B30, and B40 achieved 84.59%, 74.60%, and 64.30% of B0. At 28 days, B0 achieved a compressive strength of 6.92 MPa. The compressive strength of B10 relatively increased by 1.73%. As the percent of replacement increased by 20%, 30%, and 40%, the average compressive strength becomes 5.77, 5.46, and 4.21 MPa, respectively.

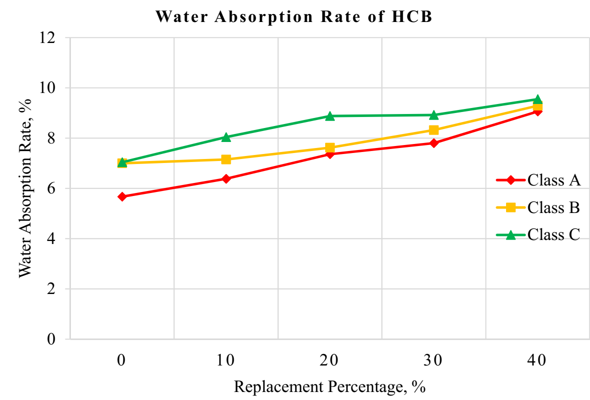

Fig. 5 Graphical representation of crusher dust effect on water absorption of HCB.

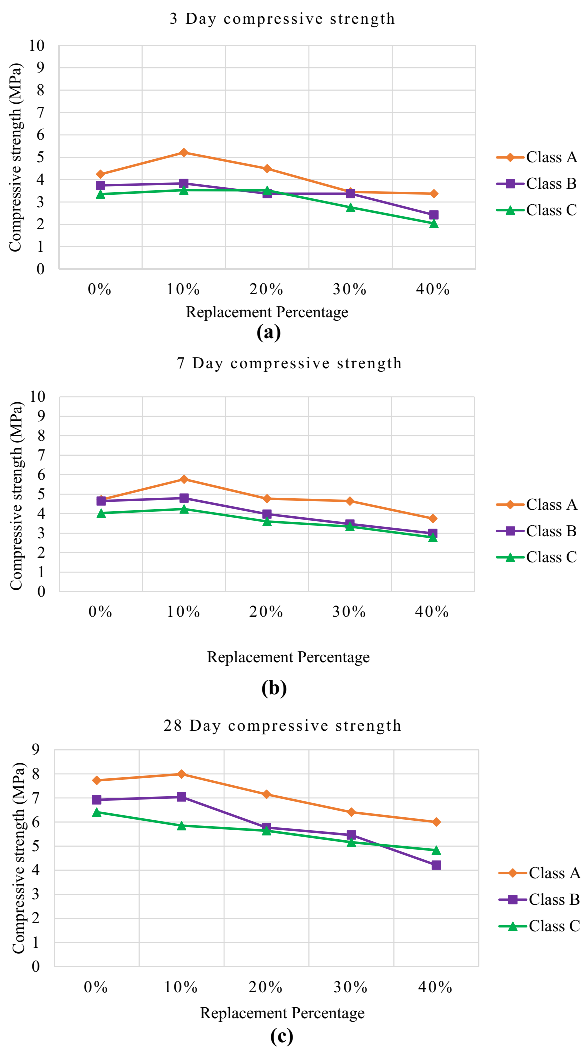

Fig. 4 Effect of cement replacement by crusher dust on compressive strength of HCB.

As given in Fig. 4, class C hollow concrete block increased by 5.37% and 5.07% in compressive strength at 10% and 20% cement replacement by crusher dust (C10 and C20) after 3 days of curing, respectively; whereas, reductions by 17.61% and 39.10% of controlled concrete mix (C0) were observed for 30% and 40% replacement ranges. After 7 days of curing, C0 achieved 4.03 MPa which is exceeded by 5.21% as the crusher dust replacement increased by 10%. The compressive strength of this class shows a reduction of 10.67%, 17.12%, and 31.02% of C0 for C20, C30, and C40 hollow concrete blocks. At 28 days, the C0 achieved a compressive strength of 6.41 MPa, whereas C10, C20, C30, and C40 concrete mixes achieved 5.85, 5.64, 5.16, and 4.83 MPa, respectively.

When it is tried to compare crusher dust replacement in classes A, B, and C, it was able to understand that the early strength developments (3 and 7 days) up to 10% replacement were fast relative to the control mix. This continues up to 20% replacement for class A at these curing ages; whereas, the strength development is limited to 3 days of curing for Class C blocks. At 28 days, the compressive strength of class A and B increased for 10% replacement of crusher dust, whereas the compressive strength of class C HCB declines as the replacement percentages increased from 10 to 40%. In all classes of hollow concrete blocks, the compressive strength at all ages decreases for 30 and 40% of crusher dust in concrete. This might be the amount of reduction in cement content in the concrete mix, thus reducing the anhydrous products to form C–S–H gel. Despite the reductions in compressive strengths, the hollow concrete blocks of class A and C with different percentage replacement of cement by basaltic crusher dust achieve the minimum requirement of compressive strength specified in Agency (2012). The class B hollow concrete block achieves this requirement for replacement of 10 to 30% crusher dust, after which it fails to achieve.

3.5 Water Absorption of PPC–Basaltic Crusher Dust Hollow Concrete Blocks

The water absorption test results of hollow concrete blocks were taken at the age of 28 days of curing as shown in Fig. 5.

Different results as described in Fig. 5, where the absorption satisfied the standard at all replacement percentages for all the classes of the hollow concrete block. The class C block at the replacement percentage of 40% only reached the absorption rate of 9.55%. This is far below the maximum absorption rate, 25%, recommended by the Ethiopian standard. The achievement in water absorption requirement benefits the hollow concrete block in durability aspects.

An increase in crusher dust increased by water absorption percent for all classes of hollow concrete blocks. This is might be due to the high void spaces or pores created because of the replacement of finer material (cement), with coarser material (crusher dust). In other words, Pores would be increased as the number of cement was being limited to bind higher portions of aggregates so that the void of the air will be available. As the air space between particles increased more water is absorbed to fill the gap during wet conditions. It was also observed that the absorption percentage is higher in class C for all replacement percentages and class B HCB is the second most absorbent. Furthermore, class A has a higher variation in absorption as the cement content is replaced by the range of 20% to 40% of crusher dust which varies from 29.81 to 59.79% for the corresponding percent of replacement. The water absorption test on class B shows that the relative variation in absorption for 10%, 20%, 30% and 40% cement replacement to be 2.14%, 8.86%, 18.86% and 32.71%, respectively, whereas a variation of 14.20%, 26.14%, 26.70% and 35.65% was found in class C for the corresponding replacement percentages. The results show that the coarser particles of crusher dust decreased the packing density of fresh concrete leading to an increase in pore volume in hardened hollow concrete blocks. This causes a higher rate of absorption.

3.6 Density of PPC–Basaltic Crusher Dust Hollow Concrete Block

The average HCB density recorded at the age of 28 days of curing is given in Fig. 6 and the experimental results showed that the density of specimens reduced for all classes of HCB.

A slight reduction of density up to 1.20% was recorded in class A when 40% of cement was replaced by crusher dust; whereas, a reduction of 0.73%, 0.92% and 1.06% were found at 10%, 20% and 30% replacement range. The experimental class B hollow concrete

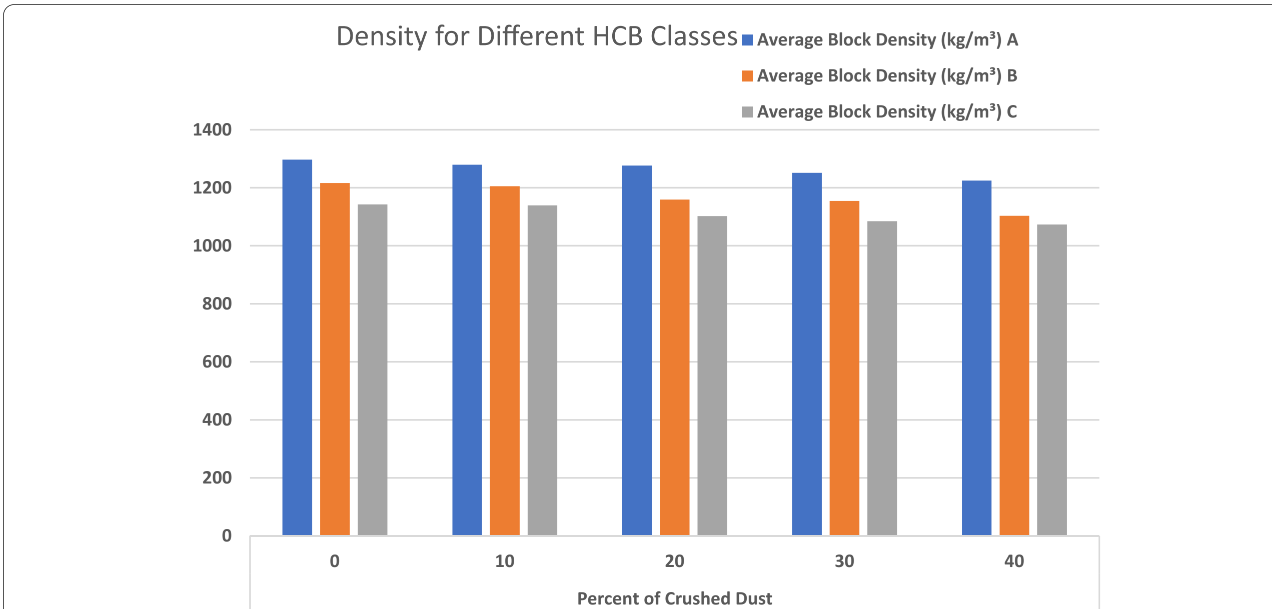

Fig. 6 Comparison of density for different classes of HCB.

blocks, i.e., B10, B20, B30, and B40, show a reduction in density of 0.38%, 2.72%, 4.19%, and 4.40% from the controlled specimen, B0. Similarly, it was found that the class C hollow concrete blocks exhibit 1.11%, 1.25%, 1.50%, and 4.53% density reduction for the corresponding replacement percentage. The low specific gravity of basaltic crusher dust, 2.59 as compared to cement, i.e., 3.14, resulted in a reduction of the density of the blended hollow concrete block.

4 Conclusion

Despite the basaltic crusher dust satisfying the pozzolanic chemical requirements, it is coarser than the Portland Pozzolana Cement. This means the basaltic crusher dust cannot be used as a filler in cement because a mineral admixture is required to have a specific surface area that is equal to or greater than cement.

The basaltic crusher dust as investigated in the study can be used as cement replacing material with economic and technical advantages. However, there is no way for either separating blended dusts or constructing storage pond for the dust at the crusher sites. Therefore, the concerned bodies, i.e., government entities and the aggregate crusher companies, need to be aware of this potential so as to dispose carefully and ease of access.

The basaltic crusher dust sample can replace cement partially up to 40% in production of load-bearing hollow concrete blocks; conversely, it is observed that there are a limited numbers of hollow concrete block producing companies with no experience in using crusher dust as cement replacing materials. Therefore, it is necessary to increase the number of hollow concrete production factories close to aggregate production plants as well as to give training in order to make the use of this waste feasible.

The result of the research has found that cement can be advantageously replaced up to 40% in class A and C hollow concrete blocks; whereas, it goes up to only 30% in class B. Replacing cement with 40% crusher dust results in a saving of 0.99% and 0.70% cost of production per single block of class A and C HCBs, respectively, with comparable characteristics in compressive strength, water absorption, and density. Similarly, the concrete block of class B saves a maximum of 0.71% per block at a 30% replacement percentage. In fact the construction industry in Ethiopia is booming, however, there is a limitation in using industrial wastes and by-products as an alternative cement replacing material in a cost-effective manner and conserve the natural resources. The crusher dust from different crusher sites of other parent rock types such as ignimbrite, trachyte, or limestone should be studied and compared with the result of this study. Detailed study of the durability of the hollow concrete block made by basaltic crusher dust blended cement should be done. Considerations should be made for more variation in the crusher dust amount. Maximizing the clay content may also be an advantage in order to cover more crusher sites with arrangement closer to the quarry site and lacks scalping of parent rock and screening process.

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All the listed three authors have their own contribution for this research with regard to their arrangement. All authors read and approved the final manuscript.

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