Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 12, Issue 4, June 2021:843-849
Research Article

Improving The Performance of Hollow Concrete Block Through the Use of Alternative Aggregate: The case of Adama Town Ethiopia.

Lemma Beressa[1], Battula Vijaya Saradhi[2]

[1] Lemma Beressa, Research Scholar, Civil Engineering Department, College of engineering (A), Andhra University, India. lberessa1975@gmail.com

[2] Professor, Faculty of Civil Engineering Department, College of Engineering (A), Andhra University, India. bvsaradhi70@gmail.com

ABSTRACT

Conventionally, hollow concrete block (HCB) is produced from ordinary Portland cement (OPC) and pumice aggregate in Adama town-Ethiopia. This study aims to improve the performance of conventional hollow concrete blocks through the use of alternative aggregate (pumice-scoria blend). A two-phased experimental study was conducted where initially the physical properties of the two aggregates were tested and an appropriate pumice-scoria blend was investigated. The result from the first phase of the study showed that the conventional pumice aggregate is poorly graded, while the new blend containing 60% coarser pumice and 40% finer scoria (P60-S40) is a well-graded aggregate. In the second phase of the study, two groups of HCB samples were produced using conventional and blended aggregates with 1:8 cement to aggregate and 1:6 water to cement ratios. Samples were cured and tested for their standard properties at the age of 28 days as per ASTM C140/C140M–20 procedures. The test results showed compressive strength, density, and water absorption of conventional blocks as 1.56 MPa, 1066.60 kg/m^3, 26.17%, respectively; whereas the corresponding result for the improved block was 3.51 MPa, 1181.85 kg/m^3, and 20.57%. As noted from the result, the use of P60-S40 improved the compressive strength of conventional HCB by more than 100%. And from the result, it can be concluded that HCB producers in Adama town can improve the strength of the conventional HCB by using P60-S40 aggregate instead of the poorly graded conventional pumice aggregate.

Keywords: Conventional hollow concrete block; improved hollow concrete block; pumice; scoria; blended aggregate.

1. Introduction

Modern housing construction in Ethiopia uses hollow concrete block (HCB) as walling material. As per Ethiopian standard, there are four classes of HCB namely: class A, B, C, and D. Class A to C are used for load-bearing walls while class D is used for non-load bearing walls [1]. This widely used walling material is produced from ordinary Portland cement (OPC) or pozzolana Portland cement (PPC) and pumice aggregate. Pumice aggregate is conventionally used for HCB manufacturing in Ethiopia, particularly in Adama town. Most HCB producers in Adama town use unprocessed pumice aggregates for HCB production. Many studies mentioned pumice and scoria are volcanic minerals with different engineering applications [2]. These volcanic minerals are used as an aggregate for lightweight concrete and concrete block production. Apart from these natural aggregates, various alternative materials are used as aggregate in concrete block manufacturing. For instance, industrial wastes such as blast furnace slag were used as lightweight aggregate [3]; the test results on the compressive strength, water absorption, and density of these blocks showed a better

mechanical and cost performance as compared to the conventional block produced from conventional materials. Kumar studied the load-bearing capacity and moisture absorption of masonry blocks made of recycled aggregates obtained from concrete and brick along with pozzolanic cementing materials [4]. As per the test results of 28 days compressive strength and density, Kumar confirmed that both results were found to fulfill the minimum standard requirements. Besides, an experimental study was conducted on the performance of concrete blocks produced by partial replacement of natural aggregates (NA) and ordinary Portland cement with glass cullet (GC) or construction demolition aggregate (CDA), and the sewage sludge ash (SSA) respectively [5]. After testing the physio-mechanical properties of the samples, the result confirmed that the block made by partial replacement of OPC with 20% of SSA and NA with over 50% of GC had satisfactory strength. Sabia also studied the performance of load-bearing CB which was produced by replacing all-natural aggregate with recycled aggregates from construction demolition (CD) wastes [6]. The test results of compressive strength at the age of 28 days revealed that blocks made from CD aggregate were weaker than those produced from natural aggregates. A study on concrete blocks produced from geo-polymers, such as fly ash or blast furnace slag showed that the production process consumed less energy and low cost in terms of raw materials [7]. More composites from industrial wastes, such as steel slag, granite waste, building demolished concrete, were used for the production of concrete blocks [8].

2. Aim of the study and research questions.

This experimental study aimed to improve the performance of conventional HCB through the use of alternative aggregate. The alternative aggregate is made from pumice and scoria; pumice and scoria are volcanic materials found in many parts of the Ethiopian rift valley including Adama town and its outskirts. The study will answer the following research questions: does the pumice aggregate used in the conventional HCB production (used by the producer in the case study) fulfill ES or ASTM standard requirements? Is the conventional HCB produced from pumice aggregate satisfies ES/ASTM standard requirement? Can we produce an alternative aggregate from a blend of pumice and scoria which can improve the performance of HCB relative to conventional HCB?

3. Method and materials

This experimental research was conducted in two phases; the first phase was about the physical characterization of pumice and scoria aggregate aiming to understand their physical properties for a better combination in the blending process. And in the second stage of the experiment, a comparative study on the performance of conventional and improved blocks manufactured from conventional and blended aggregates was conducted. The project area (Adama town) is located in the refit valley where Pumice and scoria are abundantly available. Scoria was collected from quarries nearby to Adama town, while pumice was sampled from the stockpile of local HCB producers. The quarries for pumice and scoria are located at 18km and 8km from the local HCB producers in Adama town. Ordinary Portland cement (OPC) and tap water were used for the production of both conventional and improved hollow concrete blocks.

3.1 Study on the aggregate materials.

The study proposed the combined use of scoria and pumice aggregate for the production of an improved HCB. Before the use of the two aggregates for blending, tests were conducted on the physical properties of the aggregates aiming to understand their properties for a better combination in the blend. Both aggregates were sampled and reduced to test sizes as per ASTM D75 practice and C702 procedure. Physical properties including the grading, average grain size, fineness modulus (FM), dry loose bulk density, and water absorption were determined based on standard procedures as depicted on ASTM [9-11]. The grading, dry loose bulk densities, and water absorption test results were summarized and compared with ASTM C127, C331, C331M requirements for light aggregates; the comparison is summarized in table 1.1 below.

Figure1.1 Pumice and scoria aggregate, and laboratory tests on their physical properties.

Table 1.1 Comparison of physical properties with ASTM C127, C331, C331M requirements

Sieve size	Gradation (% Passing)			Dry loose bulk density (kg/m3)			Water absorption (%)		
	Pumice	Scoria	ASTM	Pumice	Scoria	ASTM	Pumice	Scoria	ASTM
9.50mm	37.61	4.03	0 - 2	341	785	Max.			
4.75mm	23.94	14.64	0 - 10	410	929	880	23.20	10.90	5 – 25
2.36mm	18.58	24.85	15 - 35	467	965				
1.18mm	10.35	20.83	15 - 35	543	996				
600µm	5.04	13.85	5 - 20	674	1030	Max.	NA	NA	NA
300µm	2.57	10.12	5 - 15	868	1033	1120			
150µm	1.90	6.39	5 - 15	869	1035				
Pan	0	5.30	8 - 20	872	1046				

(NA - not applicable, Max. - maximum)

As per the comparison of dry loose bulk densities of the aggregates with ASTM standard requirements, both pumice and scoria aggregates satisfied ASTM requirements for the lightweight aggregates. In addition, the water absorption properties of both pumice and scoria aggregates are found within the ASTM limits. However, both pumice and scoria aggregates do not comply with ASTM grading requirements for lightweight aggregates. The average grain size or fineness modulus (FM), and the weighted average dry loose bulk densities were computed. Accordingly, the average grain sizes of pumice and scoria were 5.22mm (FM =5.22) and 3.83mm (FM= 3.83mm), respectively. In addition, pumice and scoria have weighted average dry loose bulk densities of 442.16 and 983.59 kg/m^3, respectively.

3.2 Appropriate pumice-scoria blending ratio.

As noted from results on the dry loose bulk density and grading tests, the as quarried pumice is coarser and lighter than scoria. From a structural point of view, it is advantageous to produce a lighter concrete block for the reduction of dead load in the building structure. Hence, to produce lighter HCB, blending was done using coarser pumice and finer scoria in line with their natural gradings. Initially, before planning the blending process, both pumice and scoria aggregates were screened and sorted to different sizes using the ASTM standard sieve sizes. Five trial aggregate blending scenarios were proposed complying with the ASTM grading requirement for LWA (column 3, Table 1.2 below). The five trial blending scenarios (on a volumetric basis) are designated as P30-S70, P40-S60, P50-S50, P60-S40, and P70-S30. In the designation of trial blending scenarios, the letters "P" and "S" stand for pumice and scoria, whereas the number following the letters refers to their percentage (For instance P30-S70 stands for 30% pumice and 70% scoria within their size ranges). The minimum percentage of pumice in the blend (30%) was decided based on the sum of the minimum range of sizes specified on the ASTM suggested grading shown in table 1.2 below. Those five trial blends contained 30%, 40%, 50%, 60%, and 70% of coarser pumice aggregate retained on sieves 9.5mm, 4.75mm, 2.36mm,1.18mm, and 70%,60%,50%,40%, and 30% of fine scoria aggregate retained on sieves 600µm, 300 µm, 150 µm and pan respectively. All five blending scenarios were checked for complying with ASTM C331 /C331M−17 grading requirement.

Table 1.2 Blending scenarios and ASTM-C331/C331M–17 suggested grading requirement

Aggregate type	Sieve size	ASTM suggested grading	Percentage pumice - scoria in the blend (%)				
			P30-S70	P40-S60	P50-S50	P60-S40	P70-S30
Pumice	9.5mm	0-2	0	1	1	2	2
	4.75mm	0-10	0	7	8	8	10
	2.36mm	15-35	15	16	21	25	29
	1.18mm	15-35	15	16	20	25	29
Scoria	600µm	5-20	20	18	16	11	8
	300 µm	5-15	15	13	12	11	7
	150 µm	5-15	15	13	12	10	7
	Pan	8-20	20	16	10	8	8

Using OPC and the trial blended aggregates, five groups of 15cmx15cmx15cm concrete cubes were molded with 1:8 cement to aggregate and 1:5 water to cement ratios. After proper curing, the 28 days compressive strengths of three cubes from each group were tested, and the results of each unit and their average compressive strengths are summarized in table1.3 below.

Figure 1.1 Testing compressive strength of cube samples

Table 1.3 Compressive strength of cubes produced with five aggregate blending scenarios

Cube sample no	Compressive strength of cube units produced with trial aggregates (KN/mm2)				
	P30-S70	P40-S60	P50-S50	P60-S40	P70-S30
1	7.00	7.20	7.64	8.39	8.17
2	7.29	8.30	8.23	8.22	8.02
3	7.76	7.99	8.39	8.32	7.92
Average	7.35	7.83	8.09	8.31	8.04

Comparing the compressive strengths of cubes produced with the five trail blending scenarios, the blend with 60% coarser pumice and 40% finer scoria(P60-S40) gave the maximum compressive strength for the constant cement-aggregate and water-cement ratios. Accordingly, P60-S40 is chosen as the appropriate binary aggregate that could be used for the production of HCB.

4. Production of hollow concrete block.

This section presented the production and tests on conventional and improved HCBs produced from conventional pumice aggregate and the blended aggregate respectively. Two groups of HCBs (each group consisting of six- HCB units) were manufactured using OPC. The first group of HCB was produced using OPC and unprocessed pumice aggregate, while the second group was manufactured from OPC and P60-S40 (blended aggregate).

4.1 Hollow concrete block production and curing.

Although a suitable cement to aggregate ratio has to be obtained by testing trial cement to aggregate ratios, the study used a constant 1:8 ratio which is used by the local HCB producer. In addition, constant water to cement ratio of 1:6 was used where the moisture content of the mix was continuously checked if adjustments were required to compensate for the amount of water added. The pre-blended aggregates were mixed in a dry state using a mechanical mixer; water was added and the mechanical mixing process continued until a uniform mixture was obtained. The uniform mixture was placed into the block molding machine having an internal dimension of 40cm x 20cm x 15cm and mechanically vibrated for adequate compaction. After adequate compaction of samples, blocks were de-molded and laid in the open air for curing by spraying water twice a day for 28 days.

4.2 Hollow concrete block tests.

At the age of 28 days, each block specimen was checked and tested for the standard properties. Those properties include deviation from standard dimensions, density, water absorption, and compressive strength. The sampling and testing were conducted as per ASTM and Ethiopian standard (ES) methods including sampling and testing concrete masonry units ASTM standards [9-15], ES 2310:2005 [16-17], and laboratory manual for testing materials [18]. Regarding the number of samples to be tested, both ASTM and ES specified three full-sized units with similar configuration and dimensions except for compressive strength and nominal dimensions. The test results would be reported as the average of results from three samples. But for checking deviations from the standard dimension, all blocks (six blocks from each group) were checked and the results were reported as the average of all. Besides, the Ethiopian standard (ES 2310:2005) specified the number of samples to be tested for compressive strength is six units, and the test results would be reported as the average of results from six samples.

Figure 1.4 HCB Production and testing in a laboratory

4. Results and discussion.

The study on the performance improvement of the hollow Concrete block was conducted in two phases. In the first phase the appropriate pumice–scoria blending ratio was determined which could be used for HCB production in the second phase. Before planning for the aggregate blending, the properties of unprocessed pumice and scoria were investigated. Series of tests were conducted to determine the grading, average grain size (fineness modulus), loose dry bulk density, and water absorption properties of pumice and scoria. As per the dry loose bulk density and water absorption test results and ASTM suggestions, both aggregates were classified under lightweight aggregates with poor grading properties. Both pumice and scoria did not fulfill ASTM grading requirements for lightweight aggregates used for HCB production. The average grain size of pumice was found to be larger than that of scoria implying pumice is relatively coarser than scoria. In addition, scoria was denser with less water absorption property as compared to porous pumice. Based on the average grain sizes and dry loose bulk density of the two aggregates, blending scenarios were suggested following their natural grading. Accordingly, five trial blending scenarios were proposed from coarser pumice and finer scoria, all blends fulfilling ASTM grading requirements.

The five trial blended aggregates were used to produce concrete cubes using OPC cement, 1:8 cement to aggregate, and 1:5 water to cement ratios. Three units of 15cmx15cmx15cm cubes were molded for each aggregate blending scenario where the compressive strengths of cubes were tested at the 28 days age. Test results on the compressive strength of cube samples revealed that a blend of 60% coarser pumice and 40% finer scoria (P60-S40) gave the maximum compressive strength. Accordingly, the blended aggregate coded with P60-S40 was selected as the appropriate binary aggregates to be used for the improved HCB production in phase two.

In the second phase of the experimental study, two groups of HCBs were manufactured, one group using conventional pumice aggregate and OPC, and the second group from P60-S40 blended aggregate and OPC. Following the standard production and test procedures for concrete block, HCB samples were molded, cured, and tested for the four standard properties at the age of 28days. According to the test results except for compressive strength, conventional HCB satisfied the all-Ethiopian standard (ES2310:2005) requirement for non-load bearing HCB. But it does not satisfy the minimum compressive strength requirement for non-load bearing HCB as per Ethiopian standard (2N/mm2). However, the improved HCB produced with the blended aggregate fulfilled the all-Ethiopian standard (ES2310:2005) requirement for non-load bearing HCB. Moreover, the compressive strength of improved HCB was found to be 2.25 times the compressive strength of conventional HCB. The pumice aggregates used by the local HCB producer in Adama town do not comply with ASTM-C331/C331M–17 grading requirement for lightweight aggregates; this is the major reason for the lower compressive strength of the conventional block. The summary of test results for the conventional block (HCB-0) and improved block (HCB-1), and comparison of results with American (ASTM), Indian (IS), and Ethiopian standard (ES) values are presented in table 1.5 below.

Table 1.5. Summary of test results compared with American, Indian, and Ethiopian standards

Physical properties	HCB type	Average results	Specification values for non-load bearing HCB		
			ASTM	IS	ES
Compressive strength (N/ mm2)	HCB-0	1.56	3.50	1.5	2.0
	HCB-1	3.51			
Density (Kg/m3)	HCB-0	1066.60	< 1682	1000-1500	600-900
	HCB-1	1181.85			
Water absorption (%)	HCB-0	26.17	30-40	10	30
	HCB-1	20.57			
Min. web thickness (mm)	HCB-0	28	12.7	25	25
	HCB-1	28			
Min. face shell thickness (mm)	HCB-0	30	12.7	25	25
	HCB-1	30			
Deviation from nominal dimension (mm)	HCB-0	0	± 3.18	± 3 to ±5	± 5
	HCB-1	0			
Percentage of solid Volume	HCB-0	63	NA	50-75	50-75
	HCB-1	63			

5. Conclusion

From the physical characterization tests on the conventional pumice aggregate, the local HCB producers in Adama town are using poorly graded aggregate that does not fulfill ASTM suggested grading. As a result of the poor aggregate grading, the compressive strength of conventional HCB produced using this unprocessed aggregate is much lower than the minimum standard requirement. Hence, the study suggests processing the as quarried pumice aggregate before use in the conventional HCB production is required. However, the use of pumice-scoria blended aggregate (P60-S40) is much preferable as it improves the compressive strength of HCB by more than 100%. And the study concluded that HCB producers in Adama can improve the strength of their product, HCB, by using either a blended pumice-scoria (P60-S40) aggregate without much processing or a processed pumice aggregate fulfilling ASTM grading requirements.

References

1. Kahsay, T. (2014). Study on the Effectiveness of Quality Control for the Production of Reinforced Concrete and Hollow Concrete Blocks (Doctoral dissertation, Thesis. Addis Ababa University, Ethiopia).
2. Lemougna, P.N., Wang, K.T., Tang, Q., Nzeukou, A.N., Billong, N., Melo, U.C. and Cui, X.M. (2018). Review on the use of volcanic ashes for engineering applications. Resources, Conservation and

Recycling, 137, 177-190.
3. Mahoutian, M., & Shao, Y. (2016). Production of cement-free construction blocks from industrial wastes. Journal of cleaner production, 137, 1339-1346.
4. Kumar, B. V., Ananthan, H., & Balaji, K. V. A. (2017). Experimental studies on cement stabilized masonry blocks prepared from brick powder, fine recycled concrete aggregate, and pozzolanic materials. Journal of Building Engineering, 10, 80-88.
5. Chen, Z., Li, J. S., & Poon, C. S. (2018). Combined use of sewage sludge ash and recycled glass cullet for the production of concrete blocks. Journal of cleaner production, 171, 1447-1459.
6. Sabai, M. M., Cox, M. G. D. M., Mato, R. R., Egmond, E. L. C., & Lichtenberg, J. J. N. (2013). Concrete block production from construction and demolition waste in Tanzania. Resources, Conservation and Recycling, 72, 9-19.
7. Petrillo, A., Cioffi, R., Ferone, C., Colangelo, F., & Borrelli, C. (2016). Eco-sustainable Geopolymer concrete blocks production process. Agriculture and agricultural science procedia, 8(8), 408-418.
8. Raghavan, V., Prakash, Senthamizhkumaran, Sudharsan (2017). A study on strength characteristics of building blocks using industrial wastes. Journal of Emerging Technologies and Innovative Research. JETIR (ISSN-2349-5162), 4, 108-111.
9. ASTM, C. (2017). Standard Specification for Lightweight Aggregates for Concrete Masonry Units. C331/C331M−17.
10. ASTM, C. (2007). Standard Test Method for Density Relative Density (Specific Gravity) and Absorption of Coarse Aggregate ASTM 127.
11. ASTM, C. (1992). 127-88. Test method for specific gravity and absorption of coarse aggregate. USA: Annual Book of ASTM Standards. ASTM C127-88.
12. ASTM, C. (2003). Standard specifications for evaluation of natural pozzolans. ASTM C618.
13. ASTM, C. (2010). American society for testing and materials; Hollow load-bearing concrete masonry units. ASTM C90-70.
14. ASTM, C. (2008). Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units. ASTM C140/C140M–20.
15. ASTM, C. (2011). Standard Specification for Non-loadbearing Concrete Masonry Units. ASTM C129-11.
16. ES, (2005). Ethiopian standard mixing water for concrete. ES 2310:2005.
17. ES, (2001). Ethiopian standard specification for concrete masonry units. ES 596:2001.
18. Abebe Dinku, (2002). Construction Materials Laboratory Manual, Addis Ababa University Press.