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Evaluation of Strength and Durability of Hollow Concrete Blocks Prepared by Using Concrete Waste Materials from Adama, Ethiopia.

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ABSTRACT
Hollow Concrete Blocks (HCBs) are manufactured by using coarse aggregate, fine aggregate, cement and water. We have made an attempt to replace conventional materials by concrete waste materials (CWMs) in the manufacture of HCBs. In this present work, we report the manufacture of HCBs by the replacement of coarse aggregates with 10% and 20 % of CWMs which were obtained from the construction site at Adama city, Ethiopia. The samples were cured for a curing period of 14 days and tested for their compressive strength, block density, water absorption, weight loss, dimension, tolerance and moisture movement. The results observed were found to be positive in response compared to the existing HCBs, with 40 % increase in compressive strength, 16% reduction in water absorption and 11% increase in weight for the sample with 20% of CWMs. It was also observed that there is no difference in block density and moisture movement which indicates that shrinkage is almost similar to that of existing HCBs. The major component of the manufactured HCBs was found to be calcite as confirmed by XRD patterns. The HCB can use be used for the construction purpose.

Keywords: Hollow concrete block, Light weight aggregate, concrete waste materials, Compressive strength, Calcite

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I. INTRODUCTION

Hollow concrete blocks (HCB) have been widely used in the modern construction industry because of their easy production. In addition, HCB consumes lesser time period for the manufacturing process when compared to the processes involved with other types of bricks (soil stabilized, red bricks). The cement-aggregate ratio in concrete blocks is 1:6. Proper aggregate composition and control have to be taken care of during proportioning of ingredients which contains three parts, these are, selection of suitable ingredients, determination of relative quantities and production processes such as batching, mixing, transporting, placing, compaction and curing. A hollow block is defined as one having one or more large holes or cavities which either pass through the block (open cavity) or do not effectively pass through the block (closed cavity) and having the solid smaterial between 50 and 75 percent of the total volume of the block calculated from the overall dimensions.

It is understood form the past work that building materials account for about half of all materials used and about half the solid waste generated worldwide. These materials have an environmental impact at every step of the building processes such as, extraction of raw materials, processing, manufacturing, transportation, construction and disposal at the end of a building useful life. The rapid increase in the construction works contributes not only to a depletion of natural aggregate but also leads to difficulties in finding suitable landfills. Concrete waste is generally found among construction waste, production waste and waste returned in ready mix trucks and with the development of concrete construction industry its amount will only grow. The reuse of concrete could help not only in the reduction of the concrete landfill but also in limiting the exploitation of the natural resource. The transport cost for building materials could be reduced as well. There also exist beneficial reasons for improving the quality of materials which help to extend the life of recycled materials, especially in terms of reducing the environmental pollution effect. Comiche is an Amharic word used for light weight aggregate which is a common name used in HCB manufacturing factories at Ethiopia.

1.2 Background study and literature review

The manufacture of HCB from demolished waste concrete materials was reported [1] and results stated by them fulfils the Rwanda code book standards. Suitability of HCB in terms of physical and mechanical properties by using recycled aggregate and recycled water was reported by the past researchers [15] who stated that the effect of recycled aggregate and water on axial strength was dropped by 20% at 7 days. Therefore, they suggested to use micro silica for the improvement in strength. A comparative study on the compressive strength and production cost of hollow concrete block (HCB) with and without red ash was conducted [2] in Tepi town, Ethiopia and the workers concluded that the compressive strength of the HCB without red ash was greater than the HCB with red ash. But the red ash can be replaced by 30% and after that they found lesser in weight comparatively. The other worker reported that 50% replacement of sand can be used in manufacturing of HCB [3]. The mathematical model for predicting the compressive strength and water absorption of concrete blocks developed and tested for different mix proportion of aggregate and sand for varying the strength properties [10]. The model developed by them found to be adequate. The compressive strength of double H concrete block masonry prisms was also studied in the past [4]. They reported the effects of mortar strength, grouting, and grout strength on the compressive strength of the prism. HCBs were manufactured by using 75% replacement of recycled concrete aggregates [5] and the authors concluded that 35-40% manufacturing cost was `reduced. The relationship between HCB and cylindrical compressive strength [6] can be determined by using the following equations,

$\mathbf{f_b=0.72f_c + 3.34}$ ---(1) and $\mathbf{f_b=1.5f_c^{0.8271}}$….(2)

where fb and fc are stress in block and cylinder respectively

Equations 1 and 2, valid for sample compressive strength range from 10 N/mm² to 45 N/mm². The experimental work [7] was conducted to study the load carrying capacity of HCB Masonry wall and crack patterns in the masonry wall and the results revealed that the strength of the wall constructed with hollow concrete block gives the less strength as compared to brick masonry but with lesser cost of construction. The performance of HCBs manufactured by using foundry sand and stone dust as a partial replacement of fine aggregate was reported [8] and the investigation revealed the fact that HCBs exhibited good strength to use the blocks as load bearing up to two stories. The strength of blocks was observed to be 21.11 N/mm^2 at 28 days. Recycled construction materials and demolition waste can be used in manufacturing of HCBs and the blocks can be used for non-load bearing walls was also reported [14].

The main aim of the present research is to study the mechanical and durability properties of HCBs which are casted from the locally available concrete waste materials (CWMs) recovered from the construction sites at Adama, Oromia region, Ethiopia.

II. Materials and Methodology

The concrete waste materials were collected from the construction sites at Adama, Oromia region, Ethiopia. A total number of 90 samples were casted to get the HCBs. The concrete waste material was crushed into smaller size and subjected to sun drying for 48 hrs. This sample was selected which has been passed through 10 mm sieve, as the net thickness of block is 30 mm. The mixed proportions of cement and light weight aggregates used for casting samples are in the ratio of 1:11 with constant W/B = 0.6. These materials are homogeneously mixed under dry condition, followed by addition of portable water for uniform blending of all the components such that free water being not visible, as a little additional of excess water will causes the mix to be friable and it will cause difficulty in the immediate withdrawal of the mould. This mixture is molded using machine operator, and then sample HCB blocks are subjected to 14 days of curing process (Fig-2). Table -1 gives the amount of quantity used for casting CWM 00, CWM 10 and CWM 20 HCBs All the tests were done as per IS and EBCS code.

Table 1 Composition of materials used for casting HCB Samples

Material	Standard	10 %	20%
	CWM 00	CWM 10	CWM 20
Cement 32.5 PPC (Kg)	50	50	50
Comiche (< 10 mm) (Kg)	550	495	440
Waste material (< 4.75) (Kg)	0	27.5	55
Waste material (> 4.75 < 10mm) (Kg)	0	27.5	55

Portable water (L)	30	30	30

2.1 Size of HCB

The size of the HCB block is as per EBCS code[11], with length of 400 mm, width of 150 mm and depth of 200 mm and internal thickness of 30 mm. The dimensions of prepared HCB are presented in Fig -1.

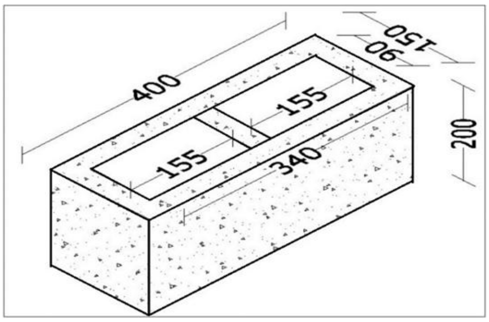

Fig -1. Dimensions of HCB

Fig-2 (a) Concrete waste material, (b) Light weight aggregate (c) Dry mixture of CWM and LWA (d) molding of HCBs (e) HCB after casting (f) HCB for Curing.

III. EXPERIMENTAL WORK

Test results and discussion

The specific gravity, bulk density and water absorption of construction waste materials and light weight aggregates are experimentally determined and values are listed in the table 2.

Table 2: Properties of raw materials

Property	Construction waste material	Light weigh aggregate
Specific gravity	1.023	1.65
Bulk density	1.045 kg/ m^3	0.451 kg/ m^3
Water Absorption	34.3 %	62.7 %

3.1 Compressive strength of HCB

Eight samples were selected randomly from the casted samples to study the compressive strength of HCBs. The samples were tested at the age of 14 days, the samples were capped with 1:3 cement mortar of 3 mm thickness, so that pressure applied shall be uniform on the blocks [12]. The samples were allowed to dry for 24 hours before testing. The load is applied gradually at a speed of 5 N/cm^2/sec until the specimen fractures. Then the compressive strength is calculated by using the equation (3);

Compressive strength of specimen = (Load / Area) ……..(3)

The obtained compressive strength values for all the eight samples are tabulated as shown below (Table 3)

Table 3 Result of compressive strength

Sample size	CWM 00	CWM 10	CWM 20
	Stress(N/mm^2)	Stress(N/mm^2)	Stress(N/mm^2)
1	1.56	1.5	1.42
2	1.33	1.4	2.81
3	1.7	1.16	2.13
4	1.7	1.44	2.15
5	1.47	1.22	1.73

6	1.36	1.36	1.98
7	1.22	1.73	1.87
8	1.33	1.78	2.15
Avg	**1.458**	**1.448**	**2.03**

3.2 Water Absorption test

Table 4. The parameters obtained from water absorption tests on HCBs.

samples	Weight of saturated HCB(Kg)	Weight of Dried HCB (kg)	% of water absorption	Weight of saturated HCB(Kg)	Weight of Dried HCB (kg)	% of water absorption	Weight of saturated HCB(Kg)	Weight of Dried HCB (kg)	% of water absorption
	CWM 00			CWM 10			CWM 20		
1	9.54	7.71	23.74	9.89	8	23.63	10.13	8.345	21.39
2	9.165	7.335	24.95	10.08	8.28	21.74	9.97	8.205	21.51
3	9.88	7.92	24.75	9.715	7.855	23.59	10.69	8.915	19.91
Avg			24.48			22.98			20.93

It's a measurement of voids. Three samples were randomly selected for each percentage to study the water absorption of HCBs. The specimens were completely immersed in water for 4 days (as shown in figure 3) with temperature being maintained at 27± 2°C, later the samples were removed from the water and damp cloth are used to wipe the blocks and samples were weighed. Later all specimens were dried in a ventilated oven at 100 °C for 24 hours and again the samples were weighed. The average weight for the samples were evaluated and tabulated (Table 4).

Percentage of water absorption is calculated using equation (4)

Percent of water absorption = $\frac{A-B}{B}$ **x 100** …(4)

A = saturated block mass

B = dried block mass

Fig-3 HCB immersed in water for water absorption test.

3.3 Density of HCB

Table 5. The parameters obtained from density tests on HCBs

Samples	**Mass of (Kg)**	**Volume (m^3)**	**Density (Kg/m^3)**	**Mass of (Kg)**	**Volume (m^3)**	**Density (Kg/m^3)**	**Mass of (Kg)**	**Volume (m^3)**	**Density (Kg/m^3)**
	CWM 00			**CWM 10**			**CWM 20**		
1	7.83	0.00725	1078.8	8.13	0.00725	1121.7	8.415	0.007	1201.5
2	7.445	0.007165	1039.2	8.33	0.00704	1183.3	8.295	0.00734	1129.8
3	8.045	0.007084	1135.7	7.975	0.00678	1176.3	9.015	0.00718	1254.3
Avg			**1084.6**			**1160.4**			**1195.2**

Randomly selected three samples of HCBs from each percentage varying with CWM blocks were weighed [13] and weight of each samples were noted down (Table 5), later the samples were dried in oven at constant temperature 105 °C. Later blocks where cooled to the room temperature, the dimensions of each block were measured to the nearest millimeter.

$$\text{Density}= \frac{\text{mass of block in kg}}{\text{volume of specimen in cm}^3}\times 10^6\ kg/m^3 \quad \dots (5)$$

3.4 Weight Measurement

Average of three samples were considered to measure the weight of samples to know the difference in weight of HCBs, which helps to know the dead weight of wall coming on structural elements such as beams and slabs. The weights of HCBs are presented in Table 6.

Table 6 Weight of HCBs

	CWM00	CWM10	CWM20
Sample	**Weight(kg)**		
1	7.83	8.13	8.41
2	7.45	8.33	8.295
3	8.045	7.98	9.015
Average	**7.78**	**8.15**	**8.57**

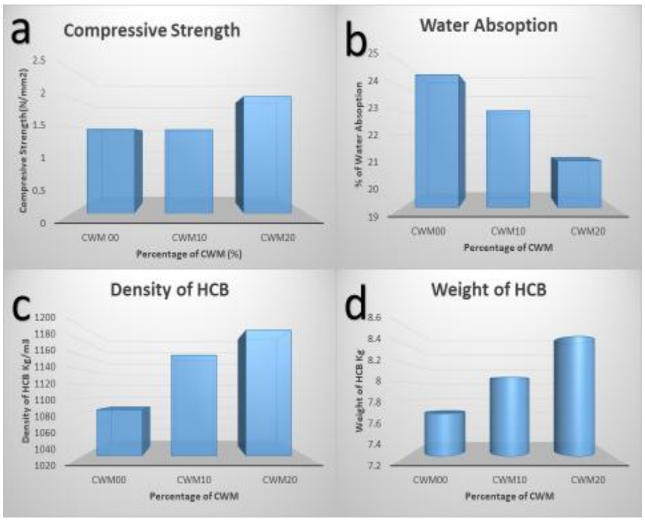

Fig- 4. Plots of compressive strength, water absorption, density and weight of as synthesized HCBs versus percentage of CWM.

3.5 Measurement of dimensions of HCBs

Randomly ten samples were selected as per IS code book to measure the dimensions of each HCB of each percentage variation of CWM. The measurement is done using non extendable ruler nearest to 1 mm accuracy and the results are shown in table 7.

Table 7. Dimensions of HCB Samples

Samples	**CWM 00 Dimensions in cm**			**CWM 10 Dimensions in cm**			**CWM 20 Dimensions in cm**		
	L	**W**	**H**	**L**	**W**	**H**	**L**	**W**	**H**
1	39.6	15	19.5	39.8	14.9	19.8	39.7	15	19.7
2	39.7	14.7	19.6	39.6	14.8	19.8	40	14.9	19.3
3	39.8	14.8	19.7	39.7	14.9	19.7	39.9	14.7	19.4
4	39.9	14.8	19.8	39.6	14.7	19.6	39.8	14.8	19.5
5	40	14.9	19.85	39.9	14.7	19.5	39.5	14.9	19.5
6	39.7	14.8	19.8	39.8	14.7	19.8	39.6	14.8	19.8
7	39.6	15	20.5	39.9	14.8	19.8	39.7	14.7	19.8
8	39.7	14.7	20	39.7	14.9	19.9	39.8	14.9	19.6
9	39.8	14.8	19.5	39.6	14.7	19.6	39.5	14.8	19.7
10	39.8	15	20	39.8	14.8	19.5	39.6	15	19.9
Average	**39.76**	**14.85**	**19.83**	**39.7**	**14.8**	**19.7**	**39.7**	**14.9**	**19.6**

3.6 Moisture Movement of HCB

Table 8. Moisture Movement of HCB

Samples	**CWM 00**				**CWM 10**				**CWM 20**			
	Wet		**Dry**		**Wet**		**Dry**		**Wet**		**Dry**	
	L1	H1	L2	H2	L1	H1	L2	H2	L1	H1	L2	H2
1	39.8	19.6	39.8	19.5	40	19.9	39.7	19.7	40	19.9	39.7	19.7
2	39.9	19.9	39.8	19.2	40	20	40	19.6	40	20	40	19.6
3	40.3	19.9	40	19.8	40	19.7	39.8	19..6	40	19.7	39.8	19..6
Average (L2-L1)	**0.133**				**0.2**				**0.133**			
Average (H2-H1)	**0.3**				**0.133**				**0.233**			

Moisture movement test is conducted as per IS code. The test results are presented in table 8

XRD pattern of HCB

The 2θ values and the respective Miller indices appeared around 23°(012), 29°(104), 39°(110), 47°(018) and 48°(116) are delegated to calcite phase which was found in all the three concrete blocks CWM 00, CWM 10 and CWM 20 without much change in the peak intensities. Thus the major component of the manufactured HCBs was found to be calcite as confirmed by XRD patterns. The major peaks of calcite (calcium carbonate) as revealed by the earlier reports were found in all the three samples of HCBs.

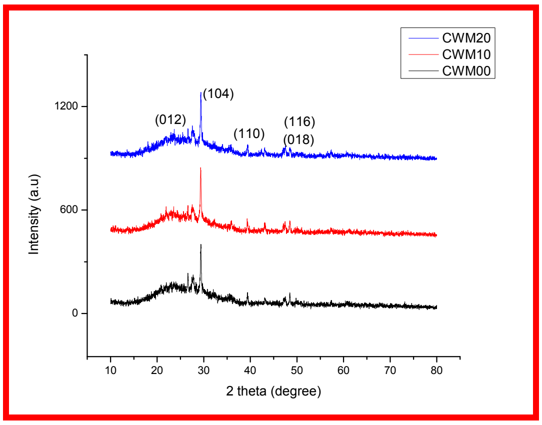

Fig-5. XRD patterns of as prepared HCBs

IV. DISCUSSION

Compressive strength

The strength of HCB block CWM 00 was found to be 1.458 N/mm^2 which is 27.1% less than the strength as per standards in IS and EBCS. This could be attributed to poor manufacturing process and because of using light weight aggregate (Pumice). But strength of HCB block CWM 20 found to increase up to 40% when compared to CWM 00 as presented in Fig -4a. In addition, HCB block CWM 20 satisfied the IS and EBCS requirement for non- load bearing structures.

Water absorption

Fig -4b shows the variation of water absorption of HCB against percentage of CWM [9]. It was observed that water absorption of CWM 00 exhibited 24.48 % efficiency while that for CWM 20 was 20.93%. This observed water absorption for CWM 20 is found to be 16 % less than standard sample which confirms superior durability property of HCB block with 20% CWM. The reduction in water absorption is due to the material property of CWM which can be observed from table 4.

Density of HCB

From the results obtained (Fig -4c,) the density of CWM 00 was found to be 1084.6 Kg/m^3 whereas that of CWM 20 was 1195.2 Kg/m^3. This is because, CWM is higher in density compared to aggregate used. It is concluded that there is 10% increase in the density for CWM 20 when compared to standard HCB block.

Weight Measurement

Weight measurement study on HCB blocks revealed 10% increase in weight on varying the percentage of CWM from 0 to 20 in synthesized HCBs. The weight of HCB CWM 00 was found to be 7.78 Kg which is lower that of 8.57Kg for CWM 20 as depicted in Fig -3d. The similar result was observed in the variation of densities of block too. This confirms that increase in density of material also increase in weight of the blocks confirming the effective packing of components of HCBs

Dimension and Tolerance Measurement

The measurement of dimension and tolerance revealed a fact that there was no much variation in their values (Table 7) compared with the reference sample. All the HCBs satisfied the standard code requirements.

Moisture Movement of HCB

From Table 8, it is observed that there are changes in moisture movement along the length of the block but on height, 30% reduction in moisture movement of CWM 20 compared to CWM 00 was recorded. This is due to less porous nature of HCB CWM 20.

V. CONCLUSION

A study on the reuse of construction waste materials in the manufacture of medium hollow concrete blocks has been conducted successfully. HCBs were prepared by including 10 and 20 weight percentage of CWMs in HCBs. The strength of HCB block CWM 00 was found to be 1.458 N/mm^2 which is less than the strength as per standards in IS and EBCS. The water absorption for HCB CWM 20 is found to be 16 % less than standard sample which confirms its superior durability. An increase of 10% density was observed for HCB CWM 20 when compared to standard HCB block. HCB with 20% CWM replacement showed 10% increment in density and weight compared to HCB CWM 00. From the crystallographic point of view all the blocks contained calcite as major element as revealed by XRD study.

The above results confirm that CWM can be used in manufacturing of HCB with the replacement of LWA material up to 20%. Hence the usage of CWM can solve the problem of finding dumping site for demolition and construction waste materials and there by protect the environment.

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