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Performance Evaluation of Hollow Concrete Blocks Made with Sawdust Replacement of Sand: Case Study of Adama, Ethiopia

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ABSTRACT

Hollow concrete blocks (HCBs) are substitutes for conventional bricks and stones in building construction. Experimental testing has been performed on the feasibility of producing HCBs from sawdust (SD). Sawdust is substituted with fine aggregate (pumice) by weight proportions 3, 6, and 9%. Sawdust is treated with tap water to remove foreign materials. Different tests were performed on blocks in order to find the effect of sawdust and to confirm whether blocks produced will satisfy the minimum acceptable standards. Different tests were conducted on the samples for 21 days as in Ethiopia to reflect the pratical application. Compressive strength of sawdust with additions of 3, 6, and 9% was 1.17, 0.99, and 0.51 N/mm^2, respectively. Replacement with 9% resulted in a higher rate of water absorption. The density of HCBs was found to be between 633.06 and 638.21 kg/m^3. In light of the results, it is concluded that 3% of sawdust can be optimized for the production of blocks.

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1. INTRODUCTION AND BACKGROUND STUDY

Wood is exploited in the construction industry for residential and public buildings in all parts of the world. Woodworking is done by cutting, drilling, and sanding, which generates waste in powder and coarser form. Wood powder is also generated by wood-dwelling insects such as woodpeckers and carpenter ants. The residue in the form of powder is called sawdust. An increase in unmanaged waste, particularly in developing countries, has heightened environmental concerns. In addition to tackling the pollution problem, recycling waste as a building material can also contribute to a more cost-effective structure. Sawdust has various practical uses. It can be used as a building material in concrete, solid and hollow concrete blocks, ceiling tiles, furniture, plywood etc. [1].

In rural Ethiopia, sawdust is used as fuel and reformed into charcoal briquettes. The construction industry in Ethiopia has skyrocketed over the past two decades, and many middle-class. Ethiopians have typically reached for building blocks due to high prices. Many small carpentry and sawmills have started operations in Ethiopia over the past few decades and are facing challenges when it comes to disposing of this waste. It was observed that sawdust was being deposited in landfills or in uncontrolled outdoor rubbish pits outdoors. This suggests that sawdust is relatively abundant and could increase in the future. There is no clear statistical data on the availability of sawdust in Ethiopia. However, the export volume of sawdust is estimated at 184.93 tons, which was exported in 2018 [2].

The study will aid in reducing the amount of construction material (Pumice) utilized in the production of HCBs. Thus, promoting the optimum utilization of lumber received from nature and facilitating in the campaign for environmental consideration. Additionally, lumber companies will be able to dispose of their waste materials at the same time as generating additional revenue. In the present study, fine powder sawdust is utilized to produce HCBs.

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Several studies have been carried out with rice husk ash, concrete waste, fly ash, blast furnace slag, rubber waste, glass powder and paper waste for manufacture of concrete and hollow concrete blocks [3]. In order to produce concrete with different mixed fractions for the first time [1]; the volume of cement was substituted with sawdust, and noticed a sustainable enhancement in strength properties of concrete. Compressive strength and density properties of sawdust ash and slaked lime mixture with cement substitute were investigated by [4]. A combination of cement/SDA-lime proportions of 90:10 (cement: SDA-lime) was perceived to have the highest strength and the density reduced with an incremental in SDA-lime.

Limestone dust and sawdust have been used in various combinations to prevent brittle failure of bricks [5]. Compressive strength and weight of HCBs were compared for different mixed proportions [6] of sawdust with sand by volume replacement. Accordingly, the addition of 10% sawdust did not meet the minimum strength requirements. This is because sawdust contains a large amount of tannin, which inhibits the internal hydration process and reduces the strength. Blocks were lighter when 10 percent sawdust is added. [7] also investigated the compressive strength, water absorption and thermal properties of sawdust treated with engine oil. The thermal conductivity of the blocks decreased with increasing sawdust content, and the strength decreased with the addition of 10% sawdust. Boob [8] investigated how curing type affects the compressive strength and density of HCBs when replacing sand with sawdust. With 15 % and substituted sawdust, a cement/sand mix of 1:6 demonstrated effective strength properties compared to sprinkling, the gunny bag method is found to be more efficient. For the production of HCBs, Albera [9] used a different volume ratio to replace sawdust with sand. According to his results, an optimal replacement rate of 15% can be used for strength, but an increase in water absorption was also observed. Recent studies has been done on Fly ash-based GPC which has exceptional compressive strength, making it ideal for structured applications [10]. A Study on roof tiles using metakolin with different percentages of EPS, sodium silicate and flexi cool coating paint was studied by Raheem and Sulaiman [11] .The researcher suggested 20% metakolin has higher strength compared to ordinary tile, which is 9.1% and 39.6% in terms of compressive strength and transverse breaking strength.

Furthermore, several studies were performed using sawdust ash as a substitute for cement and sand to determine density, compressive strength, and water absorption rate of HCBs for 28 and 56 days. According to Raheem and Sulaiman [11], based on their observations, the 28-day strength did not meet the national building code (NBC) standards, but the 56-day strength increased by 20%. For the production of concrete, different proportions of sawdust ash were used as supplementary of cement by weight in order to produce concrete [12]. An amount of 5% has been used as an optimal ratio for achieving optimum compressive strength. Additionally, the addition of sawdust ash to concrete at an early age has a lower strength, but improves significantly up to 90 days, adding sawdust ash to concrete will lead to a reduction in workability of concrete. Concrete blocks with coconut shells (CS) was studied [13] and stated that addition of CS has improved the strength property by 32%. Stabilized blocks made up of rice husk with different percentage is studied by Mousavi [14] and suggested optimum percentage of rice husk was 12% with 1.6 % increment in strength.

Several researchers studied the behavior of concrete, concrete blocks, and bricks mixed with different mix proportions by volume and weight of sawdust, sawdust ash with the combination's other mineral admixtures. The use of sawdust in HCBs is usually limited to 10% due to its organic nature and higher affinity towards the water absorption. It has also been observed that there is an increase in strength for lower percentage up to 10% replacement but not the same for higher replacements. However, it is also observed that addition of sawdust has low strength property at early age but enhances the strength at later stage up to 90 days. In addition, it has good thermal conductivity and decrease in weight of the blocks with increase in percentage of sawdust. To date, there is a dearth of information in Ethiopia, on the application of sawdust on HCBs. Hence, this study aims to works on locally available sawdust from Adama science and technology university (ASTU), Ethiopia production unit to investigate the effect of sawdust in HCBs. This research presents some physical and mechanical properties of HCBs of different mix proportion of 3, 6 and 9% by volume. This percentage is selected to determine the optimization from the previous study and utilize the large quantity of sawdust and reduce the usage of natural resource fine aggregate. Due to limited laboratory resources, chemical composition of materials and microscopic studies could not be conducted. It is observed that the usage of sawdust by volume replacement will have impact of the quantity of usage in sawdust compared to weight replacement. In this research, in order to reduce the weight of HCBs and increase the quantity of sawdust and reduce the environmental dumping problem, we have used sawdust by weight replacement and overcome the workability problem with an increase in the quantity sawdust. Sawdust was pre-soaked for 30 minutes before in use.

2. MATERIALS AND METHODOLOGY

To investigate the effect of sawdust on Hollow concrete blocks, 63 samples were casted with 3, 6, and 9% of sawdust, replacing sand with mixing ratio of 1:8 (cement: sand). The samples were tested to study the mechanical and durability properties of HCBs for 21 days. It is observed the sawdust has a high-water absorption capacity when soaked for 30 minutes. The water absorbed by the sawdust during mixing and curing time will releases its moisture content to the surrounding medium and act as an internal curing during the hydration process once curing of the blocks is stopped through external. This keeps the blocks to satisfy the both industrial and codal requirement indirectly by curing the samples for 21 days. 21 samples were taken from the local factory for comprative studies. Initially the material properties of cement, aggregate and sawdust are examined according to Ethiopia Standard Agency [15]. Table 1 summarizes the quantity of materials required to produce HCBs. SD indicates sawdust and 0 indicates percentage of sawdust.

2. 1. Properties of Materials

32.5 grade Portland Pozzolana cement brand produced by Ethio cement is used as binding materials for the production of blocks. Pumice and scoria are commonly used for the production of HCBs in Adama city, Ethiopia. This research only uses pumice as an aggregate, available from Mikiyas Concrete Block Factory at Kebele 14, Adama City to produce HCBs. To compare the results directly, all blocks were made with the same sawdust and pumice stone (see Figure 1). The properties of sawdust and pumice are summarized in Table 2.

From Figure 2, it is observed that the crushed pumice size is not within the limits of upper and lower limits of ASTM D6913 [16] for coarser grain size. The crushing percentage is high and within the limits which indicates that the most of the aggregate size are smaller than the

(a) (b)

Figure 1. (a) Crushed pumice and (b) Cleaned sawdust

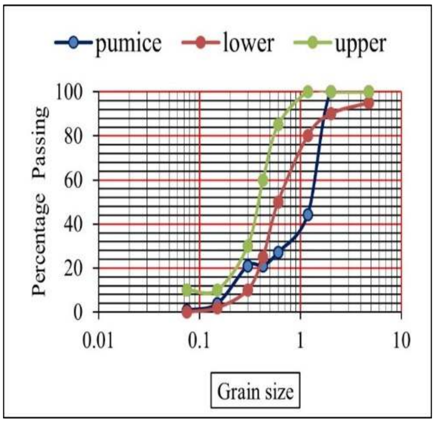

Figure 2. Grain distribution of pumice

requirement needed for the production of blocks. This is due to the random crushing of the coarser aggregates at the production site. Due to the smaller particle size, high-water absorption and an increase in weight of the blocks are to be expected. It is observed that the curve for pumice shows a gradation gap between the particle size, which influences the strength of HCBs [17]. It is also observed the particles size between 0.6 and 0.3. Figure 2 shows flattened horizontal, which indicates that there is absence of grain size. These uneven variations of aggregate size can impact on the strength and density of the block. The grain distribution of sawdust is shown in Figure 3.

TABLE 1. Mix Design of HCBs

Notation	Cement (kg)	Sand (kg)	Sawdust (kg)
SD 0	32.13	226.5	-
SD 3	32.13	219.71	6.79
SD 6	32.13	212.91	13.58
SD 9	32.13	206.11	20.39

TABLE 2. Characteristic properties of pumice and sawdustused in the production of reference and sawdust blocks

Properties	Pumice	Sawdust
Specific gravity (g/cm^3)	1.34	1.34
Density (kg/m^3)	850	365
Water absorption (%)	52	98.87
Cc	10	7.5
Cu	1.225	1.225

2. 2. Mixing, Casting, Curing and Drying Sawdust HCBs

Concrete blocks with dimensions of 400 x 150 x 200 mm (L x W x H), were cast in the Mikiyas Block Factory in Adama Kebele 14, Ethiopia using different sawdust ratios. The pumice is initially crushed to produce fine aggregate without particular attention. Sawdust is washed with water and dried before it used for mixing. Later it is again soaked in water for 30 minutes to absorb maximum water before it is in used for mixing process. According to Portland cement association, it has substantial improvement in properties of concrete through the addition of washed sawdust. The required

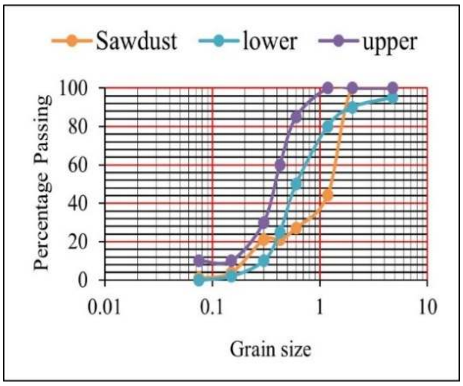

Figure 3. Grain distribution of Sawdust

quantities of materials are subsequently dry mixed until homogeneity is achieved. Depending on the workability of each mix design, a certain amount of water is added until consistency is achieved without special care being required to promote homogeneity. The mixing of the materials took longer with a comparative sample with an increased proportion of sawdust. Similar observation was made by Paramasivam and Loke [1]. The forms were made of wood that was neither damp nor strewn with sand (to ensure easy removal) and were filled with a shovel and compacted in the vibrating device as shown in Figure 4. To reduce evaporation of water and increase the strength of blocks, casting and curing samples were done in the evening. For the initial 12 hours, samples were dried on wooden planks and then placed on a non-absorbent surface and cured by spraying three times a day for 21 days. Once the external curing process is stopped at 21 days, the water absorbed from the sawdust will start releasing to the surrounding medium through channels at microlevel and act as on internal curing. Which indirectly satisfies the standard curing period of 28 days.

2. 3. Methodology The experimental procedures are followed for mechanical and durability properties. All

Figure 4. Methodology for casting of samples

samples are examined for compressive strength, water absorption, density, fire resistance, dimension measurement and tolerance and weight. The samples are tested for various parameters and are done in accordance to ASTM standards [15]. The casting method for preparation of samples is shown in Figure 4.

2. 3. 1. Compressive Strength To determine the compressive strength, randomly six samples from each mix ratio are tested by applying uniaxial compressive load. Steel sheets of 10 mm are attached to the top and bottom to ensure even loading. The specimens are tested under controlled loading at a constant rate of 2.5 mm/min. The crushing strength of the specimens are calculated using according to Equation (1).

$$f_c = \frac{P}{A} \quad (1)$$

where, fc= compressive strength, P = load at which the specimen sustained maximum load and A = net area on which the load was applied.

2. 3. 2. Water Absorption Three samples are taken from each mixture ratio. All samples are oven dried for 24 hours at 115 °C, and their weights are recorded. These samples are then soaked in water for 24 hours while their weight was recorded every two hours for the first six hours and final weight at 24 hours. Equation (2) is used to calculate the percentage of water absorption.

$$\text{\% of water absorption} = \frac{\text{Weight of wet sample} - \text{weight of dry sample}}{\text{weight of dry sample}} \text{ x } 100 \quad (2)$$

2. 3. 3. Density Three samples of each blend portion was oven-dried at 100°C for 24 hours to examine the density propertiesThe samples were gradually brought to room temperature and their weights were recorded. The Density of blocks is calculated using Equation (3).

$$\text{Density of blocks} = \frac{\text{Weight of dried blocks}}{\text{Volume of spciemen}} \quad (3)$$

2. 3. 4. Fire Resistance Three samples of each mixed proportions are open fired for one hour in an uncontrolled temperature by keeping in a practical condition. After firing process, the samples are set to cool and it was observed whether the material bond was lost. The fire resistnce test is depicted in Figure 5.

2. 3. 5. Dimension and Tolerance Measurement Six samples are selected to conduct the test. The measurements of each sample are recorded in all three dimensions and compared to the mold size as filled with wet mix.

2. 3. 6. Weight Measurement Three samples were randomly selected from each and the accuracy

Figure 5. Fire resistance test

weighted to 0.1 g. An average of three sample weights were taken. All blocks with a mixed design are compared to the reference to control weights, the blocks are light/ heavy. The reference HCBs and sadust HCBs are shown in Figure 6.

3. ANALYSIS RESULTS AND DISCUSSION

3. 1. Effect of Compressive Strength on HCBs using Sawdust From the test results, it is observed that 3% sawdust substitute is more effective than the reference sample. Replacement of 3 and 6% of fine aggregate with sawdust, the strength of sawdust blocks is increased by 81 and 52.3 %, respectively. Adding a higher percentage of sawdust decreases the compressive strength. Similar trends were observed in literature [16-20] for a replacement of 2% and higher with sawdust.

(a) (b)

Figure 6. (a) Reference HCBs and (b) Sawdust HCBs

Since saw dust is finer than the pumice and fills the gap between the particles and increases bonding strength at the microscopic level. The strength attained for 3% replacement is below the minimum requirement of 1.8 N/mm^2 according to ASTM standards [15] for class D classification of non-load bearing walls. The sawdust contains bark, which prevents from hydration at initial stage. Hence, there is a reduction in strength at early ages. If curing process is carried out for 28 days as per codal requirement, the strength of blocks is expected to increase, as its observed in several studies [8, 21-23]. In Figure 7, the strength of blocks are reduced at 6% and 9%. From the physical observation of the blocks it is observed, with the addition of higher percentage of sawdust, cement mortar is coated with the ample amount of sawdust (organic material) instead of fine aggregate which impacts in the reduction of the bond between at micro level which makes the reduction in strength of the blocks.

3. 2. Effect of Compressive Strength on Water Absorption Property using Sawdust The average percentage of water absorption of three samples were 17.94, 20.86, 22.12 and 26.60%, for 0, 3, 6 and 9%, respectively and test results are presented in Table 3. These results are consistent with the results reported in

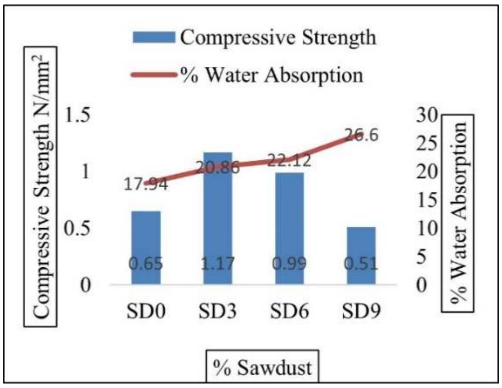

Figure 7. Effect of Compressive strength, Water Absorption Vs Sawdust

TABLE 3. Summary of the experiments

Notation	HCBs	Compressive strength (N/mm^2)	Water absorption (%)	Density (kg/m^3)	Dimension (cm)			Weight (kg)
					L	W	H	
Reference	SD0	0.65	17.94	638.21	39.7	14.8	20.05	7.47
	SD3	1.17	20.86	689.45	40	15.1	20.15	8.068
Sawdust	SD6	0.99	22.12	683.47	39.9	14.9	20	8.002
	SD9	0.51	26.6	633.06	40	15.15	20.25	7.401

literature [19, 21] a significant increase in water absorption was observed. with an increase in sawdust percentages up to 6%. This is due to the high absorption capacity of sawdust at an early stage. The percentage of water absorption decreases with an increased percentage for above 6%, which indicates that the optimum moisture capacity is reached at 6%. It is also obsrved that the compressive strength is maximum at 3 % replacement and gradually decreases thereafter, which is observed in Figure 7. At 3% replacement of sawdust, the water absorption rate is slightly higher than the specified [15]. The effect of reduction in water absorption can ve achieved coating the sawdust with kerosene as its an non-absorbent proerty.

3. 3. Effect of Compressive Strength Versus Density on HCBs using Sawdust From results, for 0, 3, 6 and, 9% the density of blocks are 638.21, 689.45, 683.47 and 633.06 kg/m^3, respectively. [18,19,24] observed a similar effect in blocks as well as in the concrete. Figure 8 shows that the density of HCBs for 3% is higher than that of other percentage replacement. This increase in density of blocks is due to the finer grain size of the sawdust, which is finer than fine aggregate [25], which is similar and is observed in Figure 3. This finer sawdust fills the voids between the aggregates and increases the density of blocks. In contrast, the density of the blocks for reference and other mixed proportions is decreased. The oversaturation of water absorption in the sawdust at the initial stage and the subsequent evaporation during the oven drying of the samples will form the air pockets at the micro level, which lead to the reduction in the density of the blocks. These blocks meets the class D classification according to ASTM standards [15].

From Figure 8, it is observed that the compressive strength decreases with decrease in density of the blocks. With the increased density of blocks, the compressive strength of the blocks for 3% replacement is found to be

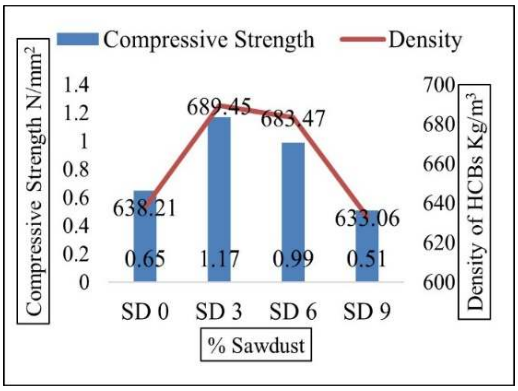

Figure 8. Effect of Compressive Strength Vs Density of HCBs

increased. From this it is concluded that density of blocks has significant effect in compressive strength. Similar results were reported by Omar et al. [24].

3. 4. Effect of Fire Resistance on HCBs with Sawdust This test is done for hollow concrete blocks to ensure that they are non-flammable and is their any reduction in cross sectional dimensions as well to now the effect of bond strength in the matrix if the blocks are burnt for one hour as per the Indian Standard (IS: 1077-1992) [25]. Random tests were performed on three samples from each mixture. Physical observations was done on all the blocks, and it is observed smouldered like charcoal but didn't burn the blocks and slight reduction in size was observed. The edges of the blocks were damaged for the small application of force for all the mix proportions except 3% replacement of sawdust. The damage at the edges was found due to its brittle nature and due to the reduction in bond strength between the sawdust and cement matrix and fine aggregate. Similar observations were reported by Popoola et al. [18] for the blocks made with waste material of papercrete.

3. 5. Effect of Weight on HCBs with Addition of Sawdust In comparision to the reference blocks, the blocks with addition of sawdust are found to be 8% higher. The reference blocks are lighter because combined use of scoria and pumice and their density ranges 500 -1000 kg [26]. The results showed a slight increase in the weight of 0.5 kg for 3 and 6% of sawdust blocks compared to the reference blocks and the same observation was reported by Sunagar and his coworkers [27]. It was expected the weight of blocks would be reduced to its low density when compared to pumice. However, it was found to be higher than the expected, this is due to the finer particles filling the voids leading to the addition of weight to the blocks, as well as the high-water absorption of sawdust. In the presence of 9% sawdust, the weight of the blocks decreased. This is the result of over-saturation of water absorption and the formation of air pockets after curing and creating micro voids in the matrix. The additional weight of blocks can be compansiated with the strength, drop fall and fire resistance properties of the blocks.

4. CONCLUSIONS

The feasibility of HCBs using sawdust, with different percentage replacements of 3%, 6% and 9% by sand has been investigated for various properties.

The research showed that 3% sawdust replacement with sand is effective. The compressive strength of the blocks for 3% is 80% higher than the reference blocks. Water absorption for 3% is found to be 15% higher than the recommended. Density and weight of blocks for reference blocks is 8% lower than sawdust blocks. A 3% replacement of fine aggregate with sawdust is found to be better at fire resistance than any other mix ratios. Dimensions tolerance along width and length are reduced, and the reduction are within the permissible limits. Hence, it is recommended that 3% of the fine aggregate can be replaced with sawdust as it meets the standard requirements. As their strengths are higher than the reference blocks. The use of sawdust with treatment could be further explored to improve water absorption property of blocks.

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Persian Abstract

چکیده

بلوک های بتنی توخالی (HCBs) جایگزین آجر و سنگ های معمولی در ساخت و ساز ساختمان هستند. آزمایشات تجربی بر روی امکان سنجی تولید HCB از خاک اره (SD) انجام شده است. خاک اره با نسبت های وزنی ۳، ٦ و ۹ درصد با سنگدانه های ریز (پومیس) جایگزین می شود. خاک اره برای حذف مواد خارجی با آب لوله کشی تصفیه می شود. آزمایش‌های مختلفی بر روی بلوک‌ها به منظور یافتن اثر خاک اره و تأیید اینکه آیا بلوک‌های تولید شده حداقل استانداردهای قابل قبول را برآورده می‌کنند، انجام شد. آزمایش‌های مختلف روی نمونه‌ها به مدت ۲۱ روز مانند اتیوپی انجام شد تا کاربرد عملی را منعکس کند. مقاومت فشاری خاک اره با افزودن ۳، ٦ و ۹ درصد به ترتیب ۱.۱۷، ۰.۹۹ و ۰.۵۱ نیوتن بر میلی‌متر مربع بود. جایگزینی با ۹٪ منجر به نرخ بالاتر جذب آب شد. چگالی HCBs بین ٦۳۳.۰٦ و ٦۳۸.۲۱ کیلوگرم بر متر مکعب است. با توجه به نتایج، می توان نتیجه گرفت که ۳ درصد خاک اره را می توان برای تولید بلوک بهینه کرد.