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PARTIAL REPLACEMENT OF CEMENT BY COFFEE HUSK ASH FOR C-25 CONCRETE PRODUCTION

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Abstract — Concrete is a mixture of aggregates and binders. From concrete ingredients, the binder and the costliest and environmental-unfriendly element is cement, which is an ecological unsociable process due to the discharge of CO2 gas into the atmosphere and ecological degradation. Coffee husk (CH) has been considered as a category of agriculture by-product; as its quantity rises, the disposal of it is becoming an environmental problem. Hence, this study investigated the suitability of coffee husk ash (CHA) as a partial replacement for ordinary Portland cement (OPC) in conventional concrete production. Initially, CH samples were collected from different coffee treatment centres. The CHA was then ground and its chemical and physical properties were investigated using Atomic Absorption Spectrophotometer method. After that, the pastes containing OPC and CHA at different levels of replacement were investigated. For this purpose, six different concrete mixes with CHA replacement 0, 2, 3, 5, 10, and 15% of the OPC were prepared for 25MPa conventional concrete with water to cement ratio of 0.5 and 360 kg/m3 cement content. The results of the study show that, up to 10% replacement of OPC by CHA achieved advanced compressive strength at all test ages, i.e. 7, 14, and 28 days of age using compressive test machine.

***Keywords*:** Coffee husk ash, compressive strength, concrete, environment

1.0 INTRODUCTION

Cement production is an ecological unsociable process due to the discharge of CO_2 gases into the atmosphere and environmental degradations. Portland cement clinker production is a major source of CO_2 and other greenhouse gases within the contribution of 5% of the annual global atmospheric CO_2 emission [17].

Beyond its adverse environmental impact, cement is also one of the most expensive materials when compared to other ingredients of concrete due to its huge energy consumption for productions. Twenty to forty percent of the total production cost of cement is attributed by energy [17]. On the other hand, residue from coffee processing factories, principally coffee processing effluent and release from the factory, can cause significant pollution to water courses, while those living around the coffee processing stations have complains about pollution of rivers and other associated health impacts [9,18].

Coffee silver skin and spent coffee grounds are the main coffee industry residues, obtained during the beans burning up, and the process to prepare "instant coffee," respectively. Recently, coffee husk ash (CHA) had been tested in some countries for its pozzolanic possessions, which has been found to develop some of the properties of the paste, mortar and concrete-like compressive strength and water tightness in confident substitution percentages and fineness [14].

Once the cherries of coffee beans are harvested, the beans have to be extracted by using either the dry or the wet method [8, 15, 22]. The dry method (natural method) is the oldest and the simplest, which requires little machinery and the process is slow, ranging from three to four weeks. The method involves drying the whole cherry. Coffee husks (CHs), which are produced through these methods, are the major solid residues from the handling and processing of coffee, since for every 1 kg of coffee beans produced, approximately 1 kg of husks is generated [8,11]. The wet method requires the use of specific equipment and substantial quantities of water. Hence, the coffee produced by this method is usually regarded as being of better quality and commands higher prices [11, 20].

Coffee husk ash acts as a pozzolanic material when added to cement because of its silica (SiO_2) and aluminate content, which reacts with free lime released during the hydration of the cement and forms additional calcium silicate hydrate as a new hydration product [12]. This additional calcium silicate hydrate improves the mechanical strength of the cement concrete. The silica content of the ash depends on the nature of soil, its harvest, and flaming temperature of the CH. High temperature helps to remove impurities in CHA. A research conducted on the burning of CH at 400, 500, 600, 700, and 800 ^{o}C identified the suitable burning and seat time to be 600 ^{o}C [12,14]. The elevated temperatures will give superior amount of silica content, but the ensuing silica is in crystalline form that is not in active state.

2.0 STATEMENT OF THE PROBLEM

Making concrete is not an easy task, especially to achieve the desired strength of concrete. Many studies have conducted various techniques to determine the most suitable and environmental-friendly ingredients to produce different types of concrete with acceptable strength. In fact, the strength of concrete relies on the quality of the ingredients used [10].

Among those ingredients, binder and the costliest and environmental-unfriendly element is cement. As a result, the necessity to decrease the sky-scraping cost of OPC in order to supply sustainable and cost-effective structure for the public and private sectors has led researchers to focus on some nearby obtainable construction materials that can be used as fractional substitution for OPC in construction industries. Various studies have performed two-fold blends of OPC with different cementitious materials, such as fly ash, blast furnace slag, silica fume, rice husk ash, CHA, and metakaoline, in making cement composites confirmation to be valuable in meeting of the necessities of environmental-friendly, sustainable and durable concrete structures [19].

Cement production is a common ecological unsociable process due to the discharge of CO_2 gas into the atmosphere. In addition to its release of different gases, its raw material extraction is environmental-unfriendly due to degradation and disruption to the existing natural environment. It indicates that the cement industry contributes to the present worldwide concern, which is global warming.

Beyond its adverse environmental impact, cement is also one of the most expensive materials when compared to the other ingredients of concrete due to its huge energy consumption for productions. 20 - 40% of the total production cost of cement is attributed by energy [16]. The raw materials for the cement production, such as lime, is also being exploited in large amount that may result in running out of them, as it is predicted to happen in some places of the world and in the same way also in Ethiopia [13].

Coffee husk is more often considered waste of agricultural activities; when its mass rises, the disposal of CH becomes an ecological crisis, especially around coffee purple centres. The residue from coffee processing factories, predominantly coffee processing waste matter and release from the plant, can be considerable sources for contamination of water sources and people living around coffee processing stations have complains about pollution of rivers and its associated health impact [9].

This study adopted well-liked and usual agricultural waste materials, CH, to manufacture the ash of CH by using high temperature burning method and applied it to C-25 concrete grades in order to investigate the fresh and hardened concrete properties with specified replacement rate of CHA as partial replacement of cement. The experiment examined the practicability of CHA as partial replacement of cement for concrete material as alternative sustainable construction material.

3.0 OBJECTIVES

The main objective of this study is to determine the suitability of CHA as a partial cement replacement for C-25 concrete grade production.

3.1 SPECIFIC OBJECTIVES

- To check the major chemical composition of CHA.
- To determine the optimal ratio of CHA as partial replacement of OPC for C-25 concrete grade production.
- To examine the engineering properties of C-25 concrete with CHA as partial replacement of OPC.
- To assess economic and environmental benefits of CH as partial replacement of OPC in C-25 concrete grade production.

4.0 MATERIALS AND METHODS

4.1 MATERIAL

4.1.1 COFFEE HUSK ASH (CHA)

Coffee husk was collected from Jimma, Ethiopia and was exposed to sun to eliminate surface moisture and burnt in an enclosed place to limit the amount of ash being blown off at several fixed temperatures and time duration. In this research, CH was burned in a carbonate furnace for two, three, and four hours at 500 ^oC, 550 ^oC and 600 ^oC, to determine the appropriate temperature and duration of it to get the required quality of CHA at JU, CAVM, Post Harvesting Department laboratory. After a general comparison, this study selected 550 ^oC and three hours' duration for the burning process. Then, the ash particle size was reduced to the required level of finesse and sieved with a 63 µm sieve to discard impurities and courser size particles.

4.1.2 COURSE AGGREGATE

This study used 25 mm size coarse aggregate obtained from Kality in Ethiopia.

4.1.3 FINE AGGREGATES

The fine aggregate was obtained from Sodery, Oromia Region, Ethiopia.

4.1.4. CEMENT

Ordinary Portland cement (OPC) was purchased from Megenagna, Addis Ababa, Ethiopia and it conformed to the requirements of ASTMC150/C150M [5].

4.1.5. WATER

Tap water supplied by Addis Ababa municipality to Material and Research Testing Centre of Ethiopian Institutes of Architecture, Building Construction and City Development was used.

4.2 METHODS

4.2.1 BATCHING AND MIXING

In this study, the weight batching method was employed and OPC was replaced partially by the weight ratio of 2, 3, 5, 10, and 15% by CHA. In addition to that, 0% replacement was used as control test for the study.

4.2.2 MIX DESIGN

In this study, ACI 211.1 method was used to specify the quantities and the proportion of concrete ingredients, OPC cement, CHA, Sand, Gravel, and water.

4.2.3 CASTING OF SAMPLES

Concrete cubes sized 150x150x150 mm were casted to assess all hardened concrete properties. Six mixes were prepared for 0, 2, 3, 5, 10, and 15% for replacement of cement by CHA. The concrete was mixed, placed and compacted in three layers, demolded after 24 hours, and kept in a curing tank for 7, 14, and 28 days as required by standards. The slump and fresh density of concrete was determined according to ASTM C143/C143M. [3].

4.2.4 SAMPLE TESTINGS

The compressive strength test of concrete cubes were conducted by using Universal Compressive Testing Machine at /Addis Ababa University/Eiabc, Materials Research and Testing Centre (MRTC)laboratory Addis Ababa, Ethiopia. This was done in accordance to ASTMC-192/C192M [6].

5.0 RESULTS AND DISCUSSIONS

5.1 RESULTS AND DISCUSSION ON CHA AND CEMENT BLEND PASTES

5.1.1 PHYSICAL AND CHEMICAL PROPERTIES OF CHA

CHA has low density (2.72 g/cm^3, as compared to OPC that has a density of 3.15 g/cm^3). The combined chemical composition; $SiO_2 + Al_2O_3 + Fe_2O_3 = 37.1 < 50$ %, which testified the pozzolanic nature of CHA and the loss on ignition (LOI) value for CHA was found to be 27.98%, which was higher than that specified as per ASTM C- 618 specifications [7]. When the burning temperature of CH increased, the major chemical compounds of CHA decreased. It is due to disintegration of the ash to the respective chemical elements. As a result, this study was performed based on 550 ^oC temperature.

CHA was found to have high alkali content, such as K_2O (19.5 %), thus implying high potential for alkali-silica reaction when used in concrete with silica reach aggregates.

CHA had higher values from some common raw materials of cement. For example, SiO_2 of CHA was greater than gypsum, bauxite, iron ore, and lime stone. Al_2O_3 of CHA was greater than limestone, bagasse ash sand, shale, iron ore, and sandy clay. Fe_2O_3 of CHA, in similar manner, was found higher than gypsum, sandy clay, clay, and limestone. This is the same for CaO of CHA, which was greater than bagasse ash, fuel ash, bauxite, sand, shale, iron ore, clay, and sandy. This shows that CHA has the required chemical requirement of raw materials for cement production.

5.1.2 CONSISTENCY OF BLENDED PASTES

The normal consistencies of pastes containing CHA are shown in Table 1. The control paste or CHA0 had normal consistency of 26%. All pastes containing CHA showed normal consistency equal and higher than the control paste, CHA0. Up to 2% replacement, the normal consistency was constant; at 3% replacement, the normal consistency showed slight increment to 31%, and it increased continuously to 38% at 15% replacement.

The usual range of water to cement ratio for normal consistency is between 26 and 33 [4]. The pastes with replacement up to 5% showed a consistency within this range, however, after 10% replacement, the results showed considerably elevated value. This was due to the fineness of CHA and its porosity.

Table 1 Normal consistency of blended pastes containing CHA

Mix Code	CHAO	CHA2	CHA3	CHA5	CHA10	CHAO15
Consistency (%) (ASTM C 187)	26	26	31	33	35	38

5.1.3 SETTING TIME OF BLENDED PASTES

The Ethiopian standard limits the cement final setting time not to exceed 10 hours, while the initial setting time not to be less than 45 minutes. The results for the setting time presented in Table 2 indicate that the addition of CHA retarded the setting; however, this retardation was within limits as specified by the Ethiopian standard. As the CHA content increased, the setting time displayed a trend of increment. The reason for the increase in setting time could be the adsorption of water on CHA surface. The higher the proportion of CHA, the higher was the adsorption of water increasing the normal consistency, which in turn, re-treaded the setting time of paste.

Table 2 Setting time of pastes containing CHA

Mix Code	CHAO	CHA2	CHA3	CHA5	CHA10	CHAO15
Initial setting time (min)	63	69	77	89	105	112
Final setting time (min)	365	392	415	431	465	475

5.2 RESULTS AND DISCUSSION ON FRESH AND HARDENED CHA CONCRETE PROPERTIES

5.2.1 WORKABILITY TEST

As observed from Table 3.3, the slumps of the concrete containing CHA displayed a reduction as the CHA content increased. In order to get a certain slump, OPC-CHA blended concretes needed higher water content than one without CHA. The possible reason for this was CHA's lower density giving it higher porosity, resulting in higher water request. In order to get similar slump for the control and OPC-CHA concrete, the water content was increased as the CHA content increased. According to [3], the slump of the study was found in the range of 30-38 mm, wherein CHA concrete is good in plastic and cohesive properties. As a result, it was found that CHA concrete will be good to minimize segregation of fresh concrete during placing and consolidating of concrete.

Table 3 Slump test results for CHA concrete

Mix Code	CHAO	CHA2	CHA3	CHA5	CHA10	CHAO15
Replaced OPC (%)	0	2	3	5	10	15
Water to Binder	0.5	0.5	0.52	0.54	0.6	0.68
Observed Slump (mm)	38	36	33	33	32	30

5.2.2 FRESH CONCRETE UNIT WEIGHT

Unit weight properties of fresh CHA concrete was investigated by using mould with constant weight and volume of 5.4 kg and 9 litres, respectively. According to [1], fresh concrete properties can be determined by their respective maximum size of aggregates as a result of the 25 mm size of course aggregates, in which the corresponding unit weight was found to be 2375 kg/m^3. In this research, the fresh concrete unit weight was calculated using equation 3.1 and as presented in Table 4.

$$\text{Density} = \frac{\text{W2} - \text{W1}}{\text{V}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{equation 1}$$

Where W1 is weight of mould that is constant 5.4 Kg, W2 is weight of mould plus weight of fresh concrete in Kg, and V is volume of mould in M^3 that is constant 9 litres.

As shown in Table 4, the fresh CHA concrete density reduced when the percentage of CHA increased and from overall, CHA concrete had been good in producing lightweight concrete structures.

Table 4 Fresh concrete density

Mix Code	CHAO	CHA2	CHA3	CHA5	CHA10	CHAO15
W2 (Kg)	27.8	27.5	27	26.4	25.2	24.0
Density of fresh concrete (Kg/M^3)	2489	2456	2400	2333	2200	2066
Reduction of density in %	0	1.34	2.26	2.78	5.71	6.06

5.2.3 DENSITY OF HARDENED CHA CONCRETE

The density values used for the analysis of the study were measured from the concrete cubes sample after 28 days of being cured in curing tank. The experimental results showed a significant reduction of density, while CHA replacement percentages increased, as shown in Table 5.

Table 5 density of harden CHA concretes

Mix Code	CHAO	CHA2	CHA3	CHA5	CHA10	CHAO15
Density (kg/m3)	2306.2	2243.5	2209.6	2207.5	2203.3	2184.9
Density Reduction (%))	00	6.27	9.66	9.87	10.30	12.14

The low specific gravity of the CHA, 2.72, as compared to the cement, 3.15, resulted declining in the density of the CHA concrete, as shown in Table 5. Since CHA was nearly 16% lighter than cement, it was expected that the mass density of the mix would be significantly reduced. In addition to that, it could be accredited to the raise in voids in the concrete samples as the CHA percentage increased. Nevertheless, the unit weight increased as the ages of specimens increased and the concrete got denser.

5.2.4 COMPRESSIVE STRENGTH TEST

For each percentage replacement, the mean values of three cubes were taken as compressive strength. The strength reduction due to increment of CHA was calculated by using equation 2, while Figure 1 illustrates the compressive strength values:

$$\text{Decrement } \% = \frac{\text{Foj} - \text{Fij}}{\text{Foj}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equation 2}$$

Where F0j is CHA0 (control test of compressive strength), at j days of curing and Fij is the compressive strength of i% of replacement at j days of curing.

As for CHA concrete, the results showed that addition of CHA resulted in reduction of concrete compressive strength, when compared to control, CHA0. This shows that when CHA increased, the compressive strength of the concrete reduced. However, the compressive strength of the CHA concrete increased as it aged.

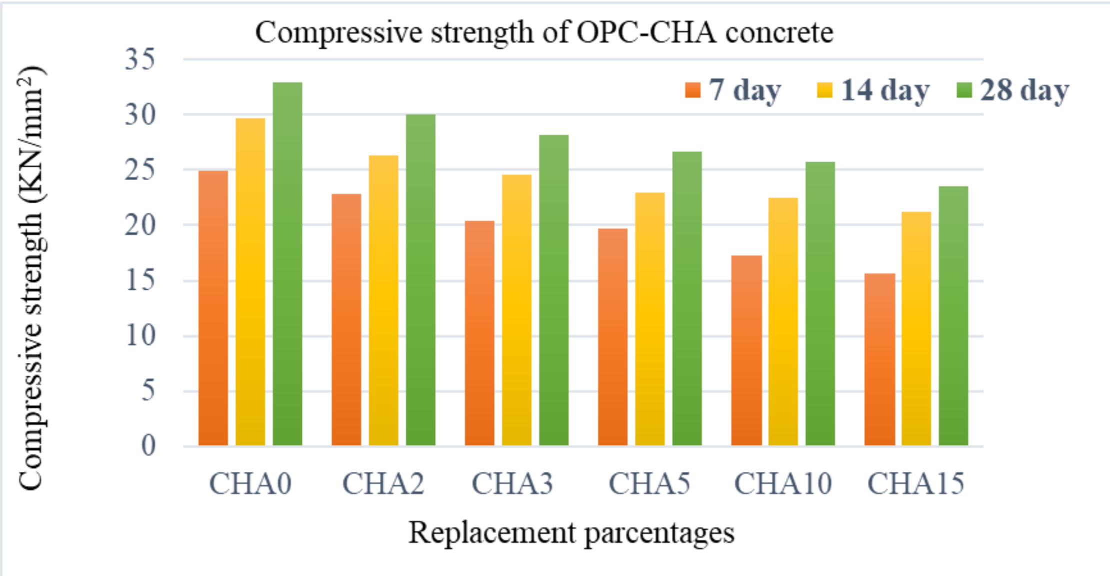

Figure 1 Compressive strength of OPC-CHA concrete

The probable reason for the decrease in CHA concrete compressive strength is because of the high percentages replacement of cement by CHA, thus reducing the content of cement in concrete, which on the other hand, reduced cement hydration reactions. Beyond this high amount of CHA, it resulted in higher water requirement, hence making water unavailable for cement hydration.

5.2.5 ENVIRONMENTAL AND ECONOMIC BENEFITS OF CHA CONCRETE

Damping of CH at landfill sites facilitates the threat of wild fires, and generates toxic chemicals that affect the ecology, such as soil, water, and plants. Hence, the flourishing use of by-product of coffee bean processing, CH, in concrete, can be placed forward as one of the environmental responsible and cost-effective eco-friendly ways of adapting coffee husk waste into valuable resources.

A. REDUCTION IN MATERIALS USAGES

Using CHA, which is a recycled material, will save a great deal of materials used for concrete production. For one ton of OPC, 1.52 tons of raw materials are required [2] and CHA is a recycled (recovered) material.

Table 3.7 shows that using CHA as a cement replacement saves use of raw materials for production of cement. For example, the 10 % replacement saved about 10.05 % of raw materials required to produce 360 kg of cement, which means 38 kg of cement per a meter cube of concrete when compared to the control concrete, which is about 38 kg/m^3 that is nearly one bag of cement per one-meter cubic of concrete. In 2016-production year of Ethiopia, coffee production and its associated residue reached 172,990 MT of CHA.

Table 7 Raw material input for cement per cubic meter of concrete

Mix Code	CHA0	CHA2	CHA3	CHA5	CHA10	CHA15
OPC (kg/m^3)	547	536	530	519	492	465
CHA (kg/m^3)	0	11	17	28	55	82
Saving of materials (%)	0	2.01	3.10	5.12	10.05	15.00

For one ton of cement production, it consumes 1.52 ton of raw materials, which is equivalent to 10 % of CHA, thus reducing the raw materials for cement production with 172,900 MT of CHA, hence saving 262,808 (172900*1.52) MT of raw materials each year.

B. ENERGY SAVING

CHA formation needs only 550 ^oC, which is reduction of 900 ^oC, in which 62.1% of temperature required for formation of clinker. This plays a great role in addressing global warming and energy cost.

In order to produce one ton of clinker, one needs to burn 0.164 ton of coals and usage of 43,223.8 KJ of energy per one kilogram of clinker [17]. If one substitutes it by CHA10, it will reduce the energy consumption by 0.1018 (i.e. 0.164 x 62.1%) ton of coal per ton of clinkers and 26,841 (i.e. 43223 x 62.1%) KJ of energy per 1 kg of clinker production.

As a result, CHA is important for energy cost reduction of cement productions that can reduce the cost of cement as cement partial replacement.

C. REDUCTION IN CO2 EMISSION

One kg of cement production emits around 0.79 kg CO_2 and from this 37%, 0.37*0.79 kg=0.2923 Kg, CO_2 comes from fuel consumption. Hence, for 10% CHA replacement, 0.02923 kg of CO_2 per kg of cement can be saved. Based on 2016 annual coffee productions of Ethiopia, there were equivalent CH production and for this, there was around 172, 900 MT of CHA productions. As a result, use of CHA as partial replacement of cement within 10% as a limit can reduce the emission of CO_2 by the quantities of 5,053.867 MT of CO_2 per year only from fuel consumption, since CHA can be produced by using lower amount of electric power instead of fuel energy. It also plays a great role in saving foreign currency due to import of fuel.

6.0 CONCLUSION AND RECOMMENDATIONS

The chemical composition test reveals that the CHA from Jimma, Ethiopia has significant values of Al_2O_3 and SiO_2, which are major components of cement.

Elevated replacements of cement by CHA resulted in advanced normal consistency (i.e. higher water requirement for workability) and longer setting time. The introduction of CHA in concrete considerably decreased both workability and slump aspects. It was observed that the slump decreased as CHA percentages were increased in all the specimens. The low specific gravity of the CHA, when compared to cement, produced a decrease in the density of the CHA concrete.

The compressive strength increased with curing period, but decreased with increased amount of CHA. The compressive test showed that more percentage replacement caused less degree of strength for the same ages of specimen. In the reveries, aged specimens resulted better strength for the same replacement percentages.

Therefore, the investigation of this study found that OPC replacement with CHA from 2% to 10% resulted in better compressive strength and density. Therefore, 10% of CHA replacement is the optimum ratio for C-25 concrete production. Similarly, 15% of CHA concrete is good for lower grade of concrete, such as C-20. Based on these preliminary results, it can be concluded that CHA can be used as an alternative cement to replace cementitious materials for the production of normal weight concrete with acceptable physical, chemical, and mechanical performances.

This research has demonstrated that concrete produced from CHA has high potential as a source of environmental-friendly cementitious material that reduces pollution and provides a sound coffee waste management option.

The recommendations of future resecah as per below;

- The CHA from different major sources of coffee producing areas throughout the country should be studied.
- Studies may want to check the chemical compositions and pozzolanic reaction of the CHA by using advanced methods, such as X-ray Diffraction (XRD) Analysis, and Scanning Electron Microscopy (SEM).
- The durability properties of CHA concrete need to be investigated in relation to concrete ages.
- The carbon dioxide emission and burning cost of CHA can be accurately calculated using several scientific methods.

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