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A Study on Effect of Partial Replacement of Cement by Cattle Bone Ash in Concrete Property

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Abstract

The study was aiming to investigate the effect of partial replacement of cement by cattle bone ash (CBA) in a concrete property. Complete silicate analysis of CBA shows that the material has high calcium oxide content (43.26%) which is the major oxide compound of cement. A C-25 concrete grade was selected for this study. The Normal consistency, setting time, soundness of cement paste, slump, compressive strength and density of concrete tests are done with (0%), 5%, 10%, 15% and 20% cement replacement with cattle bone ash. The compressive strength of concrete was done by curing 15 cm × 15 cm × 15 cm cube concrete specimens underwater for 3,7,28 and 56 days. The normal consistency of the cement paste increases as the percentage of the cattle bone ash increases in the paste attributed to high water absorption of CBA than OPC. The initial and final setting time of cement paste increase as the percentage of replacement of cement with bone ash. The slump of concrete decreases at 0% to 10% CBA mix and increases in 15% to 20% CBA mix. From the results, the partial replacement of Ordinary Portland Cement with Bone ash shows a gradual decrease in the compressive strength of concrete. The concrete density decreases as the percentage of bone ash increases. The use of cattle bone waste as an additive or supplementary cementing material production has vital importance to produce low-cost concrete and helps to conserve materials needed for cement production.

Keywords: Cement • Compressive strength • Density • Cattle bone ash • Setting time • Slump

Introduction

The construction industry has become the main ingredient of the national economy. It is growing alarmingly in the world as well as in Ethiopia. This economic growth correspondingly increases the demand for construction materials. The cost of conventional building materials continues to increase, despite the majority of the population continues under poverty. The exploitation of raw construction material becomes a major environmental burden. Thus, there is a need to search low cost locally available materials as alternatives for the building construction industry. Cement is one of the most widely used binding materials which comprises about 11% of the concrete volume, is the most expensive concrete component and encompasses 45% of the total concrete cost [1].

Meat is highly consumed as a major recipe in Ethiopian at all cultural occasions, ceremonies and regular meals. High consumptions of meat correspondingly produce a high amount of bone waste that contaminates the environment, causes health problems and needs four thousands of years to decay in radiocarbon dating [2].

There is a high gap between demand and supply of cement. In 2010, total cement demand has been 4.19 million tons and supply was 3.5 million tons, which indicates that there, had been 0.69-million-ton shortage of cement [3]. Cement demand in Ethiopia had been increasing in the last three years 2015 to 2018 by an average of 10.1% per year [4]. The production of cement consumes a high amount of energy and materials. For every one ton of cement produced, one ton of carbon dioxide is emitted to the atmosphere that causes depletion of the ozone layer [5].

Ethiopia takes the first place in Africa and the fifth in the world by its cattle population. The waste products of animal bone in Ethiopia accounted for the 10% population of its cattle which are slaughtered per year, and the average weight of cow and oxen is 300 kg plus. Out of this mass from 20% to 30% are the weight of the bone, we can get an average of 400.5 million Kilograms animal bone generated annually as waste [1].

The total cattle population of Ethiopia in 2017 is estimated to be about 59.5 million that covers 44.93% of the Ethiopian Livestock population. Over the next 15 years, the consumption of red meat (beef, sheep, goat and camel meat) in Ethiopia is projected to grow by about 276% from 775,000 tons in 2013 to 2.9 million tons in 2028 [6].

Environmental pollution by wastes from slaughtering houses and households as well as the waste disposal land requirement is one of the issues for large cities like Bahir Dar. Bone is one of the wastes removed from slaughtered animals (oxen and cows) which has high calcium content. On the other hand, 60% to 67% of portland cement is comprised of calcium oxide. This indicates that the bone waste potential for partial replacement of cement. Despite its high calcium oxide content, it causes environmental pollution due to the harmful gases released from burning in the disposal site. Waste disposal for large towns is one source of expense to waste transportation and management. Natural landscape changes due to waste disposal, loss of beauty of city scenery and disease related to respirational causes due to bad smelling are among the major negative impacts on the environment and human well-being. Proper utilization of this bone waste has a dual advantage by creating a sustainable environment and provides low-cost cementing material. The main specific objectives of the study are;

1. Investigating the potential of cattle bone mineralogical composition for supplementary cementitious material.

2. Studying the effect of partial cement replacement with CBA in initial and final setting time, normal consistency and soundness of cement paste.

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3. Investigating the effect of partial replacement of cement with CBA in compressive strength, workability and density of standard concrete mix within varied CBA proportions.
4. Determining the optimum percentage of partial replacement with CBA in concrete.

Materials and Methods

Locally available aggregates were selected and collected based on the quality requirement confirmation as in standards(ASTM and ACI). The gradation, density, moisture content, absorption and specific gravity are main physical tests were conducted to verify the quality of aggregates. Normal consistency, setting time and soundness tests are conducted to examine the physical property of Cement and to investigate the effect of partial replacement of cement with varied CBA proportion (0% to 20%) in cement paste. The mix design was done based on the physical test results of aggregates as in the ACI 211.1 mix design procedure for normal concrete. A Compressive strength test was done by taking standard cast in concrete molds of 15 cm × 15 cm × 15 cm cube moist cured for 3, 7, 28 and 56 days.

Materials used

Tap water, free from suspended solids and organic compounds, well graded crushed, angular basaltic stone collected from Mesh anti-quarry site which was located around the Bahir Dar area was used. Locally available Lalibela sand that meets ASTM C33 used for this research study. After burning cleaner and size reduced cattle bone, it was pulverized to less than(pass)75 µm size by disk mill. OPC 42.5 R and PPC 32.5 R Dangote cement were used for mixes.

Mix proportions and data analysis methods

This is discussed in detail in Table 1.

Mix design and casting

Mix proportion was done per ACI 211.1 mix design procedure. All of the concrete mixes were designed to achieve C-25 grade concrete with a target mean strength of 33.5 MPa. A cement content of 365 kg/m^3, a water-cement ratio of 0.49 and a slump of 25 to 50 mm was used to achieve the specified target mean strength. Seventy two concrete cube specimens were tested. The overall curing and compressive strength testing procedures were according to STANDARDS (2006). Test result analysis was done by using IBM SPSS version 21 software.

Results and Discussion

After testing cement, aggregate physical properties, chemical analysis of CBA, concrete mix design were conducted based on the test results of all ingredients. The experiment was done using two sets of control mixes made with OPC 42.5R and PPC 32.5R and four other mixes made with different CBA percentages. The main reason for using PPC as a control mix is that supplementary cementitious materials react slowly after the release of $Ca(OH)_2$ in cement hydration. Consequently, the later strength development of concrete made with CBA can be assessed well through comparison with concrete made from PPC.

Bone ash preparation

After collecting two sacks of cattle bone from Bahir Dar Institute of Technology waste disposal site, it was sundried by removing tissues and other detached wastes. But the selected bone sample weight is 15 kg because the selected specimens are mostly dry cortical (leg) bones due to their low organic content. The bone residue was cleaned, crushed by hand hammering to the maximum size of 25 mm that is suitable for disk milling (Figure 1).

To examine the effect of burning temperature on the physical and chemical property of bone, different trials were made based on literature sources. The prepared sample was burned by using a controlled electric furnace in open (calcined) and closed (carbonized) condition of the crucible at 600°C and 900°C for 3 hours at a heating rate 10°C/min and afterward it was cooled slowly to room temperature. For this study, a burning bone at 900°C for 3 hours is taken as optimum temperature for bone ash formation. Bone ash was burned by using ceramic crucible containers in a furnace and tested at different temperatures to identify a change in calcination, color and mass loss (Figure 2).

When a bone is burned at 600°C temperature by a furnace, it losses its carbon, organic compounds (collagen fibers and organic matter). When a bone is burned at 900°C temperature the ash completely losses its carbon and exhibits calcined property. For this study, open (calcined) burning at 900°C condition was used because carbon was removed from bone ash and it satisfies the color requirement as per (ES-1176), white-gray when pulverized by disk mill. Finally, the burned bone is milled by using a disk milling machine to get 75 micrometer.

Chemical composition of cattle bone ash

From the mineralogical test done in the Ethiopian Geological Survey, calcium oxide and phosphorus pentaoxide (P_2O_5) are major compounds comprised in the bone ash. This implies bone ash can be used as a cement additive material for normal concrete. The Loss on Ignition (LOI) content of 2.36% also complies with ASTM C618, in which the maximum value is set to be 10% (Table 2).

Bogue's equations for the chemical content in CBA blended mix

Bogue's equation is used to determine the compound composition of different mixes (0% to 20% CBA replaced concrete) and to verify the effect of CBA chemical composition change in fresh and hardened concrete properties. As ASTM C150, calculation of potential cement phase composition. Bogue's equations for the percentage of main binders are given in Equation 1 to 4. The terms in brackets represent the percentage of the given oxide in the total mass of CBA. From the chemical analysis results in Table 2, CBA contains 43.26% CaO, but its' percentage of SiO_2, Fe_2O_3 and Al_2O_3 is less than 0.01%. The calculation is done by mixing the CBA and OPC cement.

Tricalcium silicate (C_3S) = (4.071×% CaO)- (7.600 × % SiO_2)- (6.7183 ×

Table 1. Mix methods.

No.	Cement	Bone ash (CBA)	Mix designation
1	100% PPC	0	100% PPC
2	100% OPC	0	100% OPC
3	95% OPC	5%	5% CBA
4	90% OPC	10%	10% CBA
5	85% OPC	15%	15% CBA
6	80% OPC	20%	20% CBA

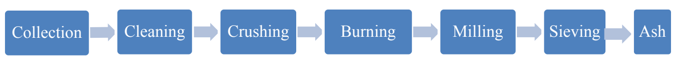

Figure 1. Bone ash preparation procedures.

Figure 2. A. Carbonized ash B. Calcined ash.

% Al_2O_3)- (1.430 × Fe_2O_3)- (2.852 × % SO_3)- (5.188×% CO_2)……….Equation 1

Dicalcium silicate (C_2 S) = (2.867 × % SiO_2) - (0.7544 × % C_3S)………. Equation 2

Tricalcium aluminate (C_3A) = (2.650 × % Al_2O_3) - (1.692 × % Fe_2O_3)…. Equation 3

Tetracalcium aluminoferrite (C_4AF) = (3.043×% Fe_2O_3)………………….. Equation 4

All mix compound compositions in Tables 3 and 4, is done by the equations 1 to 4 by varying the mix (CBA percentage in concrete) (Tables 3 and 4).

Calculated results in Table 4 indicate that as the CBA percentage increases, the content of C_2S increases. But the C_3S composition has an inverse relationship with the increase of CBA content in cement hydration attributed to the low SiO_2 content of CBA. The C_3A and C4AF compound composition are the same for all mixes due to low Al_2O_3 and Fe_2O_3 contribution of CBA in hydration. The decrease of C_3S in paste retards the setting time and early strength gain because C_3S is largely responsible for the initial set and early strength gain. The higher composition of C_2S contributes to later strength gain of concrete.

Cement test

a) **Consistency test**

The normal consistency of the cement paste increases as the percentage of replacement of CBA increases as shown in Table 5. It implies that the CBA requires more water content than normal (OPC) cement to form the normal consistency within an acceptable range of plunger penetration (9 to 11 mm penetration). The possible reason for the increase of absorption could be the higher surface area of CBA than OPC cement (Table 5).

b) **Setting time test**

The initial and final setting time increases as the percentage replacement of cement with Bone ash increases. This indicates that the hydration process of cement was slowed down because of the increment percentage of bone ash. The reason for the increase in setting time is the presence of the phosphate (P_2O_5) in CBA which exhibits the retarding of cement paste by the formation of a complex on the surface of cement particles. The reduction of C_3S percentage in cement paste is also another factor attributed to the delay of setting time since C_3S contributes to the initial setting time of cement paste (Figure 3).

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. ASTM C191 limits the initial setting time of hydraulic cement should be between 49 min and 202 min. Figure 3 indicate that the addition of CBA retarded the setting time; however, setting time was within limits as specified by the Ethiopian standard and ASTM C191.

c) **Soundness test**

The Soundness of cement is primarily affected by the presence of excess lime (CaO) in the cement. This excess lime hydrates very slowly and forms slaked lime that occupies a larger volume than the original free calcium oxide. The test result shows that as the percentage of CBA increases in cement paste, the expansion of paste decreases due to the lower calcium oxide content of CBA than cement. In all proportion mixes from 0% to 20% CBA cement paste is sound since its' expansion (L2- L1) is less than 10 mm (Figure 4).

d) **Slump test**

The concrete slump decreases as the percentage of replacement of CBA increases in concrete. Thus, the decreasing slump value with increasing CBA content implies that the mix becomes harsh and less workable as the CBA content increases up to 10% CBA replacement. It is attributed to the high-water absorption capacity of CBA compared to the OPC cement. But beyond 10% CBA replacement, the concrete slump increases due to the increment of water content and the reduction of sand content in mix design despite the higher water absorption of CBA in a concrete mix (Figure 5).

e) **Concrete density test**

The density of bone ash is 1157 kg/m³, which is 17.35% less than the density of ordinary Portland cement (1400 kg/m³). The addition of CBA in a concrete cause the reduction of the fresh and hardened concrete density.

Table 2. Cattle bone ash chemical composition (silicate analysis) test result.

No.	1	2	3	4	5	6	7	8	9	10	11
Compound	CaO	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	MgO	K_2O	MnO	P_2O_5	SO_3	LOI
Weight (%)	43.26	<0.01	<0.01	<0.01	<0.01	0.54	<0.01	<0.01	44.67	0.08	2.36

Table 3. Dangote OPC cement chemical composition (Geremew, 2017).

Chemical oxides	CaO	SiO_2	Al_2O_3	Fe_2O_3
Content (%)	66.32	22.82	5.41	3.37

Table 4. Calculations of bone ash blended cement compound component.

Elemental oxides	**100% OPC**	**5% CBA**	**10% CBA**	**15% CBA**	**20% CBA**
			Chemical composition (%)		
CaO	66.32	65.17	64.01	62.86	61.71
SiO_2	22.82	22.82	22.82	22.82	22.82
Al_2O_3	5.41	5.41	5.41	5.41	5.41
Fe_2O_3	3.37	3.37	3.37	3.37	3.37
Compounds			**Compound composition (%)**		
C_3S	55.39	50.71	45.99	41.31	36.62
C_2S	23.64	27.17	30.73	34.26	37.79
C_3A	8.63	8.63	8.63	8.63	8.63
C_4AF	10.25	10.25	10.25	10.25	10.25

Table 5. Slump test result.

Mix	**100% OPC**	**5% CBA**	**10% CBA**	**15% CBA**	**20% CBA**
Consistency (%)	26	27	27.5	28	30.5

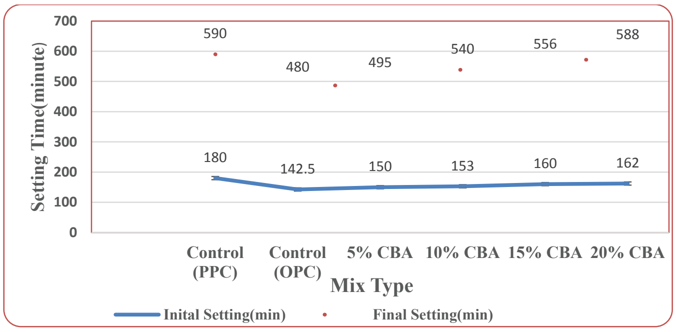

Figure 3. Initial and final setting time test results.

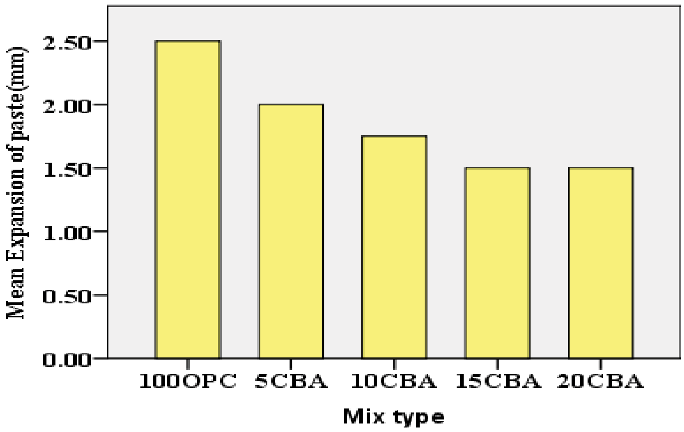

Figure 4. Cement soundness test result.

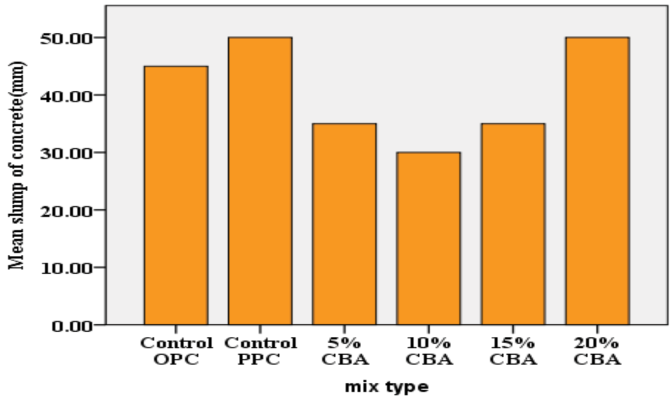

Figure 5. Slump test results.

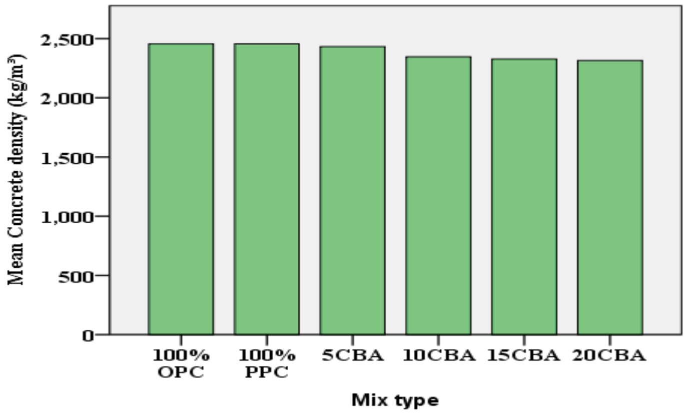

Figure 6. Fresh concrete density.

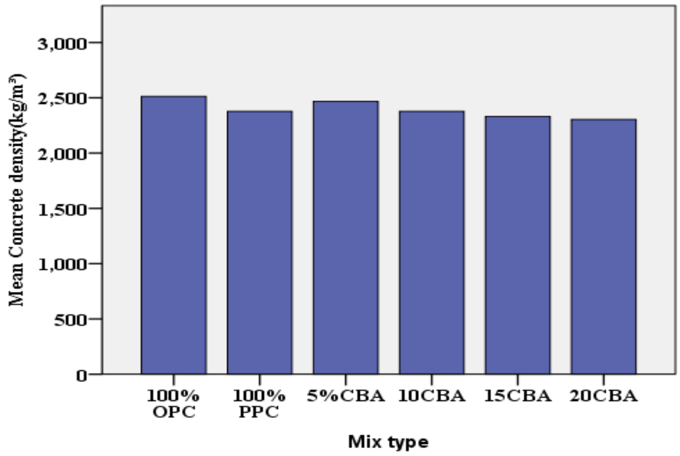

Figure 7. Hardened concrete density.

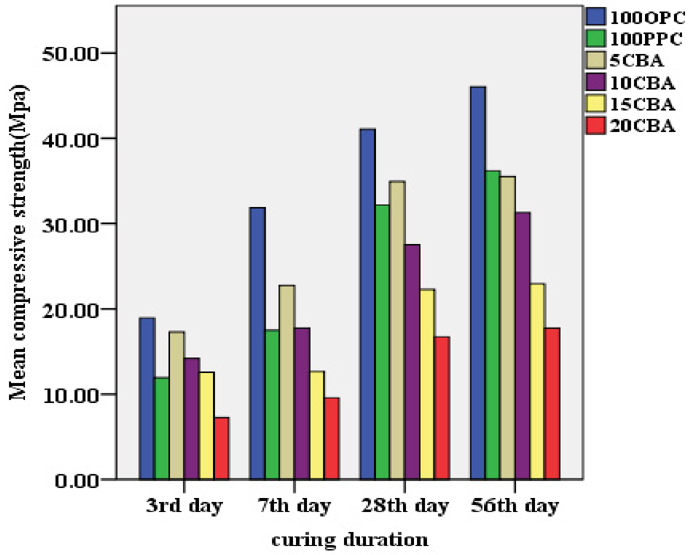

Figure 8. Hardened concrete density.

Freshly casted concrete was taken for fresh concrete and 56th day cured concrete under curing tank was taken for hardened concrete density test as shown in Figures 6 and 7. From the test results, the density of concrete decreases as the percentage of CBA increases due to less unit of bone ash compared to Ordinary Portland Cement. The reduction of concrete density is an important property of concrete to build low weight buildings, consequently suitable for the self-weight reduction of structural members and overall building weight.

f) **Compressive strength test**

As the percentage of CBA increases, the compressive strength of concrete decreases.

Figure 8 shows that the 3rd day compressive strength with varying percentage of CBA declined from the control specimen (100% OPC), but it is greater than 100% PPC. The 3rd day average control specimen (100% OPC) compressive strength was 18.94 MPa (0% CBA replacement). The test has revealed that the reduction of the compressive strength is directly proportional to an increase in the percentage of CBA.

The 3rd day lesser 100% PPC strength proves that PPC has lower early strength than OPC mix concrete (control) and varying percentage of CBA except for 20% CBA, due to its pozzolanic property. The 3rd day 100% PPC, 100% OPC, 5% CBA, 10% CBA, 15% CBA and 20% CBA compressive strength achieves; 37.16%, 46.16%, 49.51%, 51.60%, 56.35% and 43.39% of its corresponding 28th day mean compressive strength respectively.

The 7th day 100% PPC, 100% OPC, 5% CBA, 10% CBA, 15% CBA and 20% CBA compressive strength achieves; 54.32%, 77.57%, 65.08%, 64.46%, 56.84% and 57.26% of its corresponding 28th day mean compressive strength respectively. This shows that PPC cement has lower early strength than other mixes because the 3rd and 7th day mean compressive achieves 37.16% and 54.32% of its respective 28th day mean compressive strength respectively, which is less than all other types of OPC mixes.

The 28th day 100% PPC, 100% OPC, 5% CBA, 10% CBA, 15% CBA and 20% CBA compressive strength achieves; 88.92%, 89.22%, 98.34%, 87.98%, 97.12% and 94.36% of 56th day mean compressive strength respectively. This shows that there is no significant difference between 28th and 56th day compressive strength compared to the difference between 3rd and 7th days mean compressive strength.

The 3rd day mean compressive strength for the control mix (100% OPC) was 18.94 MPa. There was reduction of 1.64 MPa (8.66%), 4.74 MPa (25.03%), 6.38 MPa (33.69%), 11.68 MPa (61.67%) strength in 5% CBA, 10% CBA, 15% CBA and 20% CBA replacement respectively from the control value. The 7th day mean compressive strength for the control mix (100% OPC) was 31.86 MPa. There was reduction of 9.12 MPa (28.62%), 14.12 MPa (44.32%), 19.19 MPa (60.23%), 22.28 MPa (69.93%) strength in 5% CBA, 10% CBA, 15% CBA and 20% CBA replacement respectively from the control value.

The 28th day mean compressive strength for the control mix (100% OPC) was 41.07 MPa. There was reduction of 6.13 MPa (14.93%), 13.55 MPa (32.99%), 18.78 MPa (45.73%), 24.34 MPa (59.26%) strength in 5% CBA, 10% CBA, 15% CBA and 20% CBA replacement respectively from the control value. The 56th day mean compressive strength for the control mix (100% OPC) was 46.03 MPa.

There was reduction of 10.5 MPa (22.81%), 14.75 MPa (32.04%), 23.08 MPa (50.14%), 28.33 MPa (61.48%) strength in 5% CBA, 10% CBA, 15% CBA and 20% CBA replacement respectively from the control value.

Based on the 28th day mean compressive strength results, the 5% CBA replacement has comparable compressive strength value with the control specimen (100% OPC); it achieved 85.07% 28th day mean compressive strength of the control specimen. The 28th day 5% CBA mean compressive strength was 34.94 MPa, which was greater than 28th day C-25 required target mean strength (33.5 MPa).

g) **Environmental and economic benefits of CBA blended concrete**

Disposing of bone wastes to the environment highly pollutes the natural environment, causes bad smell and generates toxic chemicals that can pollute rivers, soil and plants. Proper waste management is very important to overcome the above problems.

The use of bone waste will save a great deal of material from concrete production. For one ton of OPC production, 1.52 tons of raw materials are required [7]. Therefore, the use of CBA saves a high amount of material required for cement production. For example, the 10% replacement saved about 55.48 kg of raw materials required to produce 365 kg of cement, which means 36.5 kg of cement per meter cube of concrete compared to the control concrete, which approximately equals one bag of raw material per one-meter cubic of concrete.

h) **Energy and cost saving**

For one-ton cement production, it needs an average of 6000 MJ energy, but by using CBA replacement the energy required for cement production can be reduced to 4905 MJ, thus it saves 18.25% of the energy required to produce one ton of Portland cement. An average temperature required to form a cement clinker is 1450°C, but CBA can be produced at 900°C temperature so that it minimizes temperature required to form clinker by 550°C, which reduces 37.93% of temperature and this plays a great role in addressing global warming and energy cost. Cost-saving is also a major advantage of using CBA in normal concrete production.

Conclusion

Finally, from the study, the following conclusions are drawn from the test results and discussions,

- Bone ash cannot be considered as pozzolanic material since the percentage sum of silicate aluminate and ferrite is less than 50%. But it can be used as cement additive material since it has high calcium oxide content.
- As the percentage of bone ash in cement paste increases, the normal consistency of cement paste increases attributed to high water absorption of CBA than OPC.
- Initial and final setting time of cement paste increases, as the percentage of replacement of cement with cattle bone ash increases.
- The cement paste expansion (L2-L1) decreases as the percentage of CBA increases.
- Concrete slump decreases as the percentage of replacement of cement with cattle bone ash increases, due to the high water absorption capacity of CBA than cement.
- As the percentage of bone ash in concrete increases, the compressive strength decreases
- The optimum percentage of replacement cement with CBA, without significantly affecting the compressive strength of concrete is 10%, based on 28th day average strength.
- As the percentage of CBA in concrete increases, the density of concrete decreases.

Recommendations

1. To compensate for the low silicate content of bone ash, the addition of silicate containing materials with bone ash, such as rice husk ash and glass powder will improve the compressive strength of concrete containing CBA.
2. To increase the economic feasibility of bone ash production, burning and milling should be done with more advanced machines like a bone-crushing plant to reduce energy consumption per kilogram of ash.

The effect of partial replacement of CBA on the durability of normal concrete should be studied to examine its resistance to chemical actions in concrete [8,9].

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