Study on Partial Replacement of Cement with Animal Bone Ash in Concrete at Elevated Temperatures

Solomon Dagnaw[1] and Tesfaye Alemu Mohammed[2(✉)]

[1] Civil Engineering Department, University of Gondar, Gondar, Ethiopia
[2] Civil Engineering Department, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia
tesfaye.alemu@aastu.edu.et

Abstract. It is not uncommon to find inefficient waste disposal systems in third world countries like in Ethiopia where the human factor is crucial in generating wastes like animal bones. Animal bone ash constitutes high calcium, offering good binding characteristics to employ bone ash (BA) as a partial replacement of cement in concrete production. This study experimentally investigates use of animal bone ash (BA) as partial replacement of cement in structural concrete production at elevated temperature. Parameters studied in this study include elevated temperature intensity (300 °C, 600 °C and 900 °C), duration of temperature exposure (1 h and 3 h), cooling methods and various bone ash (BA) cement blending percentages (0%, 5%, 10%, 15% and 20%). A total of 237 concrete cylindrical test specimens was casted and tested to study behavior of concrete with cement replaced by bone ash (BA) at elevated temperatures. Experimental test results showed that weight, tensile and compressive strengths of bone ash blended cement concrete reduced with an increase in temperature and their respective test values depends on choice of cooling methods. Fast cooling exhibited an additional strength loss of 35% as compared to natural air cooling. Also, concrete residual compressive strength decreases sharply beyond 10% replacement of cement with bone ash (BA). This implies optimum threshold value of bone ash (BA) replacement of cement in concrete at elevated temperature is 10%.

Keywords: Elevated temperature · Cement partial replacement · Animal Bone ash (BA)

1 Introduction

As compared to other construction materials, concrete constituents larger proportion of built in structures and this trend is projected to rise twice in coming 30 years [1]. Cement is essential component of concrete making and its properties influence fresh and hardened mechanical property of concrete [2]. Construction boom in Ethiopia lead cement consumption to rise 10% per year during 1997–2007 years and 16.1% per year

M. A. Delele et al. (Eds.): ICAST 2020, LNICST 385, pp. 3–16, 2021.
https://doi.org/10.1007/978-3-030-80618-7_1

in last five years [3]. However, cement production involves release of large amount of carbon dioxide (CO_2) almost it accounts for more than 50% of combined industrial carbon dioxide (CO_2) emissions [4]. Studies indicated 0% increase in carbon dioxide (CO_2) emissions can be attained if alternative supplemental materials could be used to replace 30% of cement globally consumed cement [1, 5]. Potential cement substituting materials include animal bones ashes, rice hulk, fly ash, silica fume, textile and blast slags. Besides, these material wastes also create environmental pollution in third world countries like Ethiopia where there is no effective waste disposal systems.

Animal bone is rich in calcium constituting 97% of body's overall calcium deposit [6] and Portland cement, a crucial input for cement production, contains nearly 50% calcium oxide (CaO) [7]. Reports indicated in Ethiopia annually on average there is 400.5 million Kg animal bone wastes [8]. Animal bone calcium content and supply volume makes animal bone ash ideal replacement material for cement production industries here in Ethiopia.

Concrete in a built environment endures to uphold its strength and service requirements imposed by codes of practices. Yet, this concrete characteristic comes short and distress when concrete cis exposed to elevated temperatures of fire loading. Popularity of concrete as a construction material is attributed to its good fire resistance as compared to materials such as wood, aluminum and steel [9, 10]. However, this resistance to fire holds true up to a certain level of elevated temperature and duration of exposures. Chang et al. [11] reported behavior of concrete when exposed to a sustained fire is dependent on characteristics of concrete constituents such as aggregate type, cement paste characteristics, bond between cement paste and aggregate, rate of heating and cooling, temperature exposure time and loading types [12].

Various industrial by products and solid wastes have exhibited to enhance cement paste microstructure by densifying mix of cement paste and improving interfacial zone. Even if bone ash (BA) is not a pozzolanic material as investigated by different researchers so far, it can replace partially cement in concrete production at normal temperature due to higher percentage of CaO. However, effect of elevated temperature on concrete produced by substituting its ingredients with various waste materials particularly BA as cement substitution in concrete at elevated temperature has not been investigated by previous researchers.

This study filled in perceived void in literature by experimentally investigating effect of replacing cement with animal bone ash on mechanical properties of concrete at elevated temperature. Variables considered in this study include quantifying residual compressive and tensile strengths; marking concrete spalling and weight losses; two cooling methods such as fast and natural air cooling methods; and fire intensity exposure and duration times. In the end, this research:

- Investigates compressive and split tensile strengths of bone ash blended cement concrete at various temperature intensities and exposure times.
- Studies effect of cooling methods on bone ash (BA) modified concrete's compressive strength
- Determines optimum level of bone ash percentage cement replacement at elevated temperature

2 Materials and Methods

2.1 Materials

The animal bones solid wastes were obtained from solid waste disposal sites in Bahir Dar city, Ethiopia. Next, they were washed and sun dried after careful separation of flesh, tissues and fats. Then, bone samples were burned in an open air and ash from burned bones had been grinded using hammer mill and passing through 150 µm (No. 100) sieve as per [13].

Concrete mix batch was prepared proportioning cement, fine aggregate, coarse aggregate and water. Ordinary Portland Cement (OPC) cement of 42.5R grade manufactured by Dangote Cement Factory was used in concrete mix. The concrete making materials used in this research are cement, fine aggregate, coarse aggregate and water. The type of cement was 42.5R Ordinary Portland Cement (OPC) satisfying [14] grade, manufactured by Dangote Cement Factory. Lalibela sand having 2.65 specific gravity was employed in concrete mix as well. Also, coarse aggregate from Meshenti aggregate crushing plant having 25 mm maximum size and portable drinking water was used in preparing concrete mix batches. Material Property tests of aggregates are carried out according to ASTM Standards [15].

2.2 Experimental Procedures

Mix Proportioning. Nominal concrete mixing ratio of 1:1.**7:**2.7cement, fine aggregate and coarse aggregate and 0.44 water cement ratio [16] was employed. Concrete batch input constituent materials were mixed by weight. Bone ash partially replaced cement in various proportions such as 0%, 5%, 10%, 15% and 20%.

Sample Preparation/Casting of Specimen. Standard cylindrical molds of size of 200 mm height and 100 mm diameter made of cast iron were used to cast concrete specimens to test required mechanical properties of concrete**.** Required volumes of mix ingredients were measured and batch mixing were performed thoroughly to ensure that homogeneous mix was obtained. Mixing was done using standard pan type mixers of capacity 56 L. Initially, a dry mix constituting cement and bone ash, fine aggregate and coarse aggregate was mixed for three minutes and then water was poured and batch mixing applied for another 4 min. Before casting, slump of the concrete is measured by compacting concrete in 3 layers with twenty five (25) strokes of sixteen (16) mm rod applied to each layer. Interior surfaces of the steel molds were thinly coated with oil to prevent adhesion of concrete. Concrete was left in a mold and allowed to set for 24 h before cylindrical molds were removed. Then concrete cylinders were transferred to a curing tank and left in a tank for 28 days at room temperature.

Heating and Cooling Down Process. Target temperature was set using a knob and temperature was increased at time intervals until target temperatures achieved. The specimens were subjected to exposure tests in an electrical furnace for temperatures intensities of (300 °C, 600 °C and 900 °C) with a retention periods of 1 and 3 h for each temperature intensity. Two types of cooling methods were studied namely air cooling (intending to simulate the natural extinction of a fire) and water cooling (intending to simulate action of firemen in fire combat). Air cooling was achieved by keeping specimens to cool naturally whereas water cooling was attained by quenching specimens' right after exiting a furnace. In both cooling methods, specimens are stored for 24 h before testing was initiated.

Test Techniques and Procedures. Objective of this research is to investigate mechanical properties of concrete produced with cement being partially replaced by bone ash (BA) at elevated temperatures of 300, 600 and 900 °C. After, specimens were cooled down using air and water cooling methods, mechanical tests were conducted at room temperature (20 ± 5 °C). Concrete samples of 105 were casted and tested for determination of compressive strength and again another 84 samples were casted and tested in order to determine split tensile strength of concrete. Also, other 48 samples were casted and tested to evaluate effect of cooling conditions on compressive strength of concrete at various bones ash (BA) cement replacement. Totally, 237 cylindrical concrete specimens were casted and tested to achieve objective of this research.

Compressive Strength Test. Compressive strength test was performed according to [17] by using a hydraulic compression machine of capacity 2000 KN. After heating, specimens were left to cool down under water and natural air conditions. Extreme care was taken when handling heated concrete specimens. Specimens were weighed before and after heating to calculate weight losses. In this study, variations in color of concrete due to heating to various intensities of temperatures were determined. Specimens were loaded to failure; and ultimate loading capacities and their respective modes of failure were recorded.

Split Tensile Strength Test. Concrete tensile strength is determined by indirect test methods like split cylinder test. This is due to inconvenience to apply uniaxial tension to a concrete specimen. Split tensile strength test was carried out according to [18] by using a hydraulic compression machine of capacity 2000 KN.

3 Results and Discussions

In this section, materials chemical characterization, consistency setting time, slump test, compressive and tensile strength test results are presented.

3.1 Chemical Composition of Bone Ash

Calcined ash cementitious characteristic is revealed by its oxide composition. As shown in Table 1, bone ash (BA) chemical analysis contains iron oxide ($Fe_2O_3 = 0.78\%$), aluminum oxide ($Al_2O_3 = 1.24$) and silicon dioxide ($SiO_2 = 3.26\%$) and their respective total sum which was 5.28% is way less than 70% minimum threshold criterion for a material to be considered as pozzolan [19].

Therefore, bone ash (BA) oxide composition employed in this study fails to meet requirements of a pozzolanic material, rather, bone ash (BA) can be considered as a cementitious filler/additive. This is primarily due to its high 26% by weight CaO content. Table 1 below shows oxide composition of BA relative to OPC oxide composition limit as per [14].

Table 1. Chemical composition of bone ash (BA)

Elemental oxides	BA (%)	OPC (%)
Calcium Oxide (CaO)	26	60–67
Silica Oxide (SiO_2)	3.26	17–25
Aluminum Oxide (Al_2O_3)	1.24	3–8
Iron Oxide (Fe_2O_3)	0.78	0.5–6
Magnesium Oxide (MgO)	0.84	0.1–4.0
Sodium Oxide (Na_2O)	0.16	0.2–1.3
Potassium Oxide (K_2O)	0.21	
Phosphate Oxide (P_2O_5)	14.26	–
Manganese Oxide (MnO)	1.23	0.03
Sulfur tri Oxide (SO_3)	1.29	1.8–4.6
Loss of Ignition (LOI)	0.85	33

3.2 Properties of Animal Bone Ash Blended Cement Paste

Vicat apparatus was used to measure bone ash blended cement consistency. This test reveals cement paste mobility and flow when water cement ratio varies due to addition of bone ash (BA) replacement in various proportion. Cement paste was mixed to normal consistency as revealed by 10 ± 1 mm penetration using Vicat plunger (Table 2).

Table 2. Fresh concrete normal consistency with various percentage of bone ash (BA)

Mix code	BA - 0%	BA - 5%	BA - 10%	BA - 15%	BA - 20%
Consistency	28	28.75	29.5	30	31

Normal consistency test results indicate batch mixing water volume demands for various animal bone (BA) replacement percentages and consistency tests reveal bone powder blended mixes require additional water volumes as compared to similar cement only control batch mixes. Normal consistency test results 26%–33% fall within standard specification ranges [20]. Next, Table 3 presents consistency test results of various BA blended cement setting time.

Test results indicated initial and final setting time rise as percentage of bone ash replacement of cement increased this is due to diminished hydration process of cement as a results increase of bone ash replacement in various proportions. Also, as compared to control, bone ash (BA) blended batch mixes with 60 to 600 min setting time ranges satisfy setting time requisite of [14].

Table 3. Initial and final setting times of BA blended Cement paste

Proportion of material	Initial setting time (minute)	Final setting time (minute)
100%cement + 0%BA	132.5	470
95%cement + 5%BA	140	485
90%cement + 10%BA	143	530
85%cement + 15%BA	150	546
80%cement + 20%BA	162	578

3.3 Workability of Bone Ash Blended Cement Concrete

Slump test was executed to determine workability bone ash blended batch mixes. A constant water cement ratio of 0.44 was used for concrete mixes and for various proportions of BA replacement slump test was measured to quantify workability changes. Table 4 presents slump test results of fresh concrete with various proportion of BA replacement. Results indicated as BA replacement proportion increases, a drop in concrete mix slump values was observed. Control mix with 0% BA scored 43 mm slump value where as 5%, 10%, 15% and 20% BA replacements exhibited 40 mm, 37 mm, 33 and 31 mm slump values respectively. Also, as compared to control, BP blended mixes demand high volume of water than cement in equal quantity. In various proportion of BA replacement, results showed BA absorbed more water leading to reduction in slump values. This is consistent with findings [21, 22] where concrete workability decrease constantly with BA incremental replacement in various proportions.

Table 4. Workability results of fresh concrete with varying replacements of BA

Mix code	BA - 0%	BA - 5%	BA - 10%	BA - 15%	BA - 20%
W/C ratio	0.44	0.44	0.44	0.44	0.44
Slump (mm)	43	40	37	33	31

3.4 Effect of Elevated Temperature on Compressive Strength of Concrete with BA as Cement Replacement – Air Cooling

In this section, compressive strength test results of cylindrical concrete specimens result are discussed by considering various factors such as intensity of temperature, exposure duration, bone ash contents and cooling methods. Table 5 and Fig. 1 below shows concrete compressive strength variations with BA content, intensity of temperature and exposure duration.

Table 5. Compressive strengths when concrete is exposed to different temperature intensities and durations

Percentage replacement of cement with BA (%)	Compressive strength (MPa)						
	RT	300 °C 1 h	300 °C 3 h	600 °C 1 h	600 °C 3 h	900 °C 1 h	900 °C 3 h
0	38.95	38.09	35.95	23.75	20.44	11.68	9.95
5	36.47	35.18	34.53	22.80	19.41	11.02	9.51
10	34.18	32.96	32.65	22.67	19.29	10.52	9.07
15	29.36	27.89	27.55	17.72	15.23	7.5	7.21
20	28.72	26.77	25.14	14.78	12.25	6.14	5.17

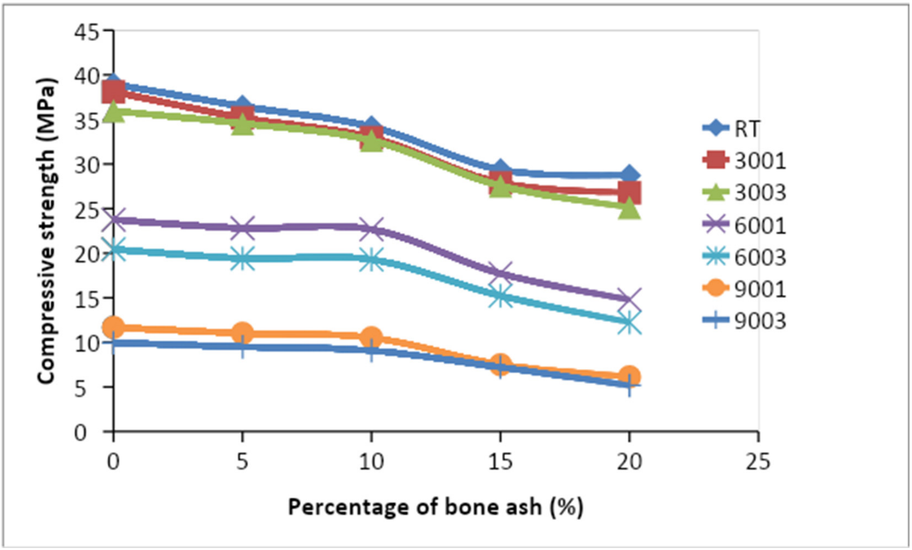

Fig. 1. Variation of compressive strength with percentage of BA and temperature (NB: The last digit in the legend of the figure represents the exposure duration. For example 3001 implies that at 300 °C for 1 h exposure duration)

As shown in Table 5, at room temperature when percentage of bone ash for replacement of cement increases from 0% to 20%, compressive strength of concrete decreases gradually and this is in conformity with report obtained by [22, 23]. The decrease was as a result of reduction of C-S-H in matrix due to OPC volume losses and lack of binding property of BA (small amount of silicate oxides). Although, specimens containing bone ash have lower 28 days compressive strengths as compared to control (0% BA), there is no significant difference between compressive strength of control samples and samples made with cement being replaced by bone ash up to 10% at 300 °C.

As Table 5 shows when time of exposure increases, reduction rate of compressive strength also increases for all levels of bone ash replacement at 300 °C. At 300 °C, with same exposure duration and for 5% and 10% replacement of cement with BA, reduction in residual compressive strength of concrete is gradual.

At 600 °C, bone ash blended cement concrete losses more than half of its strength as shown in Table 5. This is attributed to chemical transformation of cement paste like decomposition of Ca(OH)2, which is one of the most important compound in cement paste, resulting shrinkage of concrete. In addition this rapid reduction in compressive strength attributed due to degradation of calcium silica hydrates (C–S–H) which mainly occur at temperature above 400 °C–600 °C according to [24]. As percentage of bone ash in the mix increases from 5% to 20%, concrete compressive strength reduced by 5% to 30% at room temperature and this reduction in residual compressive strength increases up to 40% for temperature of 600 °C. At same exposure duration and for 5% and 10% replacement of cement with BA, decrease in residual strength of concrete is gradual and it becomes higher as the BA level of replacement increased further as it can be observed in Table 5. When exposure duration is considered, there is up to 10% reduction difference between 1 and 3 h exposures at 600 °C. The percentage reduction in residual compressive strength of concrete with bone ash as cement replacement becomes more than 80% at temperature of 900 °C and this is due to the disintegration of C-S-H at around 900 °C. When exposure duration is considered, there is up to 5% reduction difference between one and three hour exposure times at 900 °C and this is half of the value obtained at 600 °C which is 10%. This implies that effect of exposure duration diminishes as exposure temperature rises. As shown in Table 5 and Fig. 1 above, at 300 °C with 1 h exposure time, residual compressive strength of BA partially replaced cement concrete is comparable to concrete strength at normal temperature with maximum percentage reduction of 6.79% at 20% bone ash replacement whereas at 600 °C, reduction in compressive strength reaches 48.54% at same BA content & temperature duration. At 900 °C, reduction in residual compressive strength reaches about 78.62% with 20% BA content and 1h exposure duration. On the other hand, at 300 °C with 3 h exposure duration, residual compressive strength of BA partially replaced cement concrete reduced by 5.91% and 12.47% at 10% and 20% BA replacement respectively whereas at 600 °C, reduction in compressive strength reaches 44.41% and 57.35% at same BA content & temperature duration. At 900 °C, reduction in residual compressive strength reaches about 73.46% and 81% for the aforementioned bone ash contents and exposure time. These results indicate that temperature intensity has significant influence on compressive strength of concrete particularly BA blended cement concrete at temperatures 300 °C and above. In addition, it is observed that reduction of residual compressive strength becomes steeper above 10% BA content for all levels of temperatures.

3.5 Effect of Elevated Temperature on Split Tensile Strength of BA Partially Replaced Cement Concrete – Air Cooling

It is not uncommon to neglect concrete tensile characteristics in strength calculations at elevated and room temperatures. Nevertheless, concrete tensile strength is essential since concrete cracking is due to tensile stress and evolution of micro cracks resulting in structural damage of a member in tension. When concrete is exposed to fire aforementioned formation of cracks can be overwhelming because of spalling due to elevated temperature. Table 6 and Fig. 2 below shows split tensile strength variation as function of temperatures and percentages of replacement.

Table 6. Compressive strengths when concrete is exposed to different temperature intensities and durations

Percentage replacement of cement with BA (%)	Split tensile strength (MPa)						
	RT	300 °C 1 h	300 °C 3 h	600 °C 1 h	600 °C 3 h	900 °C 1 h	900 °C 3 h
0	4.1	3.14	2.7	1.93	1.83	1.03	0.75
5	4.09	2.71	2.55	1.87	1.38	0.96	0.57
10	4.08	2.38	2.35	1.8	1.19	0.73	0.45
15	3.97	2.3	2.15	1.75	1.06	0.70	0.39

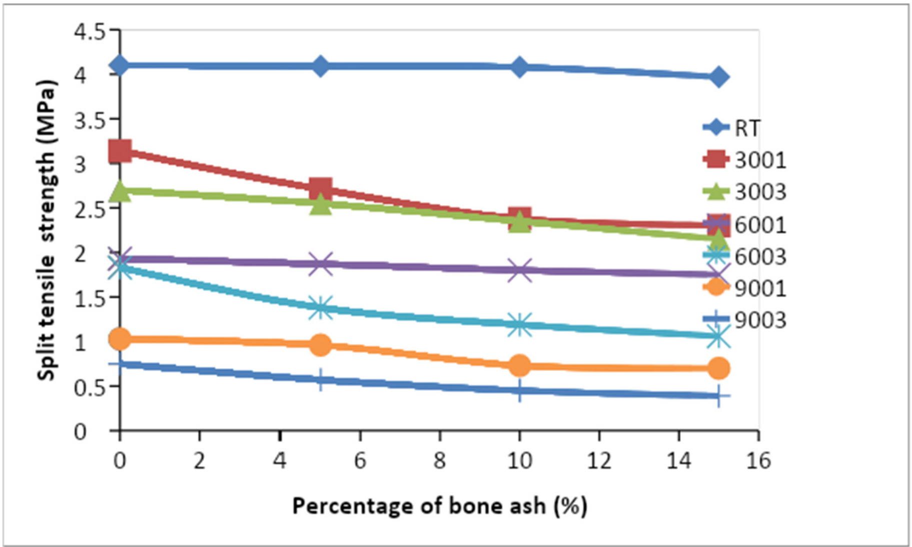

Fig. 2. Variation of split tensile strength with percentage of BA and temperature (NB: The last digit in the legend represents the exposure duration. For example 3001 implies that at 300 °C for 1 h exposure duration)

As shown in Table 6 and Fig. 2 above at both room temperature and 300 °C, when the percentage of bone ash for the replacement of cement increases from 0% to 15%, the split tensile strength of concrete also decreases gradually. At 300 °C in 3 h exposure, normal concrete losses about 34.15% of its initial tensile strength and this reduction become 45.84% when the percentage of BA is 15%.

At 600 °C, there is a high scale thermal damage in form of micro cracks and as a result BA partially replaced cement concrete had only 26.7% of its initial strength at 3 h exposure with 15% BA content. As shown in Table 6 at 1 h duration, the split tensile strength of concrete reduced by 9.33% at 15% replacement of cement with BA. At temperature of 900 °C and duration of 3 h, concrete with 15% BA had only about 10% of its original split tensile strength.

Generally, as it can be observed in Table 6 and Fig. 2 above as the temperature increases from 300 °C to 900 °C, the percentage reduction in residual tensile strength also increase for all percentage replacements of cement with BA. This linear variation of tensile strength as the compressive strength indicates that tensile strength also depends on the same parameters as the compressive strength. Again, the residual split tensile strength reduces as the exposure duration and Percentage of bone ash increases keeping the temperature intensity constant. Split tensile strength losses of bone ash (BA) blended concrete at elevated temperatures might be due to weak microstructure of BA blended cement concrete due to less silicate compounds of BA allowing initiation of micro cracks.

3.6 Effect of Elevated Temperature on Compressive Strength of BA Blended Cement Concrete - Water Cooling

Cooling method affects heated concrete properties. In practice, it is not uncommon to exercise concrete fast cooling by water pouring. Table 7 and Fig. 3 below summarize comparisons between normal and water cooling regimes.

Table 7. Summary of percentage reduction in compressive strength through water cooling and air cooling

Percentage replacement of cement with BA (%)	Percentage reduction in compressive strength (%)								
	RT	Natural (Air) cooling				Water cooling (quenching)			
		3001	3003	6001	6003	3001	3003	6001	6003
0	38.95	2.21	5.03	39.02	47.52	7.47	20.74	46.67	60.59
5	36.47	3.54	5.32	37.48	46.78	14.78	21.14	56.32	58.68
10	34.18	3.57	5.91	34.67	44.41	24.93	32.91	59.74	67.79
15	29.36	5.01	6.16	39.65	48.13	40.57	47.34	74.76	82.66

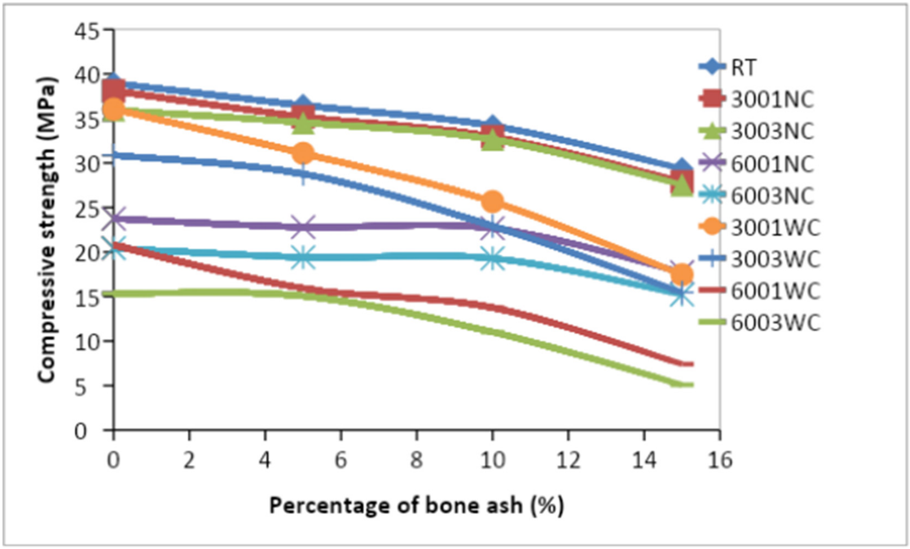

Fig. 3. Comparisons of residual compressive strength through water and air cooling (NB: NC = normal/ air cooling, WC = water cooling/quenching)

Relationship of cooling methods and compressive strength is presented in Table 7 and Fig. 3. As it can be observed on aforementioned table and figure by considering all contents of BA and exposure durations, at 300 °C in normal cooling regime the percentage reduction in compressive strength is from 2.21% to 6.16% where as in water cooling regime it is about 7.47% to 47.34%. Again at 600 °C in air cooling regime, the percentage reduction in compressive strength is from 34.67% to 48.13% and in water cooling regime it is about 46.67% to 82.66%.

In average as compared to air cooling, fast cooling results in up to 35% compressive strength loss. This loss could be attributed to a thermal shock formation as a result of sharp temperature drop in short period of time. Also, test results indicate compressive strength loss becomes steeper above 10% BA replacement for both cooling schemes. Similarly, further strength losses lessen as exposure temperature increases, implying for high temperature ranges (600 °C and 900 °C) effect of high temperatures is influential variable than effect of selected cooling method]. Concrete strength values gap with various cooling methods decreases as temperature increases. Overall, this research indicates cooling methods affects concrete compressive strength.

3.7 Effect of Heating on the Weight Loss of BA Blended Cement Concrete

Next, Table 8 below presents weight loss of specimens for various percentages of bone ash in different temperatures.

Table 8. Weight loss of concrete specimens for different percentages of bone ash at different temperatures

Percentage replacement of cement with BA (%)	Percentage weight loss (%)						
	RT	300 °C	300 °C	600 °C	600 °C	900 °C	900 °C
		1 h	3 h	1 h	3 h	1 h	3 h
0	0	3.62	5.97	5.09	8.24	9.89	10.10
5	0	3.77	6.64	6.36	8.79	9.4	9.72
10	0	3.94	6.92	7.17	9.11	9.26	10.34
15	0	4.12	7.11	7.35	9.40	10.06	10.43
20	0	4.94	7.49	8.50	9.73	10.39	10.78

As it is shown in Table 8 above, in general, weight loss increases with increasing temperature intensity and duration of exposure. Duration of temperature has significant effect on weight loss of bone ash partially replaced cement concrete especially at lower temperatures (300 °C), but its effect diminishes as temperature intensity increases. Temperatures of 600 °C and 900 °C cause hardened paste to lose its cementing property and thus significantly reduced hardened concrete mechanical properties. Due to temperature changes in concrete cause differential changes in concrete constituents, these results reduction of weight loss. Low temperature cannot remove free and capillary water and heat has low probability to transfer inner part of a concrete at this stage. Weight loss increases gradually as percentage of BA for cement replacement increases and highest loss occurred at 20% replacement of cement with BA. This is due to low binding property of bone ash as compared to cement. Also, unit weights decline as temperature surges. There is also weight loss of specimens caused by water loss. Air voids form in concrete as a result of water loss in cement paste. This results in deterioration of specimen structural integrity as temperature increases. Since BA is lightweight material as compared to OPC there is more reduction in weight as percentage of BA increases. Weight loss of specimens indicates concrete material mass loss of and subsequently excess air voids formation.

4 Conclusions

This research experimentally investigated behavior of concrete with bone ash partially replacing cement. Among other thing, variables including intensity of temperature, exposure duration, cooling method and various bone ash percentage replacements were studied. Next, findings inferred from this research are presented.

- Residual compressive strengths of normal concrete and concrete with BA as cement replacement (partial) have not shown significant loss in strength at 300 °C as compared to other temperature ranges. At 300 °C there is gradual compressive strength reduction up to 10% BA replacement where as 10% to 15% BA replacement, strength loss was doubled. Therefore, concrete produced by cement being partially replaced with 10% bone ash is stable up to temperature of 300 °C.

- The effect of exposure duration on concrete compressive strength with bone ash as cement replacement lessens for 900 °C as compared to 300 and 600 °C.
- The residual split tensile strength reduces as the exposure duration and percentage of bone ash increases keeping the temperature intensity constant.
- Fast cooling/water quenching results in further strength loss up to 35% as compared to air cooling.
- After exposure to elevated temperature, concrete with bone ash as cement replacement loses its weight and changes color. Also starting from 600 °C fine cracks begin to appear on its surface and the cracks became very pronounced at 900 °C.
- Overall as compared to control, usage of BA in concrete exposed to elevated temperatures results in compressive and tensile strengths losses. However as BA replacement up to 10% exhibited good concrete characteristics at elevated temperatures. Up to 10% BA replacement, as compared to control strength loss is statistically minute. This implies optimum threshold value of BA replacement of cement in concrete at elevated temperature is 10%. Therefore, a 10% replacement of cement with BA is a step forward in using waste materials as construction input materials and promoting green construction.

References

1. EcoSmart: Environmental Impact: Cement Production and the CO_2 Challenge. http://www ecosmartconcrete.com/envirocement.cfm. Accessed 02 Mar 2012
2. Kassaye, A.F.: Study on the uses of Derba Ordinary Portland and Portland Pozzolana Cement for Structural Concrete Production. MSc thesis, Addis Ababa University (2014)
3. ESIA Summary Greenfield Derba Cement Project DMC: Establishment of 5,600Tpd Clinker Capacity Greenfield Cement Project and Operation of Captive Mines, Ethiopia (2008)
4. Badur, S., Chaudhary, R.: Utilization of hazardous wastes and by-products as a green concrete material through S/S process: a review. Rev. Adv. Mater. Sci. **17**, 42–61 (2008)
5. Kocak, Y.: A study on the effect of fly ash and silica fume substituted cement paste and mortars. Sci. Res. Essays **5**(9), 990–998 (2010)
6. Abdul, R.: Animal bone – a brief introduction. Int. J. Sci. Environ. Technol. **3**(4), 1458–1464 (2014)
7. Kosmatka Steven, H., Kerkhoff, B., Panarese William, C.: Design and Control of Concrete Mixtures. 14th edn. Portland Cement Association, Skokie (2002)
8. Awol, A.: Using marble waste powder in cement and concrete production. MSc. thesis, Addis Ababa University (2011)
9. Karakurt, C., Topcu, I.B.: Effect of blended cements with natural zeolite and industrial by-products on rebar corrosion and high temperature resistance of concrete. Constr. Build. Mater. **35**, 906–911 (2012)
10. Akca, A.H., Zihnioğlu, N.Ö.: High performance concrete under elevated temperatures. Constr. Build. Mater. **44**, 317–328 (2013)
11. Chang, Y.F., Chen, Y.H., Sheu, M.S., Yao, G.C.: Residual stress-strain relationship for concrete after exposure to high temperatures. Cem. Concr. Res. **36**(10), 1999–2002 (2006)
12. Hager, I.: Behaviour of cement concrete at high temperature. Bull. Pol. Acad. Sci. Tech. Sci. **61**(1), 145–154 (2013). https://doi.org/10.2478/bpasts-2013-0013

13. ASTM C184-94e1: Standard Test Method for Fineness of Hydraulic Cement by the 150-μm (No. 100) and 75-μm (No. 200) sieves. ASTM International. West Conshohocken, PA (1994)
14. ASTM C150-05: Standard Specification for Portland Cement. ASTM International. West Conshohocken, PA (2005)
15. Dinku, A.: The need for standardization of aggregates for concrete production in Ethiopian construction industry. In: Third International Conference on Development Studies in Ethiopia, Addis Ababa, Ethiopia (2005)
16. ACI 211.1-91: Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete. An ACI Standard Reported by ACI Committee. 211, 38 (2009)
17. ASTM C39/C39M-18: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. ASTM International. West Conshohocken, PA (2018)
18. ASTM C496/C496M-17: Standard Test Method for Split Tensile Strength of Cylindrical Concrete Specimens. ASTM International. West Conshohocken, PA (2017)
19. ASTM C618-19: Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. ASTM International. West Conshohocken, PA (2019)
20. ASTM C187-1: Standard Test Method for Normal Consistency of Hydraulic Cement. ASTM International. West Conshohocken, PA (2011)
21. Okoye, F.N., Odumodu, O.I.: Investigation into the possibility of partial replacement of cement with bone powder in concrete production. Int. J. Eng. Res. Dev. **12**(10), 40–45 (2016)
22. W/amanuel, A.H., Quezon, E.T., Busier, M.: Effects of varying dosage replacement of cement content by animal bone powder in normal concrete mix production. Am. J. Civil Eng. Architect. **6**(4), 133–139 (2018)
23. Falade, F., Ikponmwosa, E., Fapohunda, C.: Potential of Pulverized Bone as a Pozzolanic material. Int. J. Sci. Eng. Res. **3**(7), 1–6 (2012)
24. Kowalski, R.: Mechanical properties of concrete subjected to high temperature. Architect. Civil Eng. Environ. **3**(2), 61–70 (2010)