Strength and Durability of Green Concrete

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Abstract:
The waste and by-products from industries, thermal plants, and recycled materials have been used historically in cement, concrete and other constructional activities. By-products such as fly ash ,bottom ash, silica fume, etc., gains its utilisation owing to their physical, chemical and engineering properties when used either by processing or directly on concrete. This paper was aimed in making concrete green and durable by utilization of bottom ash as sand replacement material in concrete that can conserve river sand from exploitation and also prevents environmental pollution caused by bottom ash which is dumped in the form of slurry as ash ponds. Bottom ash is replaced for river sand for that30%bottom ash can beneficially be added to the concrete produce 40–50 MP a without affecting the strength. The durability of bottom ash exhibited superior and better performance than reference concrete.

Keywords : green concrete ; bottom ash; waste disposal; coal ash; compressive strength; splitting tensile strength; modulus of elasticity; durability; rapid chloride permeability; rivers and; environmental pollution; conservation of river sand

- **Introduction**

The use of industrial by-products, waste materials, coal combustion products gained its importance due to the higher demand and rise in price of virgin construction materials. The virgin materials such as rivers and(RS) (fine aggregates),granite stones [coarse aggregates (CA)], and raw materials such as limestone, shale, clay for cement production are diminishing and decreasing as a result of continuous and enormous usage in construction activities. It was estimated that nearly five billion tons of concrete was used annually around the world (Penttala,1997). All the natural and virgin materials are decreasing due to the infrastructural demand from an exponential increase in the population, urbanisation and in dustrialisation. These factors not only require huge materials for construction, but also electric power for the development and needs. This in turn increases the amount of coal to be burnt in thermal power plants to generate electricity. The combustion of coal releases tons of coal ash such as fly ash , bottomash (BA) and boiler slag.

Excessive burning of coal results in the air, land and water pollution by disposal of coal ash in the land or as ash ponds .Leaving this ash on the phase of the earth creates ground water contamination ,destroys vegetation and other long term pollution. Total energy consumption in USA, China, India and EU has been rising since Mid-1990s and this trend is expected to increase in the future, (KuramaandKaya,2008). Many research studies after finding its physical, chemical and mineralogical properties of this coal ash have been used accordingly in the concrete and other constructional activities.

The accompanying BA is coarser than fly ash which is dark grey, size ranges from fine to gravel, porous structure particles settle sat the bottom of the furnace. Its utilisation mainly includes as embankment, or as landfill materials (Huang and Lovell, 1990). But recent studies show the importance of the BA as fine aggregates replacement in concrete.

Ghafoori and Bucholc (1996) used lignite-based BA as fine aggregates in concrete and concluded that the porous nature of the BA increases water absorption and when water admixture isused, its engineering properties are similar to that of convention a concrete. Aggarwal et al., (2007) studied the compressive strength, splitting tensile strength, flexural strength of the concrete with BA as fine aggregate replacement and suggested that 30% and 40 % BA attains compressive strength equal to normal concrete at 90 days.

Andrade e tal. (2009) studied the fresh properties of the concrete containing BA as fine aggregates and concluded that the initial and final setting time, rate of hydration is delayed which results in the loss of compressive strength due to higher water cement ratio. Bai et al. (2005) concluded from the study that 30% of naturals and can be beneficially replaced with BA to produce concrete with the compressive strength 40–60 N/mm^2 without affecting permeation and drying shrinkage.

Kim et al. (2012) studied water absorption, and mechanical characteristics of normal and high-strength mortar in corporating fine bottom ash (FBA) as fine aggregates and remarked that compressive strength of the BA is increased from 5–11% higher than there ference mixture. Kim and Lee (2011) studied by using power plant BA as fine and CA in concrete and concluded that BA concrete had more influence on the flexural strengththancompressivestrength.Kumaretal.(2013)studiedcompressive strength and modulus of elasticity of the concrete containing 100% BA as RS and concluded that BA concrete resulted compressive strength lesser but equivalent to the target compressive strength of conventional concrete.

With the pertaining BA utilisationin concrete as fine aggregates as the background of this study, lignite BA was used as fine aggregate replacement (30%,60%and100%)inconcrete. To assess its effectiveness, the compressive strength, splitting tensile strength, modulus of elasticity and rapid chloride permeability were evaluated.

- **Experimental programme**

ASTM type I (2011) ordinary Portland cement (OPC) of 53 grade was used and its physical properties are present edinTable1. A high range water reducing super plasticizer (SP) conforming to ASTM C 494 (2011) type F which was light brown in colour with relative ensity of 1.08at 25 degree Celsius with the pH of 6 was used for fixed water binder ratio and slump value for good workability. Locally available RS was used as fine aggregate conforming to ASTM C 33M-11 (2011).Crushed granite stone, size ranges from 12.5 mm and 20 mm were used as CA and its physical properties are given in Table 2. Water used formixing and curing of concrete was ordinary potable water conforming to ASTMC 1602 (2012).BA used was lignite-based with the calorific value of 2,400 Cal/kg obtained from Ney veli Lignite Corporation India Limited (NLC) which is located in Southern India. The chemical property examined through X-ray fluorescence spectro meter is furnished in Table 3. The total carbon content was determined in accordance with ASTM D 7348 (2008) and it was accepted as the permissible limit in the concrete application.

Table 1 Physical properties of cement

Specific surface area (m^2/kg)	322
Specific gravity	3.1
Consistency%	31
Physical properties	
Soundness	
By Le-Chatelie rmethod in mm	1
By auto clave in mm	0.01
Setting time	
Initial setting time (minutes)	90
Final setting time (minutes)	330
Loss on ignition(%)	1.9

Table 2 Physical properties of aggregates and BA

Type of aggregates	Fineness modulus	Specific gravity	orption in (%)
RS	2.9	2.64	1.25
12mm	-	2.71	0.54
20mm	-	2.77	0.18
BA	1.78	2.38	6.54

Table3 Chemical composition of BA determined by XRF

Chemical compounds	Amounts in percentages(%)
SiO_2	80.23
Al_2O_3	13.83
Fe_2O_3	2.91
CaO	1.24
MgO	1.03
Na_2O	0.14
SO_3	0.26
P_2O_5	0.28
TiO_2	0.08
LOI	1.68

The particle size of BA is in the range of fine gravel to fines and. Unlike RS, the BA sizes from 4.75 mm to 10 micron size. The sizes of the BA particles were angular, dissimilar, and have rough texture from the SEM image as shown inFigure1.

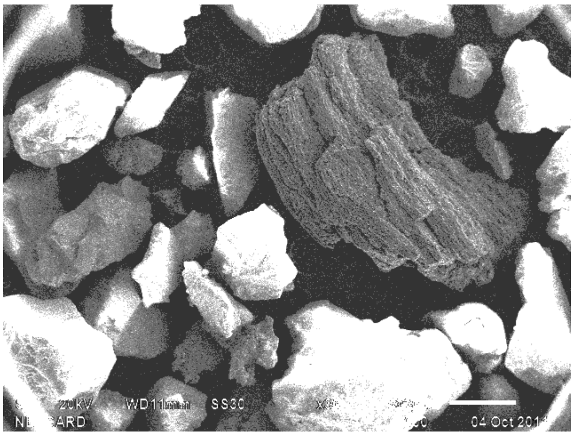

Figure1

- **Mixture proportion**

Concrete mixtures were designed and tested for hardened properties such as compressive strength, splitting tensile strength and modulus of elasticity. To determine the durability, rapid chloride epermeability test was performed. BA was replaced for fine aggregates with three proportions (30%, 60%and 100%) and the details of the mix proportions are given inTable4.

Table4 Mixture proportion

Components/mixture	Reference	0%BA	0%BA	00%BA
Cement in kg/m^3	333	333	333	333
CA in kg/m^3	1,290	1,290	1,290	1,290
Fine aggregates in kg/m^3	754	550	346	0
BA in kg/m^3	0	204	408	680
Water in kg/m^3	140	140	140	140
Water/binder	0.42	0.42	0.42	0.42
SP in kg/m^3	1.2	1.65	3.49	5.59
SP in%	0.35	0.5	1.05	1.68

- **Experimental details**

Concrete mixtures were designed for constant slump range (50–100mm) by increasing the dosage of the SP .Cube moulds of size 100 □ 100 □ 100 mm were used to determinecompressive strength and cylindrical moulds of size 100 mm diameter with200 mm height was used to test the splitting tensile strength. Further cylindrical moulds of size 150 mm diameter with 300mm height was used for modulus of elasticity in accordance toASTMC496/C496M-04 (2011). Samples were tested in accordance to ASTMC 1202-10 (2011) to determine chloride ion permeability.

- **Results and discussions**
- **Effects of BA on fresh properties of concrete**

The concrete after taken from the mixture machine was tested for slump. The water to binder ratio and slump range was fixed (50–100mm).As the percentage of BA was increased, the slump valued ecreased (100–200mm) due to higher water demand from BA. Similar behaviour was observed by Ghafoori and Bucholc (1996) and Andrade et al. (2009) by using BA as fine aggregate. The porous, smooth, irregular BA particles absorbed water that prevents the water distribution to the cement and aggregates. This resulted in poor workability and required water to induce pozzolanic action between cement, BA and aggregates. To overcome this negative effect of the BA on the fresh properties of concrete, the dosage of the SP was increased from 0.35% to1.68%.

- **Effect of BA on compressive strength of the concrete**

Compressive strength of the concrete containing BA for fine aggregate is shown in Figure3 .The compressive strength for 1,7, 28, 56 and 90 days was compared for 30% BA, 60% BA and100% BA concrete with reference mixture. The 28 days compressive strength of the reference mixture was 46.53 MP a .The percentage of decrease between the reference mix and BA replaced concrete was in the range of 9 to 30 %. The strength gain was observed after 56 days for 30% BA and 60% BA, but 100% BA was lesser than the reference mix. The compressive strength of the reference mix and 30%BA were equal at 90days,butthestrength of 60% and100% BA concrete were lesser than the reference mixture with a difference of 10–17%.For the fixed water binder ratio and slump range, the compressive strength of the concrete containing 30% BA was equivalent to reference mixture. It was clear from the compressive strength results that BA reacts with the cement matrix slowly in the beginning, but as the concrete age increases with the curing, the strength of 30% BA was equivalent to reference mixture which is similar to the previous studies Aggarwaletal. (2007) and Baiet al. (2005).

- **Effect of BA on splitting tensile strength**

The splitting tensile strength of reference mixture and BA replaced concrete (30%) increases as the age increases as shown in Figure 4. The concrete with 60% and 100% BA, the splitting tensile strength was lesser than the reference mixture. The strength gain for 28 and 90 days was 24% and 80% compared to the 28 days splitting tensile strength of the reference mixture shown in Table 5. This result is much similar to Aggarwal etal .(2007). The splitting tensile strength behaves in the same way as compressive strength for BA replaced concrete.

Table5 Splitting tensile strength and modulus of elasticity.

	28 days	90 days		28 days	90 days
Reference	2.50	3.62		27.42	29.33
30 BA	3.08	4.53		28.83	29.98
60 BA	1.70	3.01		21.11	26.32
100 BA	1.54	2.19		17.53	19.56

- **Effect of BA on modulus of elasticity of concrete**

The elastic modulus of BA behaves in the same way as that of compressive strength and splitting tensile strength. There was an increase in the elastic modulus of the concrete for 30% BA at the age of curing increases. For the concrete with 60% BA and 100% BA, the modulus of elasticity decreased like that of compressive strength and splitting tensile strength shown in Figure 5. The percentage of increase of 30% BA with reference to the 28 days modulus of elasticity was 5% and 9% for 28 and
90 days respectively. This further confirms that 30% BA beneficially improves the mechanical properties of the hardened concrete through out the ages.

- **Effect of BA on chloride permeability**

Concrete with good strength and durability is preferred for construction. The chloride permeability of the concrete with BA was evaluated for the durability. Result showed that the chloride permeability of concrete with BA was better than the reference concrete shown in Figure 6. The incorporation of BA resulted in the internal curing effect which was reported by Yuk seletal. (2007). This property of BA increases the interlocking effect, there by decreasing chloride permeability.

Table6 ASTMC 1202 limits for chloride ion penetration

Charge passed in coulombs	Chloridei on penetration
>4,000	High
2,000–4,000	Moderate
1,000–2,000	Low
100–1,000	Very low
< 100	Negligible

The chlorideion permeability of thereference concrete and concrete with 30%, 60% and 100% BA showed moderate and low for 28 and 90 days. To conclude durability performance of BA for 28 and 90 days for fine aggregate replacement showed acceptable limits based on ASTM C1202 (2010) limits shown in Table 6.

- **Conclusions**

The mechanical properties of the hardened concrete are interrelated to the type of materials used such as cement, fine aggregate, BA, CA, water and SP. Experimental results showed that in corporation of BA as fine aggregate replacement in concrete for fixed water-binder ratio and slump range positively influenced the compressive strength, splitting tensile strength, modulus of elasticity and chloride ion permeability of concrete for long term curing up to 90 days. The strength development of BA concrete at the early age was less compared to the reference mix. As the curing age increases, the pozzolanic action took place between matrixes containing BA. This lead to the equivalent strength development for 30% BA similar to reference mixture. The pozzolanic reaction of BA made concrete very dense and free performance of concrete to durability. From this experimental investigation the following conclusions can be made.

- 30% BA can beneficially be used in concrete with compressive strength, splitting tensile strength and modulus of elasticity of concrete.

- The durability performance of concrete containing BA resulted positive and there by ensuring the lifetime of the concrete.

Through this experiment, the potential application of BA is enabled by evaluating them techanical properties such as compressive strength, splitting tensile strength and modulus of elasticity of concrete to produce concrete of compressive strength of 40–50 MP a by replacing RS by 30% BA. BA can be used in structural concrete for fine aggregate replacement that can result in desirable strength and high durable performance with the addition of SP. This ultimately reduces the use of RS for construction and also prevents environmental pollution caused by BA that remains unused and disposed as ash lago on sorashponds.

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