UTILIZATION OF INDUSTRIAL BY-PRODUCTS IN THE DEVELOPMENT OF SUSTAINABLE CONCRETE

Professor Rafat Siddique[1]

1. Thapar Institute of Engineering and Technology (Deemed to be University), Patiala, India

ABSTRACT. Solid waste management of Industrial By-products and waste materials is a very challenging. There are several types of by-products and waste materials, and their generation is in millions of tons each year. With increased environmental awareness concerning potential hazardous effects, the recycling or utilization of industrial waste by-products have become an attractive alternative to disposal and can be beneficial in two ways; preserving the natural resources, and maintaining ecological balance. This paper is about the use of industrial by-products such as waste foundry sand (WFS) and coal bottom ash (CBA) in design and development of Sustainable Concrete. This paper presents an overview of the work published on physical, chemical, and mineralogical composition, and properties of concrete.

Keywords: Waste foundry sand, Coal bottom ash, Sustainable concrete

Professor Rafat Siddique is Dean of Research and Sponsored Projects & Senior Professor of Civil Engineering at Thapar Institute of Engineering & Technology (Deemed University), Patiala, India. He is Editor of Construction and Building Materials (Elsevier) and Associated Editor of Journal of Materials in Civil Engineering (ASCE). He is amongst the top 15 researchers in the world in the area of sustainable construction materials in terms of Citations (7700+) and H-Factor (47).

INTRODUCTION

Solid waste management of Industrial By-products and waste materials is gaining significant importance with their ever-increasing quantities. The major generators of industrial by-products are the thermal power plants producing coal ash, the integrated Iron and Steel mills producing blast furnace slag and steel melting slag, non-ferrous industries like aluminum, zinc, iron and copper producing red mud and tailings, wood ash, cement industry producing cement kiln dust, silica fume, etc.

The disposal of industrial by-products is becoming an increasing concern for many industries because of the increasing volume of waste by-product generated, increasing costs of operating landfills in combination with the scarcity of landfill sites. With increased environmental awareness concerning potential hazardous effects, utilization of industrial by-products has become an attractive alternative to disposal. Some of these waste materials could possibly be used in constructional materials for the production of concrete.

WASTE FOUNDRY SAND

Waste foundry sand (WFS), high quality silica sand, is a byproduct from the production of both ferrous and nonferrous metal castings. Foundries use high quality size-specific silica sands in their molding and casting operations. When it is not possible to further reuse sand in the foundry, it is removed from the foundry and is termed as waste foundry sand. Waste foundry sand (WFS) is also referred to as spent foundry sand (SFS) or used foundry sand (UFS). On the basis of the type of binder system used in metal castings, waste foundry sand is categorized as clay bonded sand (green sand) and chemical bonded sand.

Clay-bonded (Green) sand is composed of naturally occurring materials which are blended together; high quality silica sand (85–95%), bentonite clay (4–10%) as a binder, a carbonaceous additive (2–10%) to improve the casting surface finish, and water (2–5%). It is black in color due to its carbon content and is the most commonly used molding media (up to 90%) by foundries. Chemically bonded sands are used both in core making where high strengths are necessary to withstand the heat of molten metal, and in mold making. Chemically bonded sand consists of 93–99% silica and 1–3% chemical binder. The most common chemical binder systems used are phenolic-urethanes, epoxy-resins, furfyl alcohol, and sodium silicates. Chemically bonded sands are generally lighter in color and in texture than clay bonded sands.

Physical Properties of WFS

Waste foundry sand (WFS) is sub-angular to round in shape. Green sands are black or gray, whereas chemically bonded sands are of a medium tan or off-white color. The specific gravity of foundry sand varies between 2.39 and 2.79. Waste foundry sand has a low absorption capacity and is non-plastic. Typical physical properties of waste foundry are given in Table 1.

Table 1 Physical properties of waste foundry sand

PROPERTIES	GUNEY ET AL. [1]	SIDDIQUE ET AL. [2]
Specific gravity	2.45	2.61
Fineness modulus	-	1.78
Unit Weight (kg/m^3)	-	1638
Clay lumps and friable particles	-	0.9
Materials finer than 75µm (%)	24	18

Chemical Properties of WFS

The chemical composition of the spent foundry sand depends on the type of metal molded at the foundry, the type of binder and the combustible used. The chemical composition of the foundry sand may influence its performance. Spent foundry sand consists primarily of silica sand coated with a thin film of burnt carbon, residual binder (bentonite, sea coal, resins/chemicals) and dust. Table 2 lists the chemical composition of a typical sample of spent foundry sand.

Silica sand is hydrophilic and consequently attracts water to its surface. Depending on the binder and type of metal cast, the pH of spent foundry sand can vary between 4 and 8. Because of the presence of phenols in foundry sand, there is some concern that precipitation percolating through stockpiles could mobilize leachable fractions, resulting in phenol discharges into surface or ground water supplies.

Table 2 Chemical composition of waste foundry sand

CONSTITUENT	VALUE (%)			
	Guney et al. [1]	Siddique et al. [2]	Etxeberria et al. [3]	American Foundry men˒s Society [4]
SiO$_2$	98	78.81	95.10	87.91
Al$_2$O$_3$	0.8	6.32	1.47	4.70
Fe$_2$O$_3$	0.25	4.83	0.49	0.94
CaO	0.035	1.88	0.19	0.14
MgO	0.023	1.95	0.19	0.30
SO$_3$	0.01	0.05	0.03	0.09
Na$_2$O	0.04	0.10	0.26	0.19
K$_2$O	0.04	-	0.68	0.25
TiO$_2$	-	-	0.04	0.15
LOI	-	2.15	1.32	5.15

Applications of WFS

The considerable disposal expense has made the current practice of WFS disposal in landfills less favorable. WFS can beneficially be reused in different applications such as:

- Infrastructure engineering and rehabilitation works
- Hydraulic barrier or liner
- In CLSM
- In mortar and concrete
- Pavements
- Asphalt concrete
- Bricks

Properties of Concrete Made With Waste Foundry Sand

The use of spent foundry sand in concrete-related products like bricks, blocks and paving stones has been reported by Khatib and Ellis [5], Naik et al. [6,7], Siddique et al. [8]. Bakis et al. [9] has reported on the use of waste foundry sand (WFS) in asphalt concrete.

Workability

Guney et al. [1] and Etxeberria et al. [3] studied the effect of waste foundry sand (WFS) on the slump of concrete. It was observed that the waste foundry sand decreased the fluidity and the slump value of the fresh concrete. This may be due to the presence of clayey-type fine materials in the waste foundry sand, which are effective in decreasing the fluidity of the fresh concrete.

Compressive strength

Khatib and Ellis [5] observed that with the increase in the replacement level of standard sand with foundry sand, the strength of concrete decreased, whereas Bakis et al. [9] observed a decrease in the strength of asphalt concrete as the percentage of WFS increased. Siddique et al. [8, 10] and Guney et al. [1] observed that the compressive strength and modulus of elasticity of concrete mix containing foundry sand was higher than the control mix in all ages which indicated that foundry sand could be successfully used in making concrete as partial replacement of fine aggregate.

Waste foundry sand can be successfully used in CLSM, and it provides similar or better properties to that of CLSM containing crushed limestone sand. Clay-bonded sand retarded the setting time, and chemically bonded sands required a reduction in water to control bleeding. CLSM containing a combination of fly ash and chemically bonded sands was shown to have excellent characteristics for flowable backfill and excavatable base material (Tikalshy et al. [11]; Dingrando et el. [12]; Reddi et al. [13] reported reduced strength of the stabilized mixes containing clay bonded foundry sand concrete compared to chemically bonded foundry sand mixes.

Splitting tensile strength

Guney et al. [1] observed that the splitting tensile strength of 5% and 15% waste foundry sand concrete is lower than that of the control one whereas the specimens containing 10% waste foundry sand have slightly higher values than control mix. Etxeberria et al. [3] found no significant change in splitting tensile strength of concrete containing chemical foundry sand and green sand. Bakis et al. [9] reported that with increased WFS content tensile

strength decreases whereas Siddique et al. [10] observed increased tensile strength of concrete with an increase in WFS content.

Permeability

Naik et al. [14] observed the permeability of CLSM mixtures containing fly ash and waste foundry sand and determined that 30% replacement of fly ash by foundry sand reduced the permeability whereas an addition of 80% foundry sand abruptly increased the permeability.

COAL BOTTOM ASH (CBA)

The coal ash collected at bottom of furnace is called bottom ash. These particles are too large to be carried in the gases flow and fall through open grates to an ash hopper at the bottom of the furnace. Bottom ash particles are physically coarse, porous, glassy, granular and greyish in colour. Bottom ash is used as land fill material & as base material in road construction. The disposal of bottom ash in ponds poses risk to human health and the environment. Environment concerns are increasing day by day and land fill space is declining, therefore it becomes essential to initiate the effort to utilize the bottom ash. Bottom ash has the appearance and particle size distribution similar to that of natural fine aggregate i.e. river sand.

Uses of Coal Bottom Ash

Bottom ash can be beneficially utilized in a variety of manufacturing and construction applications. At present in America, coal bottom ash is predominantly used for the following applications such as Road base and sub-base, Structural fill, Backfill, Drainage media, Aggregate for concrete, asphalt and masonry and Abrasives/traction

Properties of Coal Bottom Ash

The particles of coal bottom ash are angular, irregular and porous, and have a rough surface texture. The particle size ranges from fine gravel to fine sand. Bottom ash is lighter and more brittle compared to natural sand. The specific gravity of the bottom ash varies from 1.39 to 2.33.

Bottom ash is mainly composed of silica, alumina, and iron with small amounts of calcium, magnesium, sulphate etc. Its chemical composition is controlled by the source of the coal. Table 3 show the comparative study of Chemical composition of bottom ash obtained from different sources of coal.

Table-3 Chemical properties of bottom ash

CHEMICAL COMPOSITION (%)	YUKSEL & GENC [15]	ANDRADE ET AL. [16]	BAI ET AL. [17]	GHAFOORI & BUCHOLC [18]
SiO_2	57.90	56.0	61.80	41.70
Ai_2O_2	22.60	26.70	17.80	17.10
Fe_2O_3	6.50	5.80	6.97	6.63
CaO	2.00	0.80	3.19	22.50
MgO	3.20	0.60	1.34	4.91
Na_2O	0.086	0.20	0.95	1.38
K_2O	0.604	2.60	2.00	0.40
SO_3		0.10	0.79	0.42
LOI	2.40	4.60	3.61	1.13

Properties of Fresh Coal Bottom Ash Concrete

Workability

Ghafoori and Bucholc, [18] found that in case of bottom ash concrete mixture with 100% sand replacement the water cement ratio for fixed workability is higher than that of the control mixture. For combined mixture (50%BA + 50% sand) water requirement reduced significantly. Table-3 presents the properties of fresh bottom ash concrete with partial or full replacement of river sand.

Table-3:- Fresh properties of bottom ash and natural sand concrete [18]

Type of concrete	Slump, (in)	Bleeding percent	Initial setting Time (hr)	Final setting Time (hr)	Air Content percent	Early shrinkage percent
Natural Sand Concrete	4 ^{1}/4	2.2	4.05	5.58	1.90	-0.49
Bottom ash concrete	4 ^{1}/4	4.0	4.2	5.95	1.80	-0.29
Bottom ash +Sand Concrete	4 ^{1}/4	2.8	3.81	5.55	1.85	-0.40

Yuksel and Genc [15] observed that workability of concrete mixtures containing varying percentage from 10% to 40% of bottom ash as sand replacement, 35 kg/m^3 of fly ash, 350 Kg/m^3 of cement & 167 liters of mixing water, improved with reference to control concrete. With 50 % bottom ash as sand replacement, the workability marginally decreased than that of the control concrete. Aramraks [19] observed that the mixes using bottom ash required approximately 25 to 50% more mixing water content than normal concrete to obtain suitable workability. Agarwal et al. [20] found that the workability measured in terms of compaction factor, decreases with the increase of the replacement level of the fine aggregates with the bottom ash. The compaction factor reduced from 0.9 to 0.82 when the replacement level increased from 0% to 50%. Chun et al., (2004) observed that slump decreases with increase

in content of pond-ash, indicating lower workability and the air content also shows a decline when the pond-ash content increases.

Kim and Lee [21] found that the slump flow values of fresh concrete were not changed as the replacement ratio of fine bottom ash was increased. They observed that FBA absorbed smaller amount of cement paste and water on the surface of particles due to its lower porosity and water absorption (5.45%) and higher viscosity of cement used. Pores size of FBA used in their research work was around 0.1 - 10 µm. Figure 1 presents the effect of bottom ash on the slump vales of fresh bottom ash concrete with different sand replacement levels.

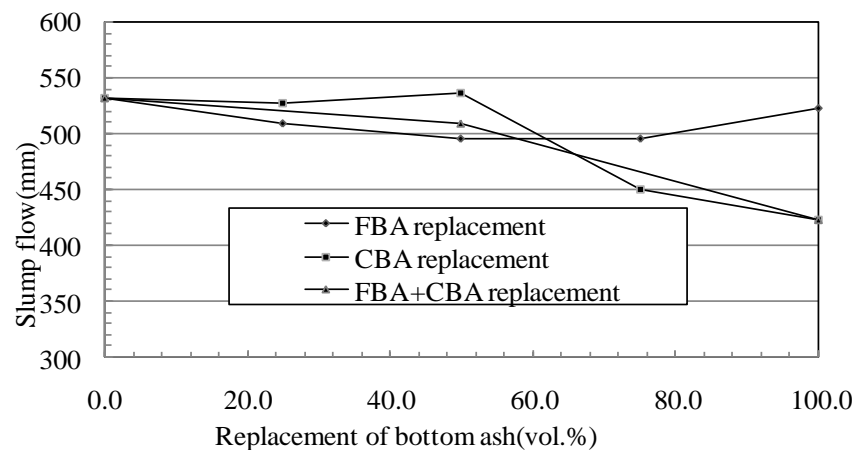Figure 1 Effect of bottom ash on flow characteristics of fresh concrete [21]

Properties of Hardened Coal Bottom Ash Concrete

Density

There is an appreciable decrease in unit weight of concrete when natural sand is substituted with bottom ash. The decrease in density of bottom ash concrete is attributed to the lower unit weight and porous structure of bottom ash as compared to natural sand. Andrade et al. [16] demonstrated that the use of bottom ash having specific gravity of 1.67 g/cm^3 and fineness modulus of 1.55 as sand replacement in concrete resulted in decrease in densities of concrete by 25 % from 2170 kg/m^3 to 1625 kg/m^3. Kim and Lee [21] observed that densities of hardened concrete decreased linearly as the replacement ratio of fine & coarse bottom ash increased. The density of high strength concrete was less than 2000 kg/m^3 when both 100% fine bottom ash and 100% coarse bottom ash were used. The decrease in density was 109 kg/m^3 (4.6%) and 228 kg/m^3 (9.6%) when sand was replaced with fine bottom ash and coarse aggregate was replaced with coarse bottom ash respectively.

Compressive strength

The strength development of concrete   is influenced by porosity of hydrated paste which is controlled by water/cement ratio and the presence of bond cracks at the interface of aggregate and hydrated paste. The strength of individual constituent material of concrete also has influence on the strength of concrete mix. Since bottom ash concrete has higher bleeding, there are more chances of more bleeding water getting trapped below the aggregates. This trapped water results in the formation of the more number of small pores close to the

aggregate surfaces. These pores prevent the excellent bonding of cement paste with the aggregate. Therefore the transition zone between the aggregate and cement paste becomes weak and porous which ultimately results in reduction in strength of bottom ash concrete mix. The weak microstructure obtained with the use of bottom ash is responsible for the decrease in compressive strength.

Ghafoori and Bucholc [18] found that compressive strength of combined bottom ash and sand mix was lower than that of control concrete. The average differences in compressive strength at the age of 3day and 7 day were 12% and 14.5 % respectively. As shown in Fig. 2, when high range water reducing admixture was used in combined mixture, compressive strength surpassed those of control sample at all levels of age. At 28 days of age the compressive strength increased by 24 %.

Andrade et al. [16] observed that concrete mixes prepared with addition of bottom ash as equivalent volume replacement, correcting bottom ash quantities according to the moisture content showed very significant loss in compressive strength. Shi-Cong and Chi-Sun [22] demonstrated that at a fixed W/C, the compressive strength decreased with the increase in the FBA content at all the ages. However when concrete was designed with a fixed slump range, bottom ash concrete showed higher compressive strength than that of the control at all the ages. The improvement in compressive strength could be attributed to the decrease in free W/C due to the fact that for a given slump, the high water absorption properties of FBA lead to reduction in demand of free water to produce the target slump value.
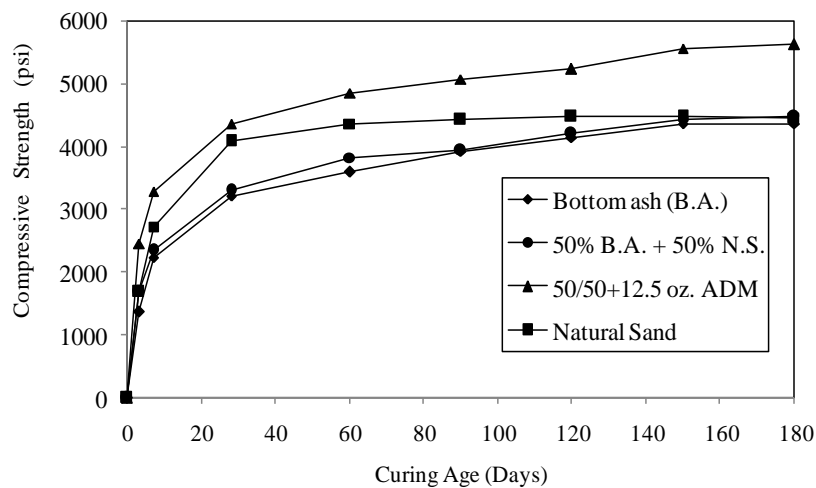
Figure 2 Compressive Strength of concrete containing 500 lb/yd^3 cement [18]

Flexural strength

The flexural strength of concrete mainly depends upon the quality of cement paste in concrete mix. Bottom ash being porous material, upon its use as sand replacement in concrete, the paste becomes weak & porous. Volume of all pores in concrete increases and as such bottom ash concrete mix displays lower flexural Strength. Ghafoori and Bucholc [23] found that flexural strength of bottom ash mixtures were lower than that of reference sample. When a super plasticizer admixture was incorporated into the bottom ash concrete, flexural strength

equaled or slightly exceeded that of control concrete. The strength improvement over that of the bottom ash concrete without super plasticizer was 29.76%, 20.3%, 11.4% and 7.5% as the cement content increased from $500lb/yd^3$ to $800lb/yd^3$. Flexural strength of bottom ash concrete decreased with increase in bottom ash content but with the addition of super plasticizer, it slightly improved at almost all the curing ages.

Topcu and Bilir [24] observed that when bottom ash was used as sand replacement, there was decrease in flexural strength with the increase of bottom ash content and the decrease rate in 7 days flexural strength was similar to that of 28 days flexural strength. The values of flexural strength were lower than that of control sample at all the curing ages. Ghafoori and Cai [25]) studied the effect of bottom ash incorporating it in roller compacted concrete on its mechanical properties. They investigated that flexural strength of bottom ash concrete increased with the curing age and at the end of 90 days it surpassed its 28 days strength by about 17 %. The ratios of flexural strength & compressive strength are fairly uniform with an average value of 1.55.

Drying shrinkage

Porous particle structure of bottom ash is beneficial for reducing the drying shrinkage of concrete. It is considered that the porous bottom ash particles slowly release the moisture during the drying phase of concrete and therefore result in reduced shrinkage. Bai et al. [17] observed that at fixed W/C Ratio of 0.45 and 0.55, drying shrinkage values of all bottom ash concrete were lower than that of control concrete, while at fixed workability, the drying shrinkage values were higher. At fixed W/C, the quantity of porous material in concrete increases with the increase of bottom ash content, which slowly release the water during drying of concrete and thus result in reduced drying shrinkage. Ghafoori and Bucholc [23] observed that despite higher water cement ratio, bottom ash concrete displayed less drying shrinkage in comparison with that of control concrete. Swelling properties of bottom ash concrete were 200% higher than the volume increase exhibited by the equivalent natural sand concrete. Water reducing admixtures had negligible effect on the swelling characteristics of the bottom ash. Ghafoori and Cai [25] in their study found that the one year drying shrinkage strain of bottom ash roller compacted concrete varies from 203×16^{-6} to 298×10^{-6} nearly half that of vibratory placed conventional concrete mixtures. Similar to that of conventional concrete, drying shrinkage of bottom ash roller compacted concrete increased with time.

Permeability

The permeability of concrete depends upon the size, distribution and continuity of pores present in cement paste and permeability of aggregates. Bottom ash concrete has higher permeability as compared to natural sand concrete. With the increase in bottom ash content in concrete its permeability increases. The main factors responsible for the increased permeability of bottom ash concrete are porous microstructure of bottom ash, increased demand of mixing water and higher loss of water through bleeding.

Aramraks [19] found that Chloride permeability of bottom ash concrete was better than that of normal concrete. As shown in Table 4, the concrete mix of 100% coarse grain (passing no.4 and retaining on no.50 standard sieves) bottom ash replacement with 2% super plasticizer showed the lowest chloride permeability. Ghafoori and Bucholc, [23] found that as per AASHTO T-277 specifications, the chloride permeability of bottom ash concrete is

higher than that of control concrete. The permeation of chloride ions into the bottom ash concrete decreases drastically when a low dosage of super plasticizer is used. The bottom ash concrete without admixtures allowed on average 120% greater current flow than the control concrete and with the use of admixture it reduced to 61% above the control concrete. Shi-Cong and Chi-Sun [22] demonstrated that at the same W/C, the resistance to chloride-ion penetration of the concrete mixes decreased with increasing percentages FBA replacement of river sand.

Table-4 Chloride permeability test of concrete at 56 days [19]

| BOTTOM ASH | | W/C | ELECTRICAL | CHLORIDE |
F.M	% BY WT.		CHARGE (COULOMB)	PENETRABILITY
-	0	0.6	4178	High
1.83	50	0.81	3040	Medium
1.83	100	0.89	1975	Low
3.07	50	0.74	3224	Medium
3.07	100	0.85	2080	Low
3.07	50	0.6	2621	Medium
3.07	100	0.80	1860	Low

Abrasion resistance

Resistance to abrasion is greatly influenced by the cementitious paste and fine aggregate of top mortar, which is highly susceptible to moisture. Bottom ash particles are porous and less stiff as compared to dense & stiffer particles of natural sand. Due to its porous microstructure, bottom ash is more venerable to moisture than natural sand, as such its use in concrete as sand replacement result in reduction in abrasion resistance. However with the addition of water reducing admixtures in bottom ash concrete, it's the abrasion resistance increases. Aramraks [19] noticed that the weight loss of normal concrete surface by abrasion test was 53% to 30% of weight loss of bottom ash concrete. The mix of 50% coarse grain (passing no.4 and retaining on no.50 standard sieves) bottom ash replacement and with the use of 2% super plasticizer was the most suitable mix regarding both abrasion resistance & compressive strength properties. Table 5 presents the weight loss of concrete surface at the age of 28 days and 56 days.

Table 5 Weight loss of concrete surface by abrasion[19]

| BOTTOM ASH | | W/C | WEIGHT LOSS (GM/SQ CM) | |
F.M	% BY WT		28 DAYS	56 DAYS
-	0	0.6	0.0535	0.0315
1.83	50	0.81	0.1305	0.0808
1.83	100	0.89	0.1758	0.1032
3.07	50	0.74	0.1318	0.0785
3.07	100	0.85	0.1681	0.1051
3.07	50	0.6	0.0993	0.0649
3.07	100	0.80	0.1452	0.0855

Ghafoori and Bucholc [23] found that the bottom ash concrete was 40 % worse than the control concrete in abrasion resistance. However, with the use of water reducing admixtures, a superior abrasion resistant bottom ash concrete was produced. Ghafoori and Cai [25] found that resistance to abrasion of RCC containing bottom ash is far superior under air–dry conditions to that obtained under wet conditions. For RCC containing 9% cement, the depth of wear under wet conditions was 7.25 times of those under dry conditions. This ratio dropped to 6.42 and 6.00 when cement content increased to 12 & 15 percent respectively. This indicates that higher cement content produces stronger paste & smoother surface layer.

CONCLUSIONS

Waste Foundry Sand

- Inclusion of waste foundry sand as partial replacement of fine aggregates adversely affects the slump and water absorption of the concrete
- Increase in foundry sand contents increases the strength properties of concrete mixtures and also with the age
- Foundry sand can be used as a replacement for regular sand in concrete manufacturing.

Coal Bottom Ash

- Inclusion of bottom ash as sand replacement in concrete influences the workability, setting times, strength, porosity, durability of hardened mass
- Bottom ash is the potential viable material to be used as fine aggregate to produce durable concrete.

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