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Utilization of industrial by-products in concrete

Rafat Siddique*

Department of Civil Engineering, Thapar University, Patiala 147004, Punjab, India

Abstract

Increasing urbanization and industrialization increases the generation of industrial waste in both developed and developing countries. With increased environmental awareness concerning potential hazardous effects, the recycling or utilization of industrial waste by-products have become an attractive alternative to disposal. Several studies have been reported on the utilization of waste materials and by-products such as waste foundry sand (WFS), coal bottom ash (CBA), cement kiln dust (CKD) and wood ash (WA) in making cement-concrete and controlled low-strength material (CLSM). This paper presents an overview of the work published on physical, chemical, and mineralogical composition, mechanical properties such as workability, setting times, compressive, splitting and flexural strength, permeability etc. of concrete and CLSM made with waste foundry sand, coal bottom ash, cement kiln dust and wood ash.

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1. Introduction

Solid waste management is gaining significant importance with the ever-increasing quantities of waste materials that is contemporarily being generated. The major generators of industrial solid wastes are the thermal power plants producing coal ash, the integrated Iron and Steel mills producing blast furnace slag and steel melting slag, non-

* Corresponding author. Prof. Rafat Siddique
E-mail address: siddique_66@yahoo.com

Tel.: +91-987-607-8644; fax: +91-175-2393005.

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.

This paper presents an overview of the work published about the physical, chemical, and mineralogical composition and mechanical properties of concrete made with spent foundry sand, wood ash, coal bottom ash and cement kiln dust.

2. Waste foundry sand (WFS)

Waste foundry sand (WFS), a high quality silica sand, is a by product 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, furfuryl alcohol, and sodium silicates. Chemically bonded sands are generally lighter in color and in texture than clay bonded sands.

2.1. 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: Typical physical properties of waste foundry sand

Properties	Javed and Lovell [1]	Naik et al. [2]	Guney et al. [3]	Siddique et al. [4]
Specific gravity	2.39-2.55	2.79	2.45	2.61
Fineness modulus	-	2.32	-	1.78
Unit Weight (kg/m ³)	-	1784	-	1638
Absorption (%)	0.45	5.0	-	1.3
Moisture content (%)	0.1-10.1	-	3.25	-
Clay lumps and friable particles	1- 44	0.4	-	0.9
Materials finer than 75µm (%)	-	1.08	24	18

2.2. 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 [5]. It has been reported that some spent foundry sands can be corrosive to metals [6]. 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. Foundry sand sources and stockpiles must be monitored to assess the need to establish controls for potential phenol discharges [5].

2.3. 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

Table 2. Typical chemical composition of waste foundry sand

Constituent	Value (%)			
	American Foundry men's Society [7]	Guney et al. [3]	Etxeberria et al. [8]	Siddique et al. [4]
SiO ₂	87.91	98	95.10	78.81
Al ₂ O ₃	4.70	0.8	1.47	6.32
Fe ₂ O ₃	0.94	0.25	0.49	4.83
CaO	0.14	0.035	0.19	1.88
MgO	0.30	0.023	0.19	1.95
SO ₃	0.09	0.01	0.03	0.05
Na ₂ O	0.19	0.04	0.26	0.10
K ₂ O	0.25	0.04	0.68	-
TiO ₂	0.15	-	0.04	-
Mn ₂ O ₃	0.02	-	-	-
SrO	0.03	-	-	-
LOI	5.15	-	1.32	2.15

2.4. 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 [9], Naik et al. [10,11], and Siddique et al. [12]. Bakis et al. [13] has reported on the use of waste foundry sand (WFS) in asphalt concrete.

- Workability

Guney et al. [3] and Etxeberria et al. [8] 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 [9] observed that with the increase in the replacement level of standard sand with foundry sand, the strength of concrete decreased, whereas Bakis et al. [13] observed a decrease in the strength of asphalt concrete as the percentage of WFS increased. Siddique et al. [12,14] and Guney et al. [3] 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 [15,16]. Reddi et al. [17] 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. [3] 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. [8] found no significant change in splitting tensile strength of concrete containing chemical foundry sand and green sand. Bakis et al. [13] reported that with increased WFS content tensile strength decreases whereas Siddique et al. [14] observed increased tensile strength of concrete with an increase in WFS content.

- Permeability

Naik et al. [2] 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.

3. Coal bottom ash (CBA)

Coal bottom ash (CBA) is the noncombustible agglomerated ash particles formed in coal furnaces of coal fired thermal power plants. 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. Indian coals have high amounts of inorganic inclusions with varying properties and on combustion result in a high ash content of up to 46%. About 100 million tons of fly ash and 25 million ton of bottom ash is produced by these thermal power plants annually. Bottom ash is used as land fill material and as base material in road construction. In India up till now a small volume of fly ash is utilized in the production of cement, but bottom ash is not used in any form. Bottom ash along with unutilized fly ash is disposed of in ponds spread over thousand acres of land. The disposal of bottom ash in ponds poses risks to human health and the environment. Bottom ash has the appearance and particle size distribution similar to that of natural fine aggregate, i.e. river sand. Because of these properties it is attractive for it to be used as sand replacement in concrete. Recently research works have been focused on the usage of bottom ash as partial sand replacement in concrete.

3.1. Physical properties of CBA

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 with a low specific gravity has a porous texture that readily degrades under loading or compaction. Table 3 shows the typical physical properties of coal bottom ash studied by different researchers.

Table 3. Typical physical properties of bottom ash [18]

Physical Properties	Yuksel and Genc [19]	Topcu and Bilir [20]	Kim and Lee [21]	Naik et al. [22]	Ghafoori and Bucholc[23]
Specific gravity	1.39	1.39	1.87	2.09	2.47
Water absorption (%)	6.10	12.10	5.45	13.6	7.0
Fineness modulus	--	--	2.36	--	2.8

3.2. Chemical properties of CBA

Bottom ash is mainly composed of silica, alumina, and iron with small amounts of calcium, magnesium, sulfate, etc. The chemical composition of bottom ash varies depending on the type of coal used and the process of burning. Table 4 shows the comparative study of the chemical composition of bottom ash, as reported in literature.

Table 4: Typical chemical properties of bottom ash [18]

Chemical composition (%)	Yuksel and Genc[19]	Andrade et al. [24]	Bai et al. [25]	Sani et al. [26]
SiO ₂	57.90	56.0	61.80	54.80
Al ₂ O ₃	22.60	26.70	17.80	28.50
Fe ₂ O ₃	6.50	5.80	6.97	8.49
CaO	2.00	0.80	3.19	4.20
MgO	3.20	0.60	1.34	0.35
Na ₂ O	0.086	0.20	0.95	0.08
K ₂ O	0.604	2.60	2.00	0.45
TiO ₂	--	1.30	0.88	2.71
P ₂ O ₅	--	--	0.20	0.28
SO ₃	--	0.10	0.79	--
LOI	2.40	4.60	3.61	2.46

3.3. Applications of CBA

Bottom ash can be beneficially utilized in a variety of manufacturing and construction applications. It is predominantly used for the following applications:

- Road base and sub-base
- Structural fill
- Backfill
- Drainage media
- Aggregate for concrete, masonry and asphalt
- Abrasives/traction

3.4. Properties of concrete made with coal bottom ash

Small size bottom ash can be used as fine aggregate whereas large size (greater than 6 mm) particles can be used as coarse aggregate in concrete and CLSM as backfill. Wei [27] demonstrated the feasibility of using bottom ash in manufacture of masonry products as a partial replacement of coarse as well as fine aggregates.

- Workability
Workability of concrete mainly depends on the number of fines and properties of fine aggregate in it. The particle size of bottom ash is generally smaller (75 μ m) than natural river sand. The use of bottom ash as a replacement of natural sand in concrete increases the number of fines and irregular shaped, rough textured and porous particles, thereby increasing the internal particles friction. These properties enhance the water demand and reduce the workability [28,18]. Aramraks [29] observed that with an addition of 50 and 100% CBA in concrete the water demand increased by 25-50% compared to normal concrete.
- Setting time
Ghafoori and Bucholc [30] observed that, respectively, the average initial and final setting times for bottom ash concretes were 6.3% and 9.5% higher than the control mixture. An addition of 50% of CBA and 50% sand in concrete reduced the initial setting time by 9%, whereas a reduction in 13.5% of the final setting time was observed [23,31] observed that a replacement of 30% sand with CBA increased the initial and final setting time by 23 and 30 min, respectively, compared to control treatment.

- **Compressive strength**

Ghafoori and Bucholc [23] observed that an addition of calcium rich bottom ash as natural sand replacement enhanced the strength of different concrete mixtures. With an addition of 100% CBA, the water-cement ratio for fixed workability is higher compared to control mixture. They also found that on 3 and 7 days of curing 12% and 14.5% compressive strength was reduced whereas after 28 days, 24% increased compressive strength was observed. Ghafoori and Cai [32,33] observed 75% of the 28 days strength in concrete mix attained after 7 days of curing. For mixtures containing 9%, 12% and 15% CBA, 90 days compressive strength exceeded the 28 days compressive strength by an average of 19%, 15% and 12% respectively, whereas after 180 days curing, the 28 days compressive strength was surpassed by 26%. Yuksel and Genc [19] found that with 50% sand replacement 31.8% reduction in strength was observed at 28 days of curing, whereas with 10% sand replacement a decrease in 6.9% strength was observed at 90 days of curing. Similar reduction in strength in concrete mixes were also observed by Aramraks [29], Aggarwal et al. [34] and Arumugam et al. [35], whereas Chun et al. [36], Kurama and Kaya [37], and Bai et al. [25] observed increased compressive strength at lower replacement levels of sand with bottom ash.

- **Flexural strength**

Kurama and Kaya [37] observed no change in 28 days flexural strength of bottom ash concrete compared to the control specimen whereas after 56 days, the flexural strength exceeded that of the control sample, except for the mix containing 25% cement replacement, due to the low activity of bottom ash at the early curing ages. Aggarwal et al. [34] and Topcu and Bilir [20] found lower flexural strength of bottom ash concrete at all the ages than control concrete. At 90 days, 113–118% increased flexural strength of concrete mix containing 30% and 40% bottom ash was observed compared to the concrete mix at 28 days. Similarly, Arumugam et al. [35] observed enhanced flexural strength upto 20% CBA replacement whereas above this percentage, flexural strength reduced.

- **Split tensile strength**

Yuksel and Genc [19] observed that for 50% FBA replacement the split tensile strength was reduced by 58%, whereas with 10% sand replacement, no change in split tensile strength was observed. In additions of chemical admixtures in bottom ash concrete mix, 12% increased split tensile strength was observed compared to the reference mix. Aggarwal et al. [34] and Ghafoori and Cai [32,33] found that the flexural strength of bottom ash concrete specimens were lower than the control concrete specimens at all ages.

- **Permeability**

The permeability of concrete depends upon the size, distribution and continuity of pores present in the cement paste and the permeability of aggregates. Ghafoori and Bucholc [30] found a higher chloride permeability in bottom ash concrete than control concrete. It was observed that concrete containing bottom ash without admixtures allowed for 120% greater current flow than the control concrete, whereas with the use of admixture chloride permeability reduced to 61%. Aramraks [29] found reduced chloride permeability in a concrete mix of 100% bottom ash replacement with 2% super plasticizer. Shi-Cong and Chi-Sun [38] demonstrated that with increasing percentages FBA replacement of river sand at fixed water-cement ratio, the resistance to chloride-ion penetration of the concrete mixes decreased.

- **Abrasion resistance**

Ghafoori and Bucholc [30] found 40% reduced abrasion resistance in bottom ash concrete than the control concrete. However, a superior abrasion resistant bottom ash concrete was produced with the use of water reducing admixtures. Similarly, Aramraks [29] noticed a 53–30% weight loss of bottom ash concrete compared to normal concrete surface. 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% and 15% respectively [32,33].

4. Cement kiln dust (CKD)

Cement kiln dust is a fine powdery material generated in large quantities during the production of Portland cement. It is collected in the control devices such as cyclone, bag house, or electrostatic precipitator during the production of cement clinker. The chemical composition of CKD depends upon the raw materials, fuels, kiln type, overall equipment layout, and type of cement being used. Coarser particles of CKD contain high contents of free

lime while the fine particles usually exhibit a higher concentration of sulfates and alkalis. CKD is regarded as a waste material and is responsible for a significant loss to the cement industry in terms of the value of raw materials, processing, energy usage, dust collection, disposal, and storage. Cement industries generate millions of metric tons of cement kiln dust, as a measure to control product quality (low alkali clinker from high alkali raw materials) and to ensure uninterrupted operation of the plant. The generation of CKD has been estimated to be 15 to 20% of clinker or cement production [19].

4.1. Physical Properties of CKD

The specific gravity of CKD ranges from 2.70 to 3.00 less than that of Portland cement (Gs- 3.15). CKD is slightly soluble in water (0.1% - 1.0%). Particle size distribution is an important physical characteristic of CKD. Corish and Coleman [40] reported that the alkali concentration in CKD depends upon the particle size fraction and suggested that the finer CKDs may contain a higher alkali content. Table 5 shows the typical physical properties of CKD, as studied by different researchers.

Table 5: Typical physical properties of CKD [41]

Property	Value
Gradation (75 % passing)	0.030 mm (no. 450 sieve)
Maximum particle size	0.300 mm (no. 50 sieve)
Specific surface (cm ² /g)	4600-14000
Specific gravity	2.6-2.8

4.2. Chemical Properties of CKD

The chemical composition of CKD depends on the raw materials used and the cement manufacturing processes. Generally, cement kiln dust has a composition similar to that of ordinary Portland cement. It is typically characterized by a higher alkali content as compared to Portland cement, particularly in terms of potassium and sulfur. Compounds of lime, iron, silica and alumina constitute the major chemical composition of CKD. Certain trace metals such as cadmium, lead, selenium, and radionuclides are generally found in concentrations less than 0.05% by weight in cement kiln dust [40]. Table 6 shows the typical chemical properties of CKD studied by different researchers.

Table 6. Typical chemical composition of cement kiln dust.

Constituents (%)	Cement Kiln Dust		
	Maslehuddin et al. [42]	Taha et al. [43]	Udoeyo and Hye [44]
SiO ₂	17.1	15.84	2.16
Al ₂ O ₃	4.24	3.57	1.09
Fe ₂ O ₃	2.89	2.76	0.54
CaO	49.3	63.76	52.72
MgO	1.14	1.93	0.68
SO ₃	3.56	1.65	0.05
K ₂ O	2.18	2.99	0.11
Na ₂ O	3.84	0.33	--
LOI	15.8	5.38	42.39

4.3. Applications of CKD

Cement kiln dust can be beneficially utilized in a variety of manufacturing and construction applications. It is predominantly used for the following applications:

- Blended cements and concrete

- Activator for pozzolans
- Waste stabilization/solidification
- Mine reclamation
- Highway bases and sub-bases
- Agricultural amendment

4.4. Properties of concrete made with cement kiln dust

CKD's cement-like properties also makes it a potential replacement for Portland cement in utilization in concrete, flowable slurry, etc. Several researchers [45,46,47,42,48,43,49,50,51,52,53,54] have reported on some aspects of the utilization of CKD in cement paste, mortar/concrete.

- Setting time

Maslehuddin et al. [47] and El-Aleem et al. [55] observed that with 10% CKD replacement of cement, the initial set time was decreased from approximately 135 min to 65 min, whereas the final set time decreased from 230 min (control) to 110 min with same 10% replacement of Portland cement by CKD. Daous[56] mentioned that blends containing as low as 70% of Portland cement exhibited an increase in setting time (up to 220%) as compared to specimens prepared with 100% cement.

- Compressive strength

Maslehuddin et al. [47] and El-Sayed et al. [57] observed no adverse effect on the compressive strength of concrete containing up to 5% substitution of CKD by weight of cement. Kunal et al. [58] observed that up to 10% cement replacement by CKD in concrete, 9% strength was increased at 91 days of curing. Udoeyo and Hye [11] reported that the strength decreased with an increase in CKD content at these very high replacement levels whereas Wang et al. [59] observed that up to 15% of cement replaced by CKD, the compressive strength of blends (47.8 MPa) increased in comparison to cement alone (46.3 MPa). Daous et al. [56] reported 94% of compressive strength of control in concrete containing 10% CKD and 4% fly ash. A reduction in compressive strength of concrete mix was observed up to 1.8% and 4.5% respectively, for 5% and 10% CKD substitution for Portland cement at water-to-binder ratio of 0.50, whereas for 0.60 water-to-binder ratio 12% and 18% and for 0.70, 8% and 13% reduction in strength was observed [49].

- Tensile strength

Al-Harthy et al. [49] indicated that the control mix (0% CKD) with all water-to-binder ratio (0.50, 0.60 and 0.70) showed flexural strengths in the range of 4.70 to 3.80 MPa at the ages of 3, 7, and 28 days. At 5% and 10% cement replacement by CKD, no significant decrease in flexural strength was observed. Wang et al. [59] found that up to 15% of cement replacement there was an increase in flexural strength (8.5 MPa) of mortar compared to cement alone (8.2 MPa), whereas a gradual decrease in splitting tensile strength of all the concrete mixes was observed by Shoaib et al. [53] as the amount of CKD increased.

- Rapid chloride permeability test (RCPT)

Maslehuddin et al. [47] reported that at 5% CKD replacement levels, 6% increase in chloride permeability was observed whereas at 15% CKD replacement the increase in permeability was 62%. Similar findings were also observed by Al-Harthy et al. [49] and Rukzon and Chindaprasit [60].

5. Wood ash (WA)

Wood ash is the inorganic and organic residue remaining after the combustion of wood and wood products such as chips, saw dust, bark, etc. On the average, the burning of wood results in about 6–10% ashes, and its composition can be highly variable depending on the geographical location and industrial processes. Approximately 70% of the wood ash is being landfilled, around 20% is being used as soil supplement, and the remaining 10% is being used in miscellaneous applications [11].

5.1. Physical Properties of WA

The average particle size of the wood ash was found to be 230 μm whereas the pH of was found to vary between 9 and 13.5 [61]. Naik [62] observed that the specific gravity for wood bottom ash is 1.65 and the average saturated surface dry (SSD) moisture content values were 10.3% for fly ash and 7.5% for bottom ash. The bulk density exhibited average density values of 490 kg/m^3 for fly ash and 827 kg/m^3 for bottom ash. Table 7 shows the typical physical properties of wood ash collected from different sources (W1-W5) reported by Siddique [63].

Table 7. Typical physical properties of wood ash [63]

Properties	Sources of wood ash				
	W1	W2	W3	W4	W5
Retained on no. 325 sieve (%)	23	60	90	40	12
Water requirement, % of control	115	155	115	126	130
Autoclave expansion, %	0.2	0.5	-0.6	-0.22	0.12
Unit weight, kg/m^3	545	412	1376	509	162
Specific gravity	2.26	2.41	2.60	2.26	2.33

5.2. Chemical Properties of WA

Carbon is the main component of wood ash present in the range of 5–30% [64]. The major element constituents of wood ash include calcium (7–33%), potassium (3–4%), magnesium (1–2%), manganese (0.3–1.3%), phosphorus (0.3–1.4%), and sodium (0.2–0.5%). The chemical properties depend upon the type of wood, combustion temperature, etc. [64,65]. Etiegni [66] and Etiegni and Campbell [61] reported that wood ash contains lime (CaO), calcite (CaCO_3), portlandite (CaOH_2) and calcium silicate (Ca_2SiO_4) as major oxides. Table 8 shows the typical chemical properties of wood ash studied by Naik et al. [11, 58]

Table 8: Chemical constituents of Wood Ash (Naik et al. 11,58)

Constituents (%)	Sources of wood ash				
	W1	W2	W3	W4	W5
Calcium Oxide (CaO)	3.5	13.7	19.6	2.2	25.3
Silica (SiO_2)	32.4	13.0	50.7	30.0	8.1
Alumina (Al_2O_3)	17.1	7.8	8.2	12.3	7.5
Magnesium oxide (MgO)	0.7	2.6	6.55	0.7	4.5
Sodium Oxide (Na_2O)	0.9	0.6	2.1	0.5	3.3
Potassium Oxide (K_2O)	1.1	0.4	2.8	2.0	2.7
Iron Oxide (Fe_2O_3)	9.8	2.6	2.1	14.2	3.0
LOI (1000 °C) (%)	31.6	58.1	6.7	35.3	32.8
Moisture (%)	2.4	0.5	0.2	0.4	3.3

5.3. Applications of wood ash

Approximately, 70% of the wood ash generated is landfilled and the remaining is utilized as:

- Soil supplement
- Construction materials
- Metal recovery
- Pollution control

5.4. Properties of concrete made with wood ash

Udoeyo et al. [67] and Abdullahi [68] reported that the addition of wood ash in replacement to cement influences the workability of concrete. Results showed that mixtures with greater wood ash content require a greater water

content to achieve a reasonable workability.

- Water absorption

Concrete specimens containing wood ash absorbed more water as the ash content increased. Udoeyo et al. [66] observed that water absorption at 5% wood ash content was 0.4% and increased to 1.05% at 30% ash content. However, these values are less than 10% which is the percentage water absorption value accepted for most construction materials.

- Compressive strength

Naik et al. [69] reported that wood ash exhibited pozzolanic properties. Based on the results, they observed increase in strength from 34 MPa (28 days) to 44 MPa (365 days) in the control mixture (without wood fly ash) whereas 33 MPa to 46 MPa of strength in concrete mixtures containing wood fly ash was observed from 28 to 365 days of curing. Abdullahi [68] reported that mixture containing 20% wood ash had higher strength than 10% wood ash content at 28 and 60 days due to the presence of silica in wood ash responsible for the formation of adequate hydration products in concrete.

- Splitting tensile strength

Naik et al. [69] concluded that control mixture (without wood fly ash) achieved a tensile strength of 3.8 MPa at 28 days and 4.3 MPa at 365 days, whereas strength of concrete mixtures containing wood fly ash varied between 3.6 and 4.0 MPa at 28 days and between 4.2 and 5.1 MPa at 365 day. It was concluded that splitting tensile strength generally followed a similar pattern as for the compressive strength.

- Flexural strength

Udoeyo et al. [67] reported decrease in flexural strength with the increase in wood ash content but at a slower rate than that of compressive strength. Flexural strength of samples containing 5% wood ash was 5.20 N/mm² at 28 days, and it decreased to 3.74 N/mm² at 30% ash content. Naik et al. [69] observed that flexural strength of concrete containing WA varied between 3.9 and 4.4 MPa at 28 days and between 4.3 and 5.3 MPa at 365 days. It was concluded that the inclusion of WA enhanced the flexural strength of concrete mixtures due to the pozzolanic contribution of the wood fly ash.

6. 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 and/or fly ash in making controlled low-strength materials without any significant modification or adjustment

Coal bottom ash

- Bottom ash is the potential viable material to be used as fine aggregate to produce durable concrete
- Inclusion of bottom ash as sand replacement in concrete influences the workability, setting times, strength, porosity, durability of hardened mass
- Decrease in strength of concrete is mainly due to higher porosity and higher water demand on use of bottom ash in concrete

Cement kiln dust

- CKD can be successfully utilized as an activator for industrial wastes such as copper slag, ground granulated blast furnace slag, etc.
- Addition of alkali or high alkali content of CKD unfavours the formation of ettringite which attributes to reduction in strength
- Increasing CKD content increased the compressive strength of the concrete upto 10% CKD content

Wood ash

- Inclusion of wood ash partial replacement of cement adversely affects the slump of the concrete
- Water absorption capacity of the concrete increases with increase in wood ash content
- Strength properties of concrete mixtures decreases marginally with increase in wood ash contents, but increases with age due to pozzolanic actions

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