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Review of beneficial uses of cement kiln dust (CKD), fly ash (FA) and their mixture

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Abstract

Beneficial use of industrial by product materials has the potential to provide economic benefits such as preserve raw resources, and avoid negative environmental impacts associated with the acquisition and processing of raw materials. Cement kiln dust (CKD) and Fly Ash (FA) are by-products formed during the manufacture of cement and coal-fired electricity generation respectively. The present work presents a general review on the applications of the CKD and FA in the field of agriculture, waste treatment, soil stabilization, concrete and cement industry. These beneficial uses of CKD and FA can contribute significant environmental and economic benefits. Environmental benefits can include reduced greenhouse gas emissions, reduced need for disposing in landfills, and reduced use of virgin resources. Economic benefits can include job creation in the beneficial use industry, reduced costs associated with CKD and FA disposal, increased revenue from the sale of CKD and FA, and savings from replacement of other more costly materials.

1. Introduction

1.1 Cement kiln dust

Cement kiln dust (CKD) is an industrial by-product formed during the manufacture of cement and is a waste material that is traditionally destined for landfills. It is a fine powdery material similar in appearance to Portland cement [1]. Wet-process kilns and dry-process kilns are the main two types of cement kiln processes, the first type accept feed materials in a slurry form; and the later one accepts feed materials in a dry ground form. The exhaust gases from cement production process are passed through dust collection system (e.g., cyclone). Part of the collected CDK from the cyclone could be returned to the kiln. The production of one ton of cement generates around 0.06-0.07 ton of CKD. Global cement production is expected to increase from 3.27 billion metric tons in 2010 to 4.83 billion metric tons in 2030; with approximately 220 million tons of cement dust is discarded annually from these cement manufacturing facilities. X-ray diffraction analysis of cement kiln dust showed that the main constituent is calcite ($CaCO_3$), quartz (SiO_2) and calcium sulfate ($CaSO_4$) [2]. CKD is generally non-hazardous because of its relatively low leaching properties for heavy metals. However, its presence in open atmosphere for a long period may have significant effects on the environment. Trace constituents include cadmium; lead, selenium, and radionuclide are generally found at concentrations of less than 0.05 percent by weight in CKD. However, since these constituents are potentially toxic, and its concentrations can vary between cement plants, it is important to assess the mobility and leach ability of these traces constituents in the CKD [3].

1.1.1 Environmental problems related to CKD:

Dust emissions originate mainly from the raw mills, the kiln system, the clinker cooler, and the cement mills. A general feature of these process steps is that hot exhaust gas or exhaust air is passing through pulverised material resulting in an intimately dispersed mixture of gas and particulates. The nature of the particulates generated is linked to the source material itself, that is, raw materials (partly calcined), clinker or cement. These emissions are not only deteriorating air quality but also degrading human health. Emissions have local and global environment impact resulting in global warming, ozone depletion, acid rain, biodiversity loss, reduced crop productivity etc. [4]

1.2 Fly ash

Fly ash is a fine grained powder left as residue after the burning of coal during the production of electricity. It mainly consists of silica, alumina and iron. It is finely separated residue that outcomes from the ignition of pounded coal and is transported from the burning chamber by fume gases. Fly ash has slight cementitious value because in moisture it reacts chemically and cementitious compounds are formed which improves its strength and compressibility characteristics [5].

Fly ash can be tan to dark gray, depending on its chemical and mineral constituents. Tan and light colors are typically associated with high lime content. A brownish color is typically associated with the iron content. A dark gray to black color is typically attributed to an elevated unburned content. Fly ash color is usually very consistent for each power plant and coal source.

Fly ash particles are generally spherical in shape and range in size from 0.5 µm to 100 µm. They consist mostly of silicon dioxide (SiO_2), which is present in two forms: amorphous, which is rounded and smooth, and crystalline, which is sharp, pointed and hazardous; aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3). Fly ashes are generally highly heterogeneous, consisting of a mixture of glassy particles with various identifiable crystalline phases such as quartz, mullite, and various iron oxides. Total Amount of FA generated all over the world reaches 750 million tons per year (China produced almost 77% of this amount), and according to statistics, the global average utilization rate of FA is about 25% [6].

1.2.1 Environmental problems related to FA

Many environmental problems could be caused by FA such as; (1) FA cannot be disposed-off in the open field because it pollutes the air, soil and ground water. (2) Transportation of FA is difficult since the lightweight particles tend to fly causing air pollution. (3) Long inhalation causes serious respiratory problems. (4) FA has adverse impacts on agriculture and forest fields. (5) Disposal in sea, river or ponds damages the aquatic life; fly ash causes siltation problems. (6) Long and continuous use of fly ash as fertilizer makes hardpan underground. (7) Requirement of huge land for making ash ponds or dikes [7].

2. Reuse of by-products

The general trend all over the world is the reuse of the various industrial wastes or by-products, particularly the solid wastes, in useful applications in order to prevent, or at least to reduce the environmental pollution [8]. In order to minimize the undesirable environmental impacts and to conserve materials, many researches have been conducted to investigate the beneficial uses of CKD and FA as a raw material, fertilizer, construction material, adsorbent and improving soil properties [9]. During the last decade extensive research has been carried out to utilize byproducts such as CKD and FA. Broadly, utilization programs can be evaluated from two points, i.e. mitigating environmental effects and addressing disposal problems. The chemical composition of CKD and FA are presented on table (1) [1].

Table (1) Chemical composition of CKD and Fly-ash

Chemical	CKD (wt%)	FA (wt%)
AL_2O_3	3.5	25.56
SiO_2	15.37	51.11
CaO	58.85	4.30
Fe_2O_3	3.08	12.48
K_2O	7.00	0.70
MgO	1.55	1.45
Na_2O	4.37	0.77
SO_3	5.66	0.24
Loss on ignition	23.79	0.57

The present study provides a literature review on the beneficial usage of CKD, FA and their mixture in the field of agriculture, waste treatment, soil stabilization, concrete and cement industry.

2.1 Agriculture reuse of byproducts

Optimizing soil chemistry is a critical process in agriculture. Acid soils or soils with depletion of essential plant nutrients can stunt seed germination and root development. These soils can also inhibit the uptake of nutrients by the plants [10]. The byproduct is considered a good alternative for being utilized in the agriculture fields if it has the following abilities; (i) Soil amendment to modify the pH of the soil. (ii) Soil conditioner to improve the physical and chemical properties of soil. (iii) Source of essential plant nutrients like P, K, Ca, Mg, Cu, Zn, Fe, Mn, etc. [7].

2.1.1 CKD reuse in agricultural filed

The chemical and physical properties of CKD provide various advantages for agricultural applications such as:
The dust could supply plants with enough amounts of S, Mg, and K, so they use CKD instead of the chemical fertilizer. Carroll et al., [11] found that they have the same ability to increase yields of alfalfa.
Calcium silicate and lime as constitute of CKD increased dry matter yield of sorghum in an acid soil, but it did not show any significant effect on dry matter yield of barley when planted in sand and soil mixed with CKD [12]. CKD contained beneficial amounts of crop micro- and macro-nutrients, and provides calcium to potatoes and is an efficient source of plant-available potassium comparable to commercial fertilizers without resulting in crop or soil contamination with heavy metals. [13].
Due to its ability to hold water from 40 to 50% of its weight, CKD can assist in drought resistance [14]. Regarding alkalinity, CKD can increase the pH of the soils, reduce fluctuation of pH in the soils, and as a result reduce plant and root stress. CKD can successfully be used as a liming agent in acidic soils [15]. Bio-solids mixed with CKD can be recycled as agricultural amendments through direct applications to crop lands, but this practice has raised numerous environmental and health issues because of the significant concentrations of metals, organic compounds and pathogens commonly found in these waste materials [16].
Treated bio-solids with CKD were more drastic than any of the other treatments and led to excessive removal by leaching and/or degradation of many lipid components and a reduction in molecular diversity. Some researchers investigated the chemical partitioning of trace metals in soils after one application of CKD and studied the effect on soybean during one growing season, and concluded that the total concentrations of metals in the bio-solids and the CKD, were relatively low compared to the maximum concentrations of these metals in clean sludge recommended by the US Environmental Protection Agency [17]. Christie et al., [18] investigated the liming and fertilizer value of alkaline-stabilized bio solids applied annually to spring barley crop. They reported that mixing with CKD produced a similar nutrient value in alkaline bio-solids which is similar to inorganic fertilizer.

2.1.2 Reuse of FA for Agriculture

Beneficial usages of FA depend on the chemical and physical properties include;
According to Khan and Khan [19] a gradual increase in fly ash concentration in the normal field soil from 0, 10, and 20 up to 100% v/v increased the pH, thereby improving the availability of sulfate, carbonate, bicarbonate, chloride, P, K, Ca, Mg, Mn, Cu, Zn and B. They also found that addition of fly ash to acidic and alkaline soil decreased the amounts of Fe, Mn, Ni, Co and Pb released from acid soil.
Fly-ash, organic and inorganic fertilizers saved N, P and K fertilizers to the range of 45.8%, 33.5% and 69.6%, respectively, and gave higher fertilizer use efficiency than chemical fertilizers alone or combined use of organic and chemical fertilizers in a rice–groundnut cropping system [20]. Ajaz and Tiyagi, [21] concluded that parameters improvement took place when the soil contained 10 - 50% of FA. The fresh weight of cucumber increased maximally by 115% at the soil mixture which contained ¼ of FA and ¾ of soil. Singh and Agrawal [22] examined the effects of different concentrations of FA addition to soil on the growth of three cultivars of mung bean. The use of fly ash had a positive influence on the mung bean growth and the crops productivity. The researchers concluded that the differences in the effects of FA application on the growth of mung bean may indicate a genetic base for variability.
Narayanasamy [23], investigate the use of fly ash as pesticide and found that more than 50 species of insect pests of various major crops were susceptible to fly-ash treatment. He also found that fly-ash dusting at 40 kg ha^{-1}on rice could control both chewing and sucking pests such as leaf folder, yellow caterpillar, spiny beetle, ear head bug, brown bug, black bug, grasshoppers, brown plant hopper and green leafhopper. Serious polyphagous pests of cotton such as Helicoverpa armigera and Spodoptera litura also could be controlled effectively.

2.2 CKD and Fly ash applications on Waste Treatment

In the field of waste treatment, byproducts should consider beneficial based on the following abilities: (i) Absorptive quality, (ii) Alkaline nature, and (iii) Could be used as an alternative to other conventional waste treatment materials.

2.2.1 Reuse of CKD for Waste Treatment

The most and popular application of CKD in wastewater treatment is for sewage sludge applications. It is used as chemical conditioner and stabilizer. CKD is cheaper than lime and could reduce the cost of sludge stabilization. Sludge stabilization process is the treatment of sewage to eliminate health hazards and noxious smells. In this

process, enough lime has to be added to maintain the pH at 12 for two hours to achieve effective sterilization of the sewage waste [24]. The sludge filter cake stabilized by CKD could be a useful fertilizer [25]. In addition, CKD-treated sludge has a higher buffering capacity than the untreated sludge. It was concluded that alkaline treatment of sludge is not only beneficial to stabilize sludge according to USEPA standards but is also beneficial in terms of heavy metals immobilization and minimization of metal solubility in the treated-sludge matrix [26].
Odor has been one of the most difficult parameters to control in the processing of municipal sludge cakes. CKD treatment process was used to reduce the sludge cake odors. Mechanisms of odor control include adsorption by the tremendous surface area of CKD, pH increase, de-nitrification, drying the moisture of normal soil microbes, aeration and chemical elimination of hydrogen sulfide [27]. According to Burnham et al. [28], the treatment of municipal wastewater sludge cakes with 35% CKD alone or a small amount of quicklime with 30% CKD will reduce the pathogenic microbial population present in the sludge to below the USEPA's standard.
Results from a modified sludge test showed that CKD treatment renders the heavy metals present in sludge insoluble thereby minimizing their ability to enter a leachate. Cement kiln dust (CKD) was evaluated for its ability to increase the pH of acidic processed effluent in activated sludge wastewater treatment [29].
Aboulfotoh and Dohdoh [2] studied the effect of using CKD on the thickening and dewatering performance of sewage sludge. The results indicated that adding CKD to sewage sludge by 60% of total solid could improve the sludge thickening, dewatering as well as stabilization. The settleability of sludge was improved as follows: the zone settling velocity increased from 43.2 to 98.4 m/d, the SRF decreased from 5.93 (10^3.m/kg) to 0.76 (10^3.m/kg) and the actual dewatering time required to achieve sludge with solid content more than 20% reduced from 5 to 2 d, while the pH value remained in the required range for stabilization.

2.2.2 Reuse of FA for Waste Treatment

Fly-ash used in waste water treatment to decrease (COD, TSS, BOD, O, G, PH) and also used as adsorption techniques for the removal of toxic metal ions. Rani and Dahiya [30] used fly ash, brick kiln ash and commercial activated carbon in the reduction of chemical oxygen demand (COD) from domestic wastewater. Starting with an initial COD concentration of 1080 mg/l the maximum COD reduction achieved for fly ash was 87.8%, brick kiln ash was 83.2% and commercial activated carbon was 99.4 %. These values were achieved when the wastewater was treated with activated carbon for 180 min, fly ash 250 min and brick kiln ash 300 min and the adsorbent dose was kept respectively at 40 g/l, 60 g/l and 45 g/l for activated carbon, fly ash and brick kiln ash.
Singh et al [31] studied the use of fly ash alone and in combined state in different ratios with wood ash for the treatment of domestic laundry waste water. Effect of various parameters such as combination ratio of fly ash and wood ash, contact time, adsorbent dosage and particle size of adsorbent have been studied. They found that TSS (total suspended solids) is reduced from 350 ppm to 15-20 ppm, total BOD from 250ppm to 10-20 ppm and pH dropped from highly alkaline range to 8.5-9.5 range, reduction of 80% in total soap content, FOG (fats, oils and grease) from visible turbid level to non-turbid and clear solution.
In sewage sludge composting, lime is used to raise the pH and thereby to kill pathogens and to reduce the availability of heavy metals enriched in sludge. Since alkaline coal fly-ash contain a large amount of CaO. Lime could be replaced by Fly ash to decrease the operational cost [32].Unburned carbon component in fly ash plays an important role in adsorption capacity. Adsorption techniques are useful for the removal of toxic metal ions, organic and inorganic compounds, and dyes [33]. The technical feasibility of utilization of fly ash as a low-cost adsorbent for various adsorption processes for removal of pollutants in air and water systems has been reviewed. Instead of using commercial activated carbon or zeolites, a lot of researches have been conducted using fly ash for adsorption of NO_x, SO_x, organic compounds, and mercury in air, and cations, anions, dyes and other organic matters in waters [34, 35]. Organic pollutants, such as phenolic compounds, pesticides, and dyes, etc., can be removed very effectively using fly ash as adsorbent [36]. The fly ash adsorbed 67, 20, and 22 mg/g for phenol, [37]. Adsorbent prepared from fly ash was successfully used to remove cresol from an aqueous solution in a batch reactor. The adsorbent was characterized, and significant removal of cresol was achieved [38]. Coal fly ash was successfully used to remove 2, 4-dimethyl phenol from aqueous solutions [39].
Batch adsorption studies of organic pollutants containing carbosyl group on activated charcoal, fly ash and granular charcoal are made. The adsorption capacity of activated charcoal, fly ash and granular charcoal is 39.6, 39.6 and 28.8 mg/g respectively. The experimental results obtained suggest the possible use of fly ash in water treatment processes for the removal of organic pollutants [40].
The ability of natural rice husk and fly ash was tested in removing Cr (III) ion from aqueous solution and industrial wastewater and found that Cr (III) ion from industrial wastewater sample with a concentration of 50 ± 2 mg/L was removed by natural rice husk and fly ash with 92.78% and 85.24%, respectively [41]. Adsorption of mercury (II) on coal fly ash was successful; the final concentration reached 10 mg/l [42].

The feasibility of using fly ash as an alternative to activated carbon was examined for removal of methylene blue from aqueous solutions [43]. The removal of some common textile dyes using the fly ash samples has been investigated as a function of fly ash dosage, dye concentration, and contact time at ambient conditions, fly ash achieved good removal efficiency [44].

2.3 Soil Stabilization

Soil stabilization is the permanent physical and chemical alteration of soils to enhance their physical properties. Stabilization can be achieved with a variety of chemical additives including lime, fly ash, and Portland cement, as well as by-products such as lime-kiln dust (LKD) and cement-kiln dust (CKD).This addition can increase the shear strength of a soil and/or control the shrink-swell properties of a soil, thus improving the load-bearing capacity of a sub-grade to support pavements and foundations. Stabilization can be used to treat a wide range of sub-grade materials from expansive clays to granular materials.Benefits of the stabilization process by addition this materils can include: Higher resistance (R) values, Reduction in plasticity, Lower permeability, Reduction of pavement thickness. [45].

2.3.1 Reuse of CKD for Soil Stabilization

Rimal et al. [45] studied using of CKD for treatment of two natural soils using various curing periods. Extensive laboratory tests were carried out to depict the variation of unconfined compressive strength by treating the natural soils with CKD at various proportions. Samples were prepared for natural soils with and without CKD. Similarly, tests were carried out in dry and immersed conditions. The sum of results highlights that significant increment in the unconfined compressive strength is achieved when CKD is used as an additive in natural soil.

Laguros and Davidson [46] studied the CKD mechanistically functions on clay they found is similarly to cement as it showed the presence of hydration products and a subsequent decrease in void space, which resulted in increased strength and a reduction in the plasticity indices with curing times. CKD sharply reduced the swell potential of the clay which was expansive in nature. The swelling of the raw clay, as determined by the ASTM-D-4546 procedure, dropped from over 9% to 0% when treated with 25% CKD. Meanwhile, the swell potential measured as a part of the CBR tests, dropped from nearly 9% to 0.5%. Modifications of the swelling behavior in clay properties are important when considered for pavement applications, as reduced volumetric changes imply more stable behavior in the sub base or elsewhere in the pavement structure. Voids in the CKD-stabilized clay samples, measured optically, decreased with CKD additions. The raw clay soil had 7% void space whereas the samples with 25% CKD gave a void space between 1 and 2.3% [47]. This may explain the strength gain as a consequence of decrease in voids. This phenomenon does not appear to be time dependent; it rather appears to be CKD-dosage dependent. The decrease in voids may result from a combination of processes occurring simultaneously, i.e., the hydration products developing early on, and the placement of CKD particles filling the voids to modify the morphology of the stabilized mass. Additional characterizations (scanning electron microscopy tests for example) of the CKD-treated clay samples would, however, be required to verify this point [47]. According to Southgate and Mahboub [48], the CBR test also positively correlates with the modulus of elasticity and strength of the stabilized soils. Sandy soils, which are commonly selected in the pavement layers, the usage of CKD may provide cementitious materials when it is mixed with water in a way similar to the mechanism by which Portland cements provide their binding characteristics. The physical and chemical composition of the dust is very important in any application of CKD, including sand and clay stabilization [45].

Addition of 15% CKD to sandy soils for pavement subgrade applications having 5.9% (free CaO and MgO), and 0.97% total alkalies (K_2O + NaO) ensured a compressive strength of 360 psi (2.5 MPa) [49]. Baghdadi and Rahman [50] studied the effects of CKD on stabilizing siliceous dune sand in highway construction. It was deduced that a mix proportion of 30% CKD and 70% sand gave peak performance for application as base materials. In a somewhat similar study conducted later, Baghdadi et al. [51] reported that the use of CKD between 12 and 50% was satisfactory to stabilize dune sand. For light applications, 12 to 30% CKD was found sufficient, and for heavily-loaded applications, about 50% CKD gave satisfactory stabilization.

Azad [52] found that an increases in the unconfined compressive strength (UCS) of soil occurred with the addition of CKD. Furthermore, the increases in UCS were inversely proportional to the plasticity index (PI) of the untreated soil. Significant PI reductions occurred with CKD treatment, particularly for high PI soils. Mohamed [53] evaluated the potential use of cement-kiln dust (CKD) for enhancing the mechanical as well as the hydraulic properties of soils in arid lands. Various tests were conducted to determine the different physical properties of the stabilized matrix and the optimum mixture that produces maximum internal energy and minimum hydraulic conductivity was selected. The analysis showed that 6% by weight of CKD is the optimum mix design, which increases the shear strength and decreases the hydraulic conductivity to less than 10^{-9} m/s. Therefore, the treated soil could be used as a soil-based barrier layer for containment of hazardous waste, [53]. In other words, the available free lime, soluble alkalies, and fineness of CKD influence the stabilization of soil, whether the underlying stabilization process is primarily pozzolanic, or ion-exchange, or a combination of both.

2.3.2 Reuse of FA for Soil Stabilization

Recent investigations suggest that FA can find better application if combined with organic amendments such as cow manure, press mud, paper factory sludge, farmyard manure, sewage sludge, crop residues and organic compost for improvement of degraded/marginal soil [54]. Few beneficial combined effects of FA and organic matter on soil have been found such as :

1- Reduced heavy-metal availability and killing pathogens in the sludge [55]
2- Improved soils through higher nutrient concentrations, better texture, lower bulk density, higher porosity and mass moisture content and higher content of fine-grained minerals [56];
3- Enhanced the biological activity in the soil [57];
4- Reduced the leaching of major nutrients [58];
5- Beneficial for vegetation [59];
6- Co-utilization of 'slash' a mixture of FA, sewage sludge and lime in the ratio of 60:30:10 had beneficial soil ameliorating effect. 'Slash' incorporation in soil showed positive effects on soil pH and Ca, Mg and P content and reduction in the translocation of Ni and Cd [60] and enhanced growth and yield of corn, potatoes and beans in pot trials. So, amendment with FA will enhance agricultural sector for crop production. Further, organic amendment application will provided anchorage and growth of the plant on a FA dumping site [61].

The main disadvantage of using FA in soil is that the use of swine manure with FA increased the availability of Ca and Mg balancing the ratio between monovalent and bivalent cations (Na^+ K^+/Ca^{2+} Mg), which otherwise proves detrimental to the soil [62].

2.3.3 Reuse of CKD-FA mixture for Soil Stabilization

Nicholson [63, 64] did investigations for a series of CKD and fly ash mixtures or producing sub-base materials with different aggregates. CKD was used up to 16% by weight of the mixture, producing a durable mass by reacting with water at ambient temperatures. Collins and Emery [65] demonstrated the effectiveness of substituting CKD for lime in a number of lime-fly ash-sandy aggregate systems for sub-base construction. The results indicated that the majority of the CKD-treated fly ash and aggregate mixtures resulted in materials which were comparable in strength, durability, dimensional stability, and other engineering properties, to those of the conventional lime-fly ash-aggregate mixtures.

Miller, et al. [66] have also reported the use of CKD and fly ash as the cementitious ingredients in developing pozzolanic bases that demonstrated comparable properties to those of a stabilized base.

It was pointed out, however, that the use of any particular CKD-fly ash combination would require an appraisal of the chemical and strength test data to establish optimum properties for a suitable mix design.

The study reveals that the action of CKD on soil is a successful technique of stabilization for problematic soils. Shortly, it is determine that utilizing this waste is a useful suggestion which is economical and atmosphere friendly, using this waste is a useful proposal which is economical and atmosphere friendly as well. Outcomes in this study have been used in designing foundations on compacted stabilize clay beds.

It has been noted that with the increment in amount of CKD, Maximum dry density (MDD) increases and Optimum moisture content (OMC) decreases. The decrement in OMC with increase in CKD amount may be credited to the addition of material which is considered as silty to the parental material. The increase in MDD as cement kiln dust content increases may be because of gradation of CKD and as the specific gravity of CKD is more than the soil, so M.D.D increases. It has been noted that with the increase in Fly ash content, OMC increases and MDD decreases, this is because the Fly ash is having the more specific surface area and thus it absorbs more water. The existence of ash having low specific gravity may be the reason for decrease in density [67].

2.4 Concrete and cement industry.

Materials with cement like properties such as CKD and FA makes it a potential replacement for Portland cement in utilization in concrete, flowable slurry, etc.

2.4.1 Reuse of CKD in concrete and cement industry.

Al-Harthy et al. [68] investigated the use of CKD as a substitute for Portland cement at different proportions in concrete and mortar samples. They also concluded that substitution of cement with CKD does not produce negative effects on strength properties of these samples when CKD was added at proper low ratios.

Research has demonstrated that CKD can act as alkaline accelerator for latent hydraulic substances including ground granulated blast furnace slag and as alkaline activator for different aluminosilicate materials used in mortars and concretes [69, 70]. The solubility of *Si, Ca, Al and Mg* in cementitious matrices are pH dependent. The equilibrium solubility of silica is low at pH below ~11[71]

CKD with its high alkaline soluble fraction can be added as an activator in blended cements containing fly ash and hydraulic slags enabling them to undergo cementations reactions [72]. However, the inconsistencies in physical and chemical properties of CKD can affect such hydration mechanisms. The resultant hydration products and strength development are also dependent on a particular type and characteristics of CKD under consideration. Adequate initial alkali concentration and presence of sulphates are both considered vital for the activation of slag in CKD-slag systems. The hydration processes, hydration products, and resulting enhanced strength are principally determined by the free *CaO* content of a particular CKD Pozzolanic processes involve siliceous and aluminosilicate materials that form cementitious substances when combined with a cementitious material (such as CKD) and water [70, 73].

Blast furnace slag possesses latent hydraulic reactivity however; its hydration in pure water is particularly slow under normal conditions due to the development of aluminosilicate coatings on slag grains that prevent hydration reactions from proceeding. Moreover, high glass content of blast furnace slag also requires elevated alkaline conditions for chemical hydration. This can be readily achieved with basic reactors such as calcium hydroxide obtained from the addition of sufficient amount of Portland cement, calcium sulphates or other calcium and alkali rich compounds such as CKD [71, 74].

2.4.2 Reuse of FA in concrete and cement industry

Fly ash is an excellent potential raw material for the manufacture of construction material like blended cement, fly ash bricks, mosaic tiles and hollow blocks. It also has other, high volume applications and can be used for paving roads, building embankments, and mine fills.

Fly ash products have several advantages over conventional products. The use of cement in the manufacture of construction products can be reduced by substitution with fly ash. While the use of cement cannot be completely avoided, for certain products like tiles, the substitution can go up to 50 percent. These products are known to be stronger and more cost-effective because of substantial savings on raw material. The fly ash has been utilized in different ways as discussed in [40, 75]. Fly ash can be used in Portland cement concrete to enhance the performance of the concrete. Portland cement is manufactured with calcium oxide (CaO), some of which is released in a free state during hydration. As much as 20 pounds of free lime is released during hydration of 100 pounds of cement. This liberated lime forms the necessary ingredient for reaction with fly ash silicates to form strong and durable cementing compounds, thus improves many of the properties of the concrete. Some of the resulting benefits are: be disposed in landfills, and conservation of other natural resources and materials. Typically, 15 to 30 % of the Portland cement is replaced with fly ash. Fly ash in concrete has significant benefits including:

1. Increasing the life of concrete roads and structures by improving concrete durability.
2. Net reduction in energy use and greenhouse gas and other adverse air emissions when fly ash is used to replace or displace manufactured cement [40].

2.4.3 Reuse of CKD-FA mixture in concrete and cement industry

Many factors such as the particle size, silicate content, composition and crystal structure of the silicate, degree of hydration, calcium magnesium ratio, among others determine the rate and extent of long-term hydration reactions of CKD-fly ash systems [76]. The effectiveness of fly ash as a binder depends on its alkalinity equivalent, which is indicated by the amount of calcium oxide (*CaO*) present. It also depends on its reactive silica, carbon and iron contents, fineness, and particle size [77]. CKD-slag systems are analogous to GU-slag systems in hydration processes since CKD also serves to activate slag resulting in precipitation and accumulation of hydration products. The early age hydration products are highly contingent upon inherit chemical characteristics of CKD under consideration, however, later hydration products essentially include *C-S-H* gel and the stable sulphoaluminate hydrate ettringite and are responsible for enhanced strength development [70].

Literature on use of CKD to activate fly ash is quite scarce. Babaian et al [78] investigated the reactivity of CKD-FA systems but the main emphasis of this investigation was the effect of grinding so no meaningful conclusions can be drawn in relation to unground binder constituents. Wang K. et al [79] investigated the effect of curing temperature and NaOH addition on the behavior of CKD–FA systems. They found compressive strengths as low as 2.1 MPa after 28days for binders of 50% CKD and 50% FA without using elevated curing temperatures or NaOH addition although the strength increased to 10.1 MPa after 56 days. Maslehuddin et al., [80] investigated concrete mixes including cement, CKD and other cement replacement materials. For their concrete mix with 70% cement, 20% fly ash and 10% CKD, they measured 3 day compressive strength of 30.3 MPa (compared with 38.3 MPa for an equivalent mix with 100% cement). They also tested a mix made with 80% GGBS, 15% CKD and only 5% cement and found a moderate 3 day strength of 23.0 MPa. Chaunsali and Peethamparan [81] examined pastes with 70% CKD (from two different sources) and 30% of either FA or GGBS cured at an elevated temperature of 75 °C. For both fly ash and GGBS mixes, they observed higher compressive strengths at all ages for mixes with the CKD that had the higher free lime and sulphate contents. They noted that the higher free lime content led to greater C-A-SH gel forming during the pozzolanic reaction and that the higher sulphate content and alumina content increased ettringite formation. They also noted that the CKD that led to greater strengths had a smaller particle size throughout the particle size distribution range.

CKD along with fly ash were utilized as waste material blends with Portland cement. The following conclusions can be made concerning the performance of such blends: Mortars of satisfactory mechanical strength can still be produced using blends containing 90% Portland cement but not more than 4% fly ash as blended waste material. Blends containing as low as 70% Portland cement can still exhibit adequate strength if only CKD is used as the blending waste material. These blends witness various degrees of increase in their hydration requirements for normal consistency, and more noticeably in their initial setting times.

Increasing the ratio of waste materials in the blended cement paste significantly increased the amount of water required to produce a neat blend of normal consistency. This increase is mainly due to the presence of the dry fly ash in the blend, which does not contribute to the hydration reactions. The increase in hydration requirement became less significant as CKD became the dominant waste material blended, and practically diminished when only CKD was blended with Portland cement.

Increasing the percentage of waste materials in the cement blend has also significantly increased the initial setting time of these blends. This increase became prohibitively large for all blends containing less than 70% cement, which is reflected on the complete loss of mechanical properties of blends containing 70% or less cement and less than 80% CKD in the blended waste material. A large jump in setting time was observed in blends containing less than 90% cement when fly ash exceeded 40% of waste materials blended. This figure, however, shows that the increase in setting time for blends utilizing 90% cement gradually became insignificant as the percentage of CKD in the blended waste material was increased [82].

2.5 Other beneficial uses of FA

Large scale use of ash as a fill material can be applied where:

- Fly ash replaces another material and is therefore in direct competition with that material.
- Fly ash itself is used by the power generating company producing the fly ash to improve the economics of the overall disposal of surplus fly ash.

Fly ash disposal is combined with the rehabilitation and reclamation of land areas desecrated by other operations. Fills can be constructed as structural fills where the fly ash is placed in thin lifts and compacted. Structural fly ash fills are relatively incompressible and are suitable for the support of buildings and other structures. Non-structural fly ash fill can be used for the development of parks, parking lots, playgrounds and other similar lightly loaded facilities. One of the most significant characteristics of fly ash in its use as a fill material is its strength. Well-compacted fly ash has strength comparable to or greater than soils normally used in earth fill operations. In addition, fly ash possesses self-hardening properties which can result in the development of shear strengths. The addition of cement can induce hardening in bituminous fly ash which may not self-harden alone. Significant increases in shear strength can be realized in relatively short periods of time and it can be very useful in the design of embankments [83].

Fly ash can be used for construction of road and embankment. This utilization has many advantages over conventional methods.

- Saves top soil which otherwise is conventionally used
- Avoids creation of low lying areas (by excavation of soil to be used for construction of embankments)
- Avoids recurring expenditure on excavation of soil from one place for construction and filling up of low lying areas thus created.
- Does not deprive the nation of the agricultural produce that would be grown on the top soil which otherwise would have been used for embankment construction.
- Reduces the demand of land for disposal/deposition of fly ash that otherwise would not have been used for construction of embankment.

Fly ash products are also environment-friendly. A case in point is fly ash bricks. The manufacture of conventional clay bricks involves the consumption of large amounts of clay. This depletes topsoil and degradation of agricultural land. Fly ash bricks do not require clay and serve two purposes; preservation of topsoil and constructive utilization of fly ash. Fly ash bricks are made up of fly ash, sand and cement. In these bricks fly ash is used as the primary filler and sand is added as secondary filler. Cement is used to binder, which helps in holding all the raw material together. Bricks can be mainly grouped into two categories:

- Fly ash bricks using cement as a binder: Raw materials include: fly ash, cement and sand.
- Fly ash brick using lime as a binder: Raw materials include: fly ash, lime gypsum and sand.

Mosaic tile are manufactured utilizing the fly ash. The process involves preparing the mix for two layers: the wearing layer and the base layer. The wearing layer consists N of a plastic mix of mosaic chips, cement, and fly ash and dolomite powder. The base layer consists of a semi-dry mix of fly ash, cement and quarry dust. The tiles are pressed in the ile-making machine and air-dried for 12 hours or more. They then undergo curing in water tanks for 15 days. The tiles are then polished and stacked for supply [83].

Worldwide, many technologies have been developed for the production of artificial aggregates from fly ash. Only two of them have reached the commercial status-the sintering process Lytag and the cold-bonded process Aardelite. Aggregates from fly ash produced can be used for a variety of applications in the construction industry, including masonry elements, precast concrete elements, and ready-mix concrete for buildings up to five floors and bituminous concrete for road foundation.

Fly ash based composites have been developed using fly ash as filler and jute cloth as reinforcement. After treatment, the jute cloth is passed into the matrix for lamination. The laminates are cured at specific temperature and pressure. Numbers of laminates are used for required thickness. The technology on fly ash Polymer Composite using Jute cloth as reinforcement for wood substitute material can be applied in many applications like door shutters, partition panels, flooring tiles, wall paneling, ceiling, etc. With regard to wood substitute products, it may be noted that the developed components / materials are stronger, more durable, resistant to corrosion and above all cost effective as compared to the conventional material i.e. wood.

This technology has been developed by Regional Research Laboratory, Bhopal in collaboration with Building Materials and Technology Promotion Council (BMTPC), New Delhi and Technology Information, Forecasting and Assessment Council (TIFAC), New Delhi. One commercial plant has also been set up based on this technology near Chennai [75].

Conclusion

The literature review revealed that the byproducts from cement production (CKD), as well as from the combustion of coal (FA) have many adverse impacts on the environment and humane health. These byproducts if not disposed-off in environmental save manner, could cause; global warming, ozone depletion, acid rain, biodiversity loss, reduced crop productivity. On the other hand these byproducts find a numerous application in the agricultural field, cement industries, soil stabilization, waste treatment, and in pollution control. Many researches have been conducted to investigate these beneficial uses of CKD, FA and there mixture as a raw material, fertilizer, construction material, adsorbent and improving soil properties. The reuse of such byproducts could achieve many advantages such as; protect environment, protect human health, and conserve raw materials.

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