Coal Bottom Ash

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Coal bottom ash (CBA) is physically similar to natural aggregates and resembles Portland cement (PC) when pulverized into finer particles.

coal bottom ash waste material recycle construction industry civil engineering

1. Introduction

The increasing trend in coal consumption will continue mainly due to the high demand for electricity. Coal is rapidly gaining favor as an energy source for generating electricity, after gas [1]. The 0.9% increase in world coal consumption in 2019 was driven by Asia (1.8%). The utilization of coal as a global source of electricity generation is expected to increase to 47% by 2030 [2][3].

The high demand for coal production has resulted in the generation of a higher amount of industrial waste. Fly ash makes up 70–80% of the total coal ash wastes, and the remaining 10–20% is bottom ash [2][4][5]. Of the millions of tons of coal ash waste generated annually, 100 million metric tons (Mt) is bottom ash, and the remainder is fly ash [6]. The World of Coal Ash (WOCA) estimated that coal thermal power plants generate 780 million metric tons of coal bottom ash (CBA), of which 66% is by Asian countries, followed by Europe and the United States [7]. China produces the highest amount of coal ash of 395 million metric tons (Mt), followed by the US (118 Mt), India (105 Mt), Europe (52.6 Mt), and Africa (31.1 Mt). The Middle East and other countries contributed a small amount to the global coal ash generation [8]. Of the 105 million metric tons of coal produced in India [8], about 35 million metric tons is coal bottom ash produced by the power plants that generate electricity [9].

The wastes produced in electricity generation are boiler slag, fly ash, clinker, and bottom ash [10][11]. The physical properties and the chemical composition of bottom ash and fly ash differ because fly ash is lighter than the bottom ash collected in a hopper after falling through the bottom furnace. The bottom ash could be wet or dry bottom ash, depending on the type of boiler.

The disposal of bottom ash landfills has raised a grave environmental concern [12][13]. The high composition of heavy metal in bottom ash, relative to fly ash, increases the risk of groundwater pollution [14][15]. One way to deal with the increasing amount of CBA generated and the scarcity of land is by recycling and reusing CBA [16].

2. Properties of Coal Bottom Ash

The specific properties of coal bottom ash are dependent on factors such as the coal source and type of coal. There are four types of coal: anthracite, bituminous, sub-bituminous, and lignite [17]. The type of coal is dependent on the types and amounts of carbon, the amount of heat energy the coal can produce, the level of carbon moisture, and other chemical elements [18]. Anthracite has the highest carbon content, followed by bituminous, sub-bituminous, and lignite. Generally, the types of coal used in energy generation are bituminous, sub-bituminous, and lignite. The geological formation of the coal determines its chemical composition; the CBA from the different types of coal have varying silica oxide (SiO 2), alumina oxide (Al 2O 3), and ferric oxide (Fe 2O 3) contents and characteristics that influence the research finding [18][19].

Researchers have investigated steel slag, coconut waste, recycled asphalt, recycled concrete, mining waste, glass, crumb rubber, palm oil shell, and palm oil clinker as natural aggregate replacement. **Table 1** summarizes the physical properties of the wastes used as aggregate replacement in asphalt pavements and concrete production.

Table 1. The physical properties of the wastes used as aggregates in asphalt pavement and concrete production.

Waste	Physical Property Parameters					Used As		
	Specific Gravity (No Unit)	Water Absorption (%)	Los Angeles Abrasion (%)	Moisture Content (%)	Fineness Modulus (%)	Fine	Coarse	Reference
Steel slag	3.41	1.49	11.29				√	[20]
	3.01	-	14.2				√	[21]
	3.42 *	3.31 *	-	1.56 *	-	√	√	[22]
	3.58 **	4.23 **		2.8 **				
	3.67	1.4	-	-	-		√	[23]
Coconut waste	1.15	21	-		6.78		√	[24][25]
	1.16	13.8	-	-	-		√	[26]
Recycled asphalt	2.68	0.20	22.2			√	√	[27]
	2.55	0.23	20.25			√	√	[28]
Recycled concrete	2.41 *	4.80 *	18.7			√	√	[29]
	2.42 **	7.40 **						
	2.18 *	2.69 *	24			√	√	[30][31][32]
	2.42 **	4.28 **						
	2.35	8.01	-	9.1	-	√	√	[33]
	2.42–2.44 *	6.5–6.8 *	-	-	-	√	√	[34]
	2.415 **	9 **						
	2.53	3.04	-	-	-		√	[35]
	2.44	5.65	-	-	6.92		√	[36]
Mining waste	2.34	0.86	20.5				√	[37]
	2.87	0.23	25.3			√	√	[38]
Glass	2.3	20–25	-	-	-		√	[39]
	2.45	0.36	-	-	-	√		[35]
Crumb rubber	1.15	-	-			√		[40]
	1.25	-	-			√		[41]
Palm oil shell	1.37	12.47	-	-	6.53		√	[42]
	1.3	25	-	-	-		√	[43]
Palm oil clinker	2.08	-	-			√		[44][45]
	1.51	5.5	-	0.31	-		√	[46]
	1.78	5.7	-	0.38	-		√	[47]

Waste	Physical Property Parameters					Used As		
	Specific Gravity (No Unit)	Water Absorption (%)	Los Angeles Abrasion (%)	Moisture Content (%)	Fineness Modulus (%)	Fine	Coarse	Reference
	1.18 *	4.35 *	-	0.28 *		√	√	[48]
	2.15 **	5.75 **		0.11 **				

* Coarse aggregate, ** fine aggregate.

The physical properties of the wastes used as aggregates in asphalt pavement and concrete production.

Asphalt construction requires a large amount of natural aggregates, namely 100% aggregates for the base and subbase courses, 95% for bituminous, and 87% for concrete pavements. The natural aggregates used to construct one kilometer of a surface course using a bituminous mixture could exceed 15,000 tons [6]. In recent years, natural aggregate replacement with CBA has reduced construction costs and minimized the need to harvest aggregates from natural resources.

3. Applications of Coal Bottom Ash

3.1. Pavement Construction

Prior studies on the utilization of coal ash waste in the construction industry focused more on fly ash than bottom ash. However, recent studies reported that bottom ash has some desired engineering properties that make it a feasible construction material. The minimum strength, stability, durability, and other specifications of the products incorporated with CBA must be complied with [49]. CBA has been used as an aggregate replacement, cement replacement, additive in bitumen, and filler in asphalt pavement. **Table 2** summarizes the effect of CBA in pavement construction.

Table 2. Summary of the utilization of CBA in pavements.

References	Function	Effect on Pavement Performance
[50]	Filler in SMA mixture	• Reduced Marshall stability, resilient modulus, tensile strength, and fatigue properties of the pavements. • Improved moisture resistance.
[51]	Filler replacement	• Reduced pavement stability and rutting resistance. • Improved moisture resistance.
[52]	Fine aggregate in HMA	• Higher OBC with 10% CBA replacement. However, there was no significant difference with a higher percentage of CBA replacement. • No significant change in moisture susceptibility. • Improved fatigue resistance.
[53]	Cement replacement in roller-compacted concrete pavement	• Increased the water/cement ratio. • The RCCP mixtures containing higher amounts of coal waste ash had a lower strength.

References	Function	Effect on Pavement Performance
		• Coal waste ash produced better mechanical properties when used in combination with limestone.
[54]	Filler replacement in asphalt mixture	• The high specific surface area of the bottom ash particles resulted in a higher percentage of asphalt binder and better mastic quality. • Lower CO_2 emissions in the processing of bottom ash compared to a commercial filler.
[55]	Filler replacement in HMA mixture	• Improved stability, resilient modulus, moisture resistance, and tensile strength.
[56]	An additive in cold recycled mixture	• Enhanced stability, resilient modulus, and tensile strength.
[57]	Fine aggregate in HMA	• Enhanced stability and Cantabro index.
[58]	Fine and coarse aggregate replacement	• The difference in performance was not significant after a particular period of service. The varying properties of CBA from various coal sources influence the strength of the asphalt mixture.

3.2. Aggregate Replacement in Concrete Production

There has been an increase in literature on using bottom ash as an aggregate substitute in concrete production due to its porous texture and low particle densities. The literature reported the promising potential of bottom ash as an aggregate and cement substitute in concrete, particularly to enhance the concrete's strength and microstructural properties. During the past several decades, there has been extensive research on using alternative materials in concrete manufacturing. The benefits of lightweight concrete are reduced weight, good thermal and sound insulation, durability, strength, low expansibility, ease of use in construction, and low cost [59].

3.3. Cement Replacement in Concrete Production

Besides using CBA as an aggregate replacement, researchers and technocrats investigated using CBA as cement replacement. The chemical properties of CBA are similar to cement as both are class F materials. The SiO_2 content of CBA is greater than 25%, and the content of SiO_2 + Al_2O_3 + Fe_2O_3 is higher than 70%, which meets the requirement for the recycling bottom ash as cement [60][61]. Moreover, replacing cement with CBA can reduce CO_2 emissions and improved energy conservation.

Cement is the most widely used material in civil constructions. However, the high amount of carbon emitted in cement production has a harmful impact on the environment. An estimated 50% of the total CO_2 emissions are from cement production. The production of each ton of cement releases 0.55 tons of CO_2, and an additional 0.39 tons of CO_2 is emitted during the baking and grinding processes, which are the key contributors to global warming [62].

3.4. Noise Barrier, Geotechnical Fill, Zeolite Composite, and Low-Cost Absorbent

Over the past four decades, extensive research has been conducted on noise barriers with different characteristics to protect the areas near roads, especially those with a high traffic volume [63]. Noise barrier wall, also known as the concrete wall, is one of the economic structures built to reduce noise pollution from transportation. Hannan et al. [60] investigated the production of concrete walls with varying CBA percentages that ranged from 0–100% fine aggregate replacement. The researchers reported that the values of fineness modulus of CBA were between 2.3 to 3.0, which is within the range as the fineness modulus of CBA was lower than the conventional fine aggregate specified in the BS 882:1992. The specific gravity of CBA was lower than the conventional fine aggregate due to the porous texture of CBA. The compressive strength of the concrete wall barriers did not increase linearly with higher CBA percentages, but increased with the concrete porosity, which is a good indicator for sound absorption structures. The sound absorption test to determine the acoustic performance showed that the walls containing 80–100% CBA were similar to the conventional wall and were class D absorbers; the remaining walls were class E absorbers. According to BS EN ISO 11,654:1997, the absorbers in class D absorb more than 30% of the sound, while class E absorbs between 15–25% of the sound [60].

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