 DOI: 10.1051/matecconf/201710301005

A Comprehensive Review on the Properties of Coal Bottom Ash in Concrete as Sound Absorption Material

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Abstract. The government is currently implementing policies to increase the usage of coal as fuel for electricity generation. At the same time, the dependency on gas will be reduced. In addition, coal power plants in Malaysia produce large amounts of industrial waste such as bottom ash which is collected in impoundment ponds (ash pond). However, millions of tons of coal ash (bottom ash) waste are collected in ponds near power plant stations. Since bottom ash has been classified as hazardous material that threatens the health and safety of human life, an innovative and sustainable solution has been introduced to reuse or recycle industrial waste such as coal bottom ash in concrete mixtures to create a greener and more sustainable world. Bottom ash has the potential to be used as concrete material to replace fine aggregates, coarse aggregates or both. Hence, this paper provides an overview of previous research which used bottom ash as fine aggregate replacement in conventional concrete. The workability, compressive strength, flexural strength, and sound absorption of bottom ash in concrete are reviewed.

1 Introduction

Major environmental problems around the world are usually due to the disposal of waste materials such as industrial waste, construction waste, household waste and etc. However, industrial waste, also known as production by-products, has been investigated extensively as sustainable alternatives to Portland cement in concrete [1][47]. Recently, waste accumulation has become a major problem to the environment as well as human beings [2]. It is now a global concern to find environmentally friendly solutions for the safe disposal of industrial waste to sustain a cleaner and greener environment.

Coal ash is one of the biggest sources of industrial waste that is produced from power plant stations. Cheriaf et al. [3] stated that 1.2 million metric tons of coal ash has been produced during the combustion of 2.9 million metric tons of coal. Coal is widely used in

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the production of electricity, steel and cement manufacturing and is therefore an important source of energy. In Malaysia, coal has classified as an significant source of fuel [4, 5]. Nowadays, fossil fuels become the foremost basis for energy generation [6]. The demand for fossil fuels has increased due to a high demand for electricity generation, as well as the consumption of fossil fuels by several countries such as USA, EU, India, and China [7-9].

However, based on Bajare et al. [10], several types of coal ash waste have been identified such as bottom ash, fly ash, boiler slag, flue gas, desulfurised material and etc. Fly ash is one of the well-known coal combustion products where it is usually used in concrete mixtures as blended cement, besides fly ash were also known as as supplementary cementitious material for increasing the workability and durability of concrete [10-13][48-49]. On the other hand, other researchers have classified bottom ash as industrial waste that have been produced at the bottom of coal furnace during the coal combustion for electricity generation. It forms from agglomerated ash particles that are glassy and coarse particles that have been produced in a pulverized coal furnace which were fall at the bottom of the furnace due to the properties of bottom ash which is heavier and harder to be carried by flue gas compared to fly ash [10, 14].

Recently, the investigation on reutilizing bottom ash as a construction material is aggressively being conducted among researchers [3, 12, 13, 14]. The usage of bottom ash as construction material has brought many benefits to the industry due to its low cost, low density fill and its suitability to be used as replacement of natural quarried sand or natural coarse aggregates which makes it a more sustainable as construction material. Kalyoncu [15] has conducted a studied and found that the size of bottom ash is similar to coarse and fine-grain, sand-like material which is collected from the bottom of coal-fired boilers. Meanwhile, the physical and chemical properties of bottom ash have the desired properties which make it suitable for use in engineering construction [3, 16, 17, 18]. But, some studies have found that bottom ash contains heavy metal and arsenic. Therefore, the Department of Environment, Malaysia, has classified coal combustion products as hazardous substances because several environmental issues have occurred due to excessive production of waste materials. Massive production of coal ash has negatively affected the environment such as by contaminating underground, adjacent soil and surface water due to limitation of dumping space. Coal ash is still being treated as waste and put in impoundment ponds, silos or landfills.

However, the American Coal Ash Association (ACAA) has lead a survey on the applications of bottom ash and it is found that usually bottom ash can be used for several construction purposes such as transportation, construction, agriculture and so on. It can also be used as soil modification, structural fillers, road base material and etc. [19]. Therefore, this paper aims to review previous research that has been carried out on the effect of bottom ash in concrete as sound absorption material. From the previous research, it had found that the presence of bottom ash in the concrete mixture can be either a partial or total replacement of fine aggregates has effect on the workability, compressive strength, flexural strength and sound absorption in concrete were reviewed to ensure either it is suitable to be replaced with natural aggregate (fine or coarse) in concrete as sound absorption material and also to verify the quality of bottom ash by confirming desired properties of the product.

2 Properties of Coal Bottom Ash

2.1 Chemical properties

A study on the replacement of coal bottom ash as a construction material such as cement or fine aggregate replacement has been carried out from the previous research. But there are some differences that can be seen on the chemical composition of CBA due to the different sources of coal that have been used as shown in Table 1. Based on Table 1, usually bottom ash is classified as a class F as a result of SiO2 + Al2O3 + Fe2O3 that exceeds 70% as described in ASTM C 618. Therefore, due to bottom ash included in class F, it has pozzolanic properties and also has a very low lime (CaO) content which is less than 7%. To produce cementitious mixtures, bottom ash requires a cementing agent such as quicklime or hydrated lime, Portland cement that reacts with water. Meanwhile, the loss on ignition (LOI) of bottom ash is still low which is less than 6% as specified in ASTM C 618. LOI is a method for identifying the mass loss of carbon, sodium and other elements from solid combustion residues by heating. Unburned carbon in coal ash can significantly affect its advantageous applications in concrete mixtures. According to Kurama et al. [20] LOI is defined as the total of unburned carbon in fly ash which is a common approach in cement and concrete applications.

Table 1. Chemical properties of bottom ash according to different locations

Power Plant Station/ Chemical Composition (%)	Spanish power plant [21]	Guru Hargobind Thermal Power Plant Bathinda, India [22]	TNB Electric power Plant Perak, Malaysia [19]	Seocheon coal-fired thermal power plant, South Korea [23]
SiO_2	52.30	56.44	54.80	44.2
Al_2O_3	25.14	29.24	28.50	31.5
Fe_2O_3	9.23	8.44	8.49	8.9
CaO	2.37	0.75	4.20	2.0
MgO	1.84	0.40	0.35	2.6
Na_2O	0.66	0.09	0.08	-
K_2O	3.72	1.29	0.45	-
TiO_2	1.45	3.36	2.71	2.4
P_2O_5	0.25	-	0.28	-
SO_3	0.03	0.24	-	-
LOI	1.07	0.89	2.46	-

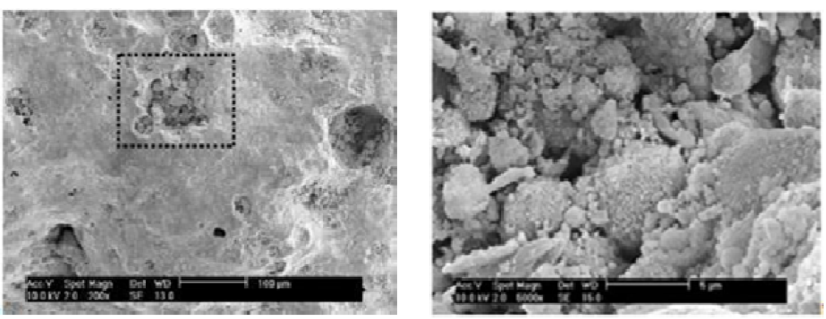
2.2 Physical properties

From the laboratory investigations that have been carried out by Singh and Siddique [24], coal bottom ash is found to be a dark grey material by having angular particles shapes. It is also an irregular, porous material which has a rough surface texture. Coal ash resulting from the coal combustion process at 1400-1500°C at the Seocheon thermal power plant station produces bottom ash of different sizes which can be divided into fine and coarse bottom ash [25]. Fig. 1 shows the different types of bottom ash. Abu Bakar et.al [26] found that the size of bottom ash during the sieve analysis test was in the range between gravel and fine sand with a very low percentage of silt-clay sized particles which pass through the 75µm sieve. Therefore, there is a good correlation to show that the size of bottom ash possesses an ideal quality thereby enhancing the quality of concrete especially in terms of strength. Park et al. [27] lead an SEM analysis on the coal bottom ash, and it has been proved that coal bottom ash has a porous surface with many voids. It was also found that the area with voids was not as dense compared to other areas. The small particles could fall out relatively easily, as shown in Fig. 2.

Meanwhile, the percentage of water absorption, specific gravity, and fineness modulus of several types of bottom ash has shown variety results due to the different sources of coal for each thermal power plant station depending on its chemical composition. Table 2 shows the specific gravity, percentage of water absorption and fineness modulus according to different thermal power plant stations in India. From the results, it was found that the specific gravity of bottom ash is between 1.39-2.66 where it differs for each power plant, which is lower than the specific gravity of coarse aggregates (2.51) and fine aggregates (2.62) [28]. According to Muhardi et al. [8], the low specific gravity of bottom ash is due to lower iron oxide content. Bradshaw et al. [29] also specified that higher carbon content in bottom ash results in lower specific gravity. Water absorption of fine aggregate (3.7%) is lower than the percentage of water absorption of bottom ash [30]. Besides that, bottom ash generally has a low specific gravity due to its porous structure and popcorn-like particles which easily degrade under loading or compaction [31].

(a) (b)

Fig. 1. Particle shape of bottom ash (measured in mm); (a) coarse bottom ash and (b) fine bottom ash [26].



(a) (b)

Fig. 2. SEM analysis of coarse coal bottom ash; (a) 200x and (b) 5000x [27].

Table 2. Physical properties of bottom ash according to different Thermal Power Plants in India

Power plant station/ Physical properties	Guru Hargobind Thermal Power Plant Bathinda India [22]	Panipat Thermal Power Plant Haryana, India [32]	Eklahare Thermal Power Plant Nashik City Maharashtra, India [30]
Specific gravity	1.30	2.66	1.93
Water absorption	31.58	12.00	10.06
Fineness modulus (%)	1.37	3.12	2.7

3 Properties of concrete

3.1 Fresh coal bottom ash concrete

Based on the current environmental issues due to the dumping of industrial waste such as bottom ash, there are various possible solutions that can be done such as reusing industrial waste in the production of concrete by replacing fine aggregates, coarse aggregates or both. Therefore, fresh concrete properties are important for a study and include workability, air content and bulk density. The tests were all conducted according to ASTM.

3.1.1 Workability

The ratio of coarse or fine aggregates in the concrete mixture is one of the factors that will affect the workability of concrete and water demand depending on the properties of the aggregates. The inter particle friction between the aggregates will be decreased due to the physical properties of bottom ash particles which are smaller than natural river sand which is fine and irregularly-shaped.. According to Singh et al. [12], the workability of bottom ash concrete decreases in the concrete mixture in which contains bottom ash for different grades of concrete. The flow characteristic of fresh coal bottom ash concrete is affected due to increased inter particles [24]. However, the workability of concrete can be measured in terms of compaction factor. M. Singh et al. [11] has conducted the test and found that the workability of concrete decreases with the increase in the total amount of the fine aggregates replaced by bottom ash.100% of coal bottom ash as fine aggregate replacement in concrete has resulted in an 86% decrease in terms of slump value. This might be due to the decreased cement content, the use of super plasticizer and higher water cement ratio. Due to the higher workability of bottom ash concrete at a fixed cement content and water cement ratio, there will be a decrease in the compressive strength of concrete [32]. Raju et al. [33] observed that the replacement of bottom ash up to 50% increases water absorption compared to sand particles. Aggregate which are porous will absorb more water to provide workability. Previous research also found that the water absorption of bottom ash affects concrete workability where porous particles of aggregates act as water reservoirs for future hydration of cement [34].

3.2 Hardened concrete

The effects of bottom ash on hardened concrete properties will be extracted from previous research. Hardened properties of bottom ash concrete include compressive strength and flexural strength.

3.2.1Compressive strength

From previous research, several discussions on the compressive strength of bottom ash concrete were found: (i) The compressive strength of the concrete that contains bottom ash as a fine aggregate replacement slightly decreases compared to normal concrete [22][45]. This is confirmed by Kou et al. [35] who found that the compressive strength and drying shrinkage decrease with the increase in fine bottom ash content. The result shows that the strength of concrete decreases when the percentage of bottom ash replacement increases due to the bonding between the aggregates in the mixture. However, according to Kim et at. [25], the compressive strength of fine bottom ash and coarse bottom ash after 7 days and 28 days were around 60 to 70 MPa respectively with various percentages of bottom ash content in concrete. The strength was also affected by the proportion of cement paste which is made using water, binder materials and superplastisizer. Besides that, when using a fixed water cement ratio with different amounts of bottom ash content, the strength of concrete may decrease due to the high initial free water content used in the mixture which reduces bleeding and poorer interfacial bonding between the aggregates and the cement paste. (ii) at the early curing stage, the compressive strength of normal concrete is higher than the mean of compressive strength of bottom ash concrete which is lower [36]. However, a longer curing time will affect the strength of bottom ash concrete which is almost similar to the strength of normal concrete [37]. Due to the replacement of stronger material with delicate material as well as the non-appearance of pozzolanic activity by bottom ash, a decrease in compressive strength of bottom ash concrete may be observed at an early stage. Mathiraja [38] observed that the pozzolanic activity of bottom ash becomes slows down at partial (14 days) curing age and after the period where the bottom ash starts reacting with calcium hydroxide to create C-S-H gel and needles.

Previous research has shown conflicting results regarding the effect of bottom ash concrete on compressive strength. Therefore, further research on bottom ash aggregates is needed to review the effect of aggregate proportion and water absorption that will influence the compressive strength of bottom ash concrete.

3.2.2 Flexural strength

Based on a study by Wongkeo et al. [39], it was found that the flexural strength value for bottom ash lightweight concrete increases when there is a decrease in bottom ash content in Portland cement. The increase of flexural strength is related to the increase of the bulk density of concrete. However, Raju et al. [33] have also conducted a flexural strength test on the bottom ash concrete and found that the flexural strength of concrete decreases when natural fine aggregates are replaced with bottom ash. The flexural strength of bottom ash concrete slightly decreases with the use of fine and coarse bottom ash [26]. Besides that, the difference sizes of bottom ash will affect the flexural strength of bottom ash concrete. From previous research, the modulus of rupture decreases when fine aggregates are totally replaced with fine or coarse bottom ash. Park et al. [27] discovered that the flexural strength of bottom ash concrete tends to reduce all aggregate grading as the bottom ash mixing ratio increases. This means that the fractured section of concrete with bottom ash aggregates shows a flatter surface than normal aggregates [40]. Therefore, it can be concluded that the flexural strength of bottom ash concrete decreases due to the crack propagation in bottom ash concrete which occurs more easily through bottom ash particles compared to normal aggregates which are difficult to penetrate. Consequently, the direction of cracks will affect the normal concrete which made by normal aggregate.

3.3 Acoustic properties

Porous material is usually effective as a sound absorber. Since bottom ash particles are angular, irregular and have a porous structure, they are suitable to be used as sound absorption material.

3.3.1 Sound absorption

Generally, to reduce the noise level, reverberation time, remove echoes as well as to avoid sound from being stuck by concave surface, there are various types of sound absorbing materials that can be used. Coal bottom ash is one of the sound absorptive materials that have the potential to absorb sound that has been produced by transportation or traffic.

Arenas et al. [41] have conducted an investigation on the development of acoustic barriers made of the co-combustion of bottom ash. Meanwhile, 80% of bottom ash used in porous concrete for sound absorbing purposes has shown similar properties as the conventional materials used for sound absorbing applications [21][44][46]. From the research, it was found that the sound absorption coefficient increases when the bottom ash particle size is larger. The grain particle size of bottom ash will influence the acoustic performance and non-acoustic performance (physical and mechanical properties) of the product which contains bottom ash. The larger particle size of bottom ash has resulted in the best sound absorption coefficient due to the higher porosity of particles [21]. Usually, there are several factors that will influence the absorption performance of concrete and previous research has found that acoustic absorption of materials depends on the thickness of the specimen being tested. The acoustic absorption of concrete which has the same composition of bottom ash but varying in thickness will influence the sound absorption coefficient. Thus, the sound absorption coefficient for the thicker specimen slightly decreases the ability of the specimen to absorb sound towards frequency level. The sound absorption coefficient of noise also depends on the materials used. Since bottom ash is a porous material that is used in concrete, the energy of sound will dissipate in the porous structure of bottom ash. In addition, due to the higher porosity of bottom ash, it can potentially cause the air to lost momentum. When a sound wave strikes a material, a portion of the energy is reflected, another portion is absorbed by the material while the rest is transmitted as sound [41, 43]. Changes in direction and viscous drag are also involved in the movement of air particles in the pores. Kucsmarski et al. [42] indicated that less energy is transmitted to the solid structure as more is reflected from the surface when the pore size decreases, this making the material less useful for acoustic absorption.

4 Conclusions

This paper had reviewed previous works that were carried out on the chemical and physical properties, fresh and hardened propertied of bottom ash concrete. The remarks of this literature review can be summarised as follows:

i) From the previous studies conceive that bottom ash has greater potential to be used as one of the construction material, where it has been proved that it is usable as an additive in concrete mixtures to produce durable concrete. Therefore, it has been proved that bottom ash can be used in the concrete mixture either as fine aggregate or coarse aggregate replacement. However, an observation was made where coal bottom ash is suitable to be used as partial or total replacement of fine aggregate (sand) in concrete. A suitable optimum percentage of bottom ash was obtained, where up to 50% of bottom ash without any admixture such as superplasticiser can be used as non-structural concrete such as noise barriers, wall panel and partitions.

ii) The slump test experiment can determine the workability of fresh concrete which refers to true slump values. The workability of concrete has affected due to the presence of bottom ash in the concrete mixture, which it is decreases as the content percentage of bottom ash in concrete mixture increases. Therefore, to obtain the best results in terms of workability, it is important to get the optimum value of mixing.

iii) The addition of bottom ash in the concrete mixture has decreased the mechanical properties of bottom ash concrete strength at early stages. This reduction of strength increases with the increase in bottom ash content. But, after 14 days of curing the strength of bottom ash concrete becomes similar to normal concrete.

iv) Modulus of rupture of concrete decreases when the fine aggregates were replaced with bottom ash. The crack propagation occurs more easily through bottom ash particles.

v) The usage of bottom ash in concrete will also help in protecting the environment especially in terms of noise pollution. The physical properties of bottom ash show that it has a higher porosity and is therefore suitable to be used in concrete as sound absorption material. Nevertheless, from the review, there is very little research focusing on the effect bottom ash with respect to the grain size particle, thickness of specimen, water absorption, air flow resistivity, porosity, density, placement of sound absorptive material, speed of sound and various percentages of bottom ash content in concrete in order to obtain good noise absorption characteristics. Therefore, this warrants further research on this matter.

The authors would like to express their gratitude to Universiti Tun Hussein Onn Malaysia for funding the research under the FRGS Grant Vot 1576.

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