

Comprehensive Review on Fresh and Hardened Concrete Containing Coal Bottom Ash as Sand and Cement Replacement

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Abstract: The related significant manufacture of Ordinary Portland cement (OPC) and huge concrete production have been experiential causing a lot of bad impact to the environment. The lack of alternative materials for cement has resulted in a large amount of CO₂ being produced and a high energy consumption, all of which are the consequences of cement manufacturing. One type of solid agricultural waste was adopted in this research, namely Coal bottom ash (CBA) as fine aggregate and cement replacement in different proportions, respectively. The different percentage of CBA by different reference was used as a partial replacement of fine traditional fine aggregate and as a partial replacement of ordinary Portland cement (OPC). This paper summarized numerous vibration response studies of the fresh and hardened properties of the concrete incorporating CBA as sand and cement replacement. The review on the effect of various parameter on fresh and hardened properties such as the density, workability, compressive strength, tensile strength, microstructure and water absorption in concrete containing CBA as sand and cement replacement was discussed in detail by classification. Finally, on the summary table of the previous study was noted, presenting the parameter studied and remarks on each study conducted. The optimum percentage of CBA to replace cement and sand effect on the properties of the concrete are discussed which it is depend on the quality of the materials.

Keywords: Sand, Strength, Microstructure, Water Absorption, Workability, Density

1. Introduction

Over a few decades, the usage of concrete through concreting work is generally utilized for major structures such as building, bridge and highway. Straightly to high command of concrete usage, numerous studies have been conducted to improve the properties of concrete as well as decrease its downside. The new enhancement for concrete fresh and hardened properties must have a high compressive strength and excellent workability for example good filling ability and passing and has high segregation resistance and bleeding.

Lately, lightweight concrete (LC) is one of the most important innovation in construction industry due to many advantages it possess both in fresh and hardened concrete. Plenty of research on the manufacture of lightweight concrete brick has been conducted. One of the most preferable lightweight aggregates materials have been used is coal bottom ash (CBA). Additionally, in most recent years, the researchers find that CBA have bought many advantages to the industry due to its low cost, low density fill and also suitability to be used as sand replacement of construction material which make a very sustainable material. It is also used in high-performance lightweight concrete as a low-cost substitute for more costly concrete sand and as a fine aggregate [1]. To determine the effect of bottom ash on shrinkage cracking the Topcu and Bilir [2] has tested non-ground bottom ash as fine aggregate replacement in concrete with various replacement ratios and they were found that the increasing content usage of bottom ash till 100% will affect the ratio of shrinkage cracking due to porous structure. Andrade et al. [3] evaluated the fresh properties of concrete has influenced by CBA as fine aggregates. They also found the setting time has affected by presence of bottom ash in concrete. Other than that, CBA also weak to water loss by bleeding. When the percentage of bottom ash is higher, lower deformation through plastic shrinkage. Aggarwal et al [3] found that the strength development for various percentages of bottom ash can be easily to compared to the strength of normal concrete at different curing days by investigated the effect of the use of coal bottom ash as a replacement of fine aggregates on the mechanical properties.

In recent research, different kinds of materials have been used, such as silica fumes, fly ash and coal bottom ash were tested as being Portland products for cement replacement [4]. Owing to environmental and technological factors, their replacement for Portland cement was an important topic for study. Clearly, because of their chemical, physical and mineralogical characteristics, different replacement materials can have different effects on the properties of the cement [5]. It has been well established that CBA use potential is primarily determined by its physical characteristics, such as the distribution of grain size, staining potential, and color. [6]. Previous research has suggested that fly ash decreases early hydration heat and offers greater longevity due to alkali-silica reaction relative to simple Portland cement [7]. As it has ample resistance to sulfate corrosion, low-quality fly ash is acceptable for cement blends [8]. The addition of alkali-activated fly ash to the mixed cement blends increases the concrete's mechanical efficiency [9]. With increasing silica, alumina and iron (III) oxide content, the compressive strength of the concrete decreases. [10]. With sufficient grinding, in Portland cement processing, coal bottom ash with pozzolanic operation can be used as a substitute material [11]. Therefore, in this paper the summary on the properties of concrete containing coal bottom ash such as density, workability, compressive strength, tensile strength, water absorption and microstructure are discussed.

2. Coal Bottom Ash (CBA)

The ashes were developed to allow for substantial improvements in the mechanical properties and durability of the structural concrete material regarding Firdaus et al [12]. Coal bottom ash (CBA) is an underused product from power plants which is commonly used as a substitute for river sand. An overview of CBA's production can give the basic background on the manufacturer of the material and the necessary features for an effective use [13]. CBA is produced by the same combustion process as fly ash and has enough chemical properties to be used in concrete as an essential binder. Increasing the fineness of a pozzolanic material could speed up the pozzolanic reaction and increase the effect of pore filling which resulted in an improved binder density [14]. According to Gooi, Mousa and Kong, the bottom ash is named with a prefix for the origin of its source of fuel. Bottom ash arising from a coal boiler or incinerator is known as CBA, whereas bottom ash produced by a municipal solid waste

incinerator (MSWI) is known as bottom ash from MSWI [13]. As such, cement manufacturers are commonly using this as a component of cement clinkers.

On the other hand, CBA is typically disposed of in landfills (called dry ponding) or wet ponding, where the ash is mixed with water until a slurry is formed and warehoused in ponds [15]. Supplementary cement materials (SCMs) are pozzolans that partially replace OPC to alter the properties of cement or produce a more sustainable product local. This class of materials contains a wide range of by-products like fly ash, blasting. Lastly, CBA also can be used as a sustainable filler or aggregate and cement replacement in concrete construction, such as road subbases, noise barriers, recesses and lightweight concrete production

2.1 Physical Attributes of CBA

To identify the physical properties that are innately present, adequate material characterization of the industrial by products is crucial. The CBA properties can affect the concrete or cement mix design in many different way. An increased SSA, for example, reinforces CBA reaction particles and substances. This increases the formation in concrete of Calcium-Silicate-Hydrate (C-S-H) or Calcium-Aluminate-Silicate-Hydrate (C-A-S-H). Fineness modulus (FM) may affect aggregate use of CBA. The FM values reported by the studies reviewed have a wide range, but the majority fit within the typical fine sand range which is 1.6-2.2 [16]. Measuring the raw CBA ratio is critical because it can affect the functionality of the mix design and must be taken in account when deciding the l / b ratio. Hamzah et al. [17] reported 37.2 percent of CBA with the highest rate. Similarly, Singh and Siddique and Singh et al. [18]. Coal boiler may trigger the high rates inefficiencies leaving behind carbon and impurities trapped in water. For use as a cement replacement or in a geopolymer binder, a longer grinding period or more sophisticated grinding equipment can drastically increase CBA SSA. The desired level of grinding, however, would increase the required energy and the associated costs. Fine grinding requires special machinery and finishing

2.2 Chemical composition of CBA

The chemical composition of CBA (especially the contents of silica, alumina, and ferric oxide) varies depending on the coal source, operating conditions, and processing. After hydration, the silica content of CBA may greatly influence the formation of C-S-H gels in cement and concrete [13] CBA carbon content stems from inefficient combustion in boilers or incinerators. Heavy metal compounds typically occur at low levels in CBA according to source. However, testing of CBA used in construction for heavy ion leaching is still necessary to minimize subsequent contamination of the groundwater [19]. This is predicted in view of the high variability in chemical composition and the variance in CBA care that the concrete, mortar or paste produced displays differences in their pozzolanic potential.

Table 1 shows the chemical composition of CBA. The burning process will affect the quality of the ash. Therefore, the chemical composition of CBA from different sources may showed a different value.

Table 1: Chemical composition of CBA [20]

| Component (%) | Ground coal bottom ash |
|---|-------------------------------|
| Silicon Dioxide, (SiO ₂) | 36.5 |
| Aluminum Oxide, (Al ₂ O ₃) | 20.0 |
| Ferric Oxide, (Fe ₂ O ₃) | 15.1 |
| Calcium Oxide, (CaO) | 18.7 |
| Magnesium Oxide, (MgO) | 1.9 |
| Sodium oxide, (Na ₂ O) | 0.2 |
| Sulfur Trioxide, (SO ₃) | 2.9 |

| | |
|-------------------------------------|-----|
| Potassium Oxide, (K ₂ O) | 2.5 |
| Loss on ignition, (LOI) | 3.6 |

3. Coal Bottom Ash as sand replacement

For the CBA studies as a fine substitute aggregate, the cement content in the concrete or mortar mixes was kept constant. The aggregate substitution is dependent upon weight or volume is uncertain in some sources. Nonetheless, the studies that published this information gave some insights into the compressive strength effects of CBA aggregate replacement (sand). There is however no discernible correlation between the LOI and the compressive strength. The strongest concrete mix in their study contained silica fume and fine blast furnace slag, whereas the lowest strength samples did not contain additives and included silica fumes, respectively. The highest recorded compressive strength of concrete using CBA as a replacement for sand (163 MPa) was achieved with steel fibers [21] These findings suggest that the high efficiency of using additives in the form of fibers or fillers instead of chemicals to increase CBA strength local.

Several studies have taken full replacement of sand (100 per cent) with concrete CBA by mass [22], yet they also received compressive strengths ranging from 24 MPa to 35 MPa. The compressive strength of concrete and mortar using CBA as a sand replacement can be significantly influenced by the number of related factors. In addition to FM, the presence of superplasticizer and l/b variation, LOI content, pozzolanic content, type of treatment, and SSA may cause significant changes in CBA concrete and mortar's mechanical properties.

3.1 Workability of the concrete incorporates CBA as sand replacement

A concrete when verifying the uniform consistency of concrete during casting, in order to assess the workability or quality of the concrete mix prepared at the laboratory, the slump test should be carried out. The easiest test is the Slump test, which requires low costs and produces quick outcomes. Hence, since 1922, it has been commonly used for workability studies. As per procedures referred to in ASTM C143 in the 40 United States.

On the plain concrete and the concrete blend containing varying amounts of coal bottom ash, slump was carried out. In Table 2, the test results are shown the slump test that conducted by Sandhya and Reshma [23]. The value of slump flow for control mix shown with 75mm, while the 30% of replacement shown 68mm and for 50% of CBA used as sand replacement show 67mm. It is observed that with the rising percentage of substitution of fine aggregates with coal bottom ash, the slump decreases. If the degree of substitution rises, for the mix to get closer, a larger volume of water is required. This is because of the bottom ash is added fineness.

While, Aydin [24] investigated that the flow and slump decreased as the volume of CBA in the paste increased as shown in Table 2 The slump flow at 100% of CBA replacement shows 13mm compare to the normal concrete with 23mm. While the slump flow at 70%, 80% and 90% of CBA replacement were continuously decrease

Then, Argawal and Gupta [25] calculated the workability in terms of compaction factor. With the rise in the substitution ratio of the fine aggregates with the bottom ash, as seen in Table 2 the workability calculated in terms of compaction factor decreases. As the substitution amounts of fine aggregates is raised, it may be attributed to the extra fineness of bottom ash. Therefore, due to improved fineness and a larger volume of water required for the blend components to get closer to packaging, changes in the basic surface result in a reduction in the workability of the mix.

Other investigated from Siddique [26] shows the value of slump flow decrease with the increasing in percentage of CBA as fine aggregate. The Table 2 shows the value of slump test at 0% of CBA was 673mm compare to 30% of CBA replacement with 627. Therefore, the increasing of CBA contains decreasing the slump flow value in the concrete. Most of the mixes, a slump flow value varying from 500 to 700 mm for concrete to be self-compacting was proposed for the slump flow period for the

concrete to achieve a diameter of 500 mm.

Singh and Siddique [18] also investigated the effects of coal bottom ash as sand substitute on slump values in both grades of concrete mixtures is shown in Table 2. The control concrete mixture slump values were 70 mm for 38Mpa concrete and 125 mm for 34Mpa concrete grade. The drop in the slump of bottom ash concrete mixtures over the respective control concrete mixture was nearly linear for both concrete types, with a rise in the content of coal bottom ash. Bottom ash concrete mixtures of concrete 38Mpa reported a larger drop in slump values compared to those of concrete 34Mpa of up to 50 % replacement stage. However, bottom ash concrete mixtures A75, A100, B75 and B100 showed nearly equal decrease in slump values. The rise in fine aggregate particles thinner than 1000 mm as bottom ash was mixed into concrete resulted in an increase in surface area that caused slump values to decrease.

Table 2: Workability in term of Slump Flow from previous studies (mm)

| Specimen with percentage of CBA replacement %/reviews | Slump Flow (mm) | | | | | | | | | | |
|---|-------------------|-----|------|------|------|------|-----|-----|-----|-----|------|
| | 0% | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 10% |
| Sandhya and Reshma[23] | 75 | - | 71 | 68 | 72 | 67 | - | - | - | - | - |
| Aydin,[24] | 23 | - | - | - | - | - | - | 18 | 15 | 14 | 13 |
| Siddique [26] | 673 | 673 | 591 | 627 | - | - | - | - | - | - | - |
| Singh and Siddique[18] Concrete 38Mpa | 70 | - | 57 | 39 | 29 | 25 | - | - | - | - | 11.2 |
| Singh and Siddique [18]Concrete 34Mpa | 125 | - | 106 | 105 | 75 | 65 | - | - | - | - | 23 |
| | Compaction Factor | | | | | | | | | | |
| Argawal and Gupta[25] | 0.9 | - | 0.87 | 0.85 | 0.84 | 0.82 | | | | | |

3.2 Compressive Strength of concrete incorporates CBA as sand replacement

Compressive strength is a material or structure is ability to bear loads without any cracks or deflections on the surface. Under compression, when in stress, a substance continues to reduce the bulk and size elongates. The percentage and the materials used for the slump test and for casting the specimens are from the same concrete. Table 3 shows the result of different size of specimens containing CBA undergo compressive strength for 28 days test from previous studies.

Singh and Sidique [18] has conducted test at the age of 7, 28 and 56 days of recovery, the compressive strength of concrete mixes developed with different percentages of coal bottom ash as fine aggregate replacement and the traditional mix was measured. The results obtained that as the percentage of the bottom ash is raised, the strength declines. The mix of concrete containing CBA as fine aggregate were replaced with 20% until 50% of CBA content. In the initial phase, the lower ash gained strength at a slower pace and gained strength after 28 days at a faster rate (above the targeted strength).

Then Siddique [26] investigated of self-compacting concrete (SCC) mixes for compressive strength tests at 7, 28, 91 and 365 days of age, SCC with (0 % bottom ash) developed a compressive strength of 29.6, 35.2, 59.0, and 61.2 MPa. SCC mixes of coal bottom ash hit power at 7 days between 25.8 and 20.8 MPa; at 28 days between 35.1 and 25.8; at 90 days between 46.5 and 36.2; and at 365 days between 48.8 and 41.8 MPa. With the rise in coal bottom ash content at all ages, the compressive power decreased. For each bottom ash substance, however, compressive strength improved with age.

Aggarval and Gupta [25], respect to their compressive strength at the age of 90 days, the gain of compressive strength by various forms of bottom ash concrete ranges from 56-65 % at 7 days, 75-85% at 28 days, and varies from 86-90 % at 56 days. Owing to the pozzolanic activity of bottom ash, the bottom ash concrete absorbs strength at a slower pace in the initial cycle and acquires strength at a faster

rate after 28 days.

Ahmad Maliki et [27], conducted the compression strength values for both blends at 7 and 28 days of curing, respectively. It can be noted from the statistics that the graph pattern indicates that the strength decreased dramatically at 10 % of CBA in concrete, but the strength steadily increased between 20 % and 20% until 40% concrete from CBA. The power of the concrete deteriorated again at 50 %. The strength value rose dramatically at 60 % of CBA concrete and declined steadily until it reached 100 % of CBA concrete. 60 % of CBA as sand replacement in concrete is the optimal percentage to meet the full strength. The general literature-based compressive strength pattern at 28 days of cure has been outlined in Table 3.

Table 3: Compressive strength of concrete at 28 days of curing at different contents of CBA

| Authors (s) | Compressive Strength of concrete contain different Percentage (%) of CBA as fine aggregate, (N/mm ²) | | | | | | | | | | |
|-------------------------|---|------|------|------|------|-------|------|------|------|------|------|
| | 0% | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% |
| Singh and Sidique[18] | 48.7 | - | 45 | 43.4 | 42.5 | 40.79 | - | - | - | - | - |
| Sidique[26] | 35.3 | 35.1 | 28.9 | 25.8 | - | - | - | - | - | - | - |
| Argawal and Gupta[25] | 33.3 | - | 30.4 | 29.5 | 28 | 26.3 | - | - | - | - | - |
| Ahmad Maliki,et al [27] | 45.6 | 42 | 43.1 | 44.8 | 45.6 | 43.5 | 46.2 | 43.9 | 42.7 | 41.1 | 36.5 |

3.3 Tensile strength of concrete incorporates CBA as sand replacement

Tensile strength is a material or structure's ability to bear loads without any cracks or deflections on the surface. Table 4 shows the result of different size of specimens containing CBA undergo tensile strength test from previous studies at 28 days of curing.

Arggarwal and Gupta [25], conducted splitting tensile strength test at 7,28,56,90 days of specimen with and without bottom ash. The splitting tensile strength of concrete declines with the rise in the percentage of substitution of fine aggregates with the bottom ash, but with the curing age, the splitting tensile strength increases. With age, the rate of increase in split tensile strength decreases. The splitting tensile strength gain is more at 20% replacement of fine aggregates with bottom ash. At higher percentages the strength gain decreases and it is minimum at 50% replacement level.

Ahmad Maliki et al [27] summarized that all percentages of CBA in concrete as a sand substitute reached lower strength for 7 days than the 32.9 MPa control concrete target requirement. For 28 days, though, the differing percentages of CBA as fine aggregate substitution rose dramatically in strength relative to 7 days of concrete curing. The 90 %, 100 % and 70 % CBA concrete strength exceeded 3.0 MPa in strength. 70% of CBA concrete, however, reached a value that exceeds the tensile strength of 3.63MPa of control concrete. The tensile strength of the control concrete is 3.50MPa at present. Consequently, 70 % is the optimal percentage of CBA in concrete to be used as fine aggregate substitution.

Then Sandhya and Reshma [23] obtained the result, the tensile strength of concrete is observed to decrease with the rising percentage of bottom ash. The tensile strength, however, rises with the curing age. The strength gain is greater at the higher curing age, but the strength gain falls at the higher percentage of substitution.

Next, Aggarwal and Siddique [27], displays the effects of the splitting of the tensile strength of FB mixes. For the 10%-50% CBA mixes, a rise of 3.1 %, to 8.46 % was observed and a decrease of 35.38 % was observed for the FB60 mix at 7 days with respect to the normal mix. The decline of 13.46 %, 1.44 % and 30.29 % was observed at 28 days for mixes 10%,20% and 50 % CBA, with an improvement of 18.27 %, 12.98 %, and 8.17 %. With an improvement of 6.39 % and 2.26 % compared to the reference mix concrete mortar for the mixes FB30 and FB40. Both FB mixes displayed a stronger strength than Concrete mortar mix with the exception of FB60 at 7 days, but all mixes showed nearly equal strengths to those of reference mix concrete mortar as the age increased to 365 days. In the

preceding paragraphs, containing most of the available studies in which CBA was used in place of fine aggregate, a mixed behavior in tensile strength test results was noted. The general literature-based tensile strength pattern at 28 days of cure has been outlined in Table 4.

Table 4: Tensile strength of concrete at 28 days of curing at different contents of CBA

| Authors (s) | Tensile Strength of concrete contain different Percentage (%) of CBA as fine aggregate, (N/mm ²) | | | | | | | | | | |
|---------------------------|--|------|------|------|------|------|------|------|------|------|------|
| | 0% | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% |
| Aggarwal and Gupta[25] | 2.62 | - | 2.52 | 2.37 | 2.26 | 2.23 | - | - | - | - | - |
| Ahmad Maliki [27] | 3.5 | 2.96 | 2.74 | 2.87 | 2.72 | 2.96 | 2.94 | 3.63 | 2.98 | 3.06 | 3.11 |
| Sandhya and Reshma[23] | 3.97 | - | 3.81 | 3.27 | 2.77 | 2.06 | - | - | - | - | - |
| Aggarwal and Siddique[28] | 2.08 | 1.8 | 2.05 | 2.46 | 2.35 | 2.25 | 1.45 | - | - | - | - |

3.4 Microstructure of concrete incorporates CBA as fine aggregate

It is well established that the main step of calcium-silica-hydrate (C-S-H) is present. The stages were shown to review the available literature, considering different scanning electron microscope images.

Regarding to Aggarwal and Siddique [28], the reference mix micrograph, the SEM image at a magnification of 1.5 KX illustrates the development of appropriate and transparent C-S-H gel in different phases. The encircled portions reflect the voids, while C-S-H gel and inert aggregates are the rest of the picture (both fine and coarse). The crucial point to be observed in the micrograph is that the C-S-H gel, the bright masses of nodules and large sections of chalky gel are scattered over the whole micrograph, since it is apparent from different literatures that the C-S-H gel is distributed over the aggregates, thereby acting as paste binders. The C-S-H gel reaction or formulation is better, suggesting comparative densification of the mixes before 50 % substitution. The micrograph of the 60% CBA blend reveals that the aggregate has crumbled from the mix of waste foundry sand and bottom ash flakes. The C-S-H gel in the micrograph could not be observed at certain sites.

Andrade [3] investigated the arguments that the bottom ash particles can be viewed as small reservoirs of water because they have a large porosity that affects the results of the concrete moisture transport tests. It can be found that, perhaps during the mixing phase, the bottom ash particle experienced a scission, suggesting a porous surface slice. The pozzolanic influence, low but occurring nonetheless, was confirmed by Figure 1 as being present in the bottom ash concrete, which presents a spherical particle surrounded almost entirely by a coating of calcium hydroxide with cement paste and fine particles of the material itself.

In addition, the demonstrated broad C-S-H gel shape, thereby forming a thick microstructure. For the ingress of chloride ions into concrete, the fibrous C-S-H structure serves as a dense impermeable membrane. This makes the concrete more resistant to the harsh climate.

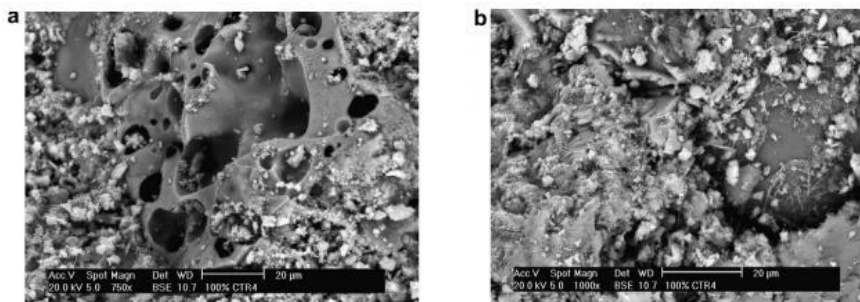


Figure 1: Micrograph SEM bottom ash concrete mix (a) porosity of bottom ash particle (760x). (b) Ca (OH)² on bottom ash particle (100x)

3.5 Density of the concrete incorporates CBA as fine aggregate

Density of the concrete is important to produce lightweight concrete. The review of previous studied about density of the concrete containing CBA as fine aggregate will has been conducted.

Singh and Siddique [18] investigated that the effect of coal bottom ash on the dry bulk density of mixtures of bottom ash concrete from both grades of concrete mixtures. For concrete 38Mpa and 2396 kg/m³ for concrete 34Mpa, the dry bulk density of the control concrete mixtures was 2327 kg/m³. The use of coal bottom ash lowered the dry bulk density of bottom ash concrete mixtures of all types of concrete mixtures nearly evenly.

While Aggarwal and Gupta [25] conducted the density of the concrete decrease with the increasing of containing CBA in concrete as fine aggregate. The normal concrete with 0% has density with 2480 kg/m³, While the density with containing 20% - 40% CBA linearly decreasing from 2467 kg/m³ to 2408. Finally, the 50 % of CBA contain shows 2400 kg/m³ less dense compare to the normal concrete. Therefore, the larger value of CBA containing, the less dense of concrete.

3.6 Water absorption of the incorporates containing as fine aggregate

The water absorption test was carried out by completely immersing the dry cube specimens in water at 25°C for 96 h and recording the percentage of the amount of water absorbed per unit of initial mass. This provides the amount consumed by water.

From the previous studied, Siddique [26] investigated the the effect of bottom ash on the water absorption of concrete SCC mixes at 7 and 28 days of age .Overall water absorption was found to range from 5.8 % to 7.1 %. It is evident that all mixtures of SCC blends have poor absorption characteristics (less than 10 %). This is consistent with the findings stated by [29].

Then, the water capillary absorption test was performed by Andrade [3] and the data was tracked for 24 hours. This is attributed not only to a large improvement in the overall w/c ratio as the bottom ash content is increased, but also because a pore structure different from the reference sample is created by the increase in the bottom ash content (with natural sand). When evaluating the analyzed mixtures, it was observed that only 25 % of the concrete style CRT4 has a value comparable to that obtained for the reference blend, with all the others having close or higher values. It can also be inferred that the rise in the volume of bottom ash contributes to a stronger filling of the pores, decreasing the diameter; moreover, the amount of water consumed by capillarity increases as an aspect requiring water by intrinsic internal absorption.

4. Coal Bottom Ash as cement replacement

OPC replacements are commonly researched, but four decades ago, the research of CBA as a cement substitution started. Pozzolanic properties of the CBA were discovered in 1999, but it has 50 has been studied since the 1970s for use in concrete as a fine aggregate and OPC substitute. [11].The use of coal bottom ash in the concrete sector also tends to minimize energy consumption and CO₂ pollution, by cement substituted with coal bottom ash in the concrete manufacturing industry results in a reduction of 0.7-1.2 tons of CO₂ emissions. According to the findings presented here, the price of concrete C30/37 can be decreased by 10% due to the use of grinded coal bottom ash combustion and the volume of CO₂ emissions can be reduced by 22.9% [14]

4.1 Workability of concrete incorporates CBA as cement replacement

Mangi et al [30] studied with and without ground CBA, the workability of concrete mixes was tested. In contrast with concrete containing ground CBA, the experimental analysis claimed that the control mix had a high slump. The lowest slump was registered at each grinding time/fineness of 25 and 35 mm with 30 % cement replacement. The average slump value for normal concrete was 56mm greater

compare to concrete mix contain 20 to 40% of CBA with 43.33 and 35. The concrete with 40 % of CBA shows the smallest value of slump flow. Slump values were found to decrease as the volume of CBA increased. This is due to the fineness of the particles that improves the surface area.

While the slump test conducted by Jaturapitakkul and Cheerarot [31] was shows. It shows that the slump value increasing due to increasing in CBA contains in concrete as cement replacement. Regarding the result, the slump value of concrete contains 25% of CBA has 110mm compare to normal concrete with 120mm. Concrete mix with 45% has the highest slump value with 140mm compare to other mixes.

Khan [32] indicates that the operability of concrete mix reduces relative to control mix as the substitution of cement with Bottom Ash increases. It also indicates that, relative to Original Bottom Ash (OBA), the inclusion of Grinded Bottom Ash (GBA) limits workability further. It may be that GBA is finer than OBA, which retains more water and thereby decreases operability. Generally, the value of the slump test decrease when increasing in bottom ash contents.

Table 5: The Slump flow of concrete containing CBA as cement from various previous studied

| Specimen with percentage of CBA replacement/reviews | Slump Flow (mm) | | | | | | | | | |
|---|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | (0%) | (10%) | (20%) | (25%) | (30%) | (35%) | (40%) | (45%) | (50%) | (60%) |
| Mangi [30] | 56 | - | 43.33 | - | 37.67 | - | 35 | - | - | - |
| Jaturapitakkul and Cheerarot [31] | 120 | - | - | 110 | - | 130 | - | 140 | - | - |
| Khan R [32]- (OBA) | 107 | 101 | 96 | - | 91 | - | - | - | - | - |
| Khan R [32]- GBO | 107 | 99 | 93 | - | 88 | - | - | - | - | - |

4.2 Compressive strength of concrete incorporates CBA as cement replacement

The compressive strength test is the most accurate hand-to-hand test carried out on concrete to determine its performance. Table 6 shows Compressive Strength of concrete contain different Percentage (%) of CBA as cement from previous studied at 28 days.

Khan [32] illustrates the compressive strength variance of the bottom ash control mix of concrete mixes after 7, 14, 28, 56 and 90 days, respectively. The strength of the BA concrete is much lower than that of the control mix concrete in the first 28 days. There is less cement in the bottom ash concrete compared to the control mix, so the strength of the bottom ash concrete is less than the control mix at 28 days. GBA is finer than OBA, so GBA is tightly packed in concrete compared to OBA, so in the initial age, the strength of GBA concrete is greater than OBA concrete. Compared to control mix, BA concrete gains more strength after 28 days and the gap between them is decreased due to the pozzolanic reaction of bottom ash with calcium hydroxide. GBA concrete gains more strength after 28 days than OBA concrete because there is more pozzolanic reaction in GBA concrete.

Jaturapitakkul and Cheerarot [31] investigated CC25, CC35, and CC45, which had a Portland cement content were found to give a compressive strength of 25.5, 36.6, and 45.8 MPa at 28 days, respectively. With 20 % of ground bottom ash as cement replacement and 260 to 440 kg/m³ of cement material, it was found that the higher cement content resulted in a faster compressive strength production rate.

Then, Hashemi [33] conducted the bottom ash mortar mixtures attained a higher compressive strength at an early curing age of 7 day than those obtained by the mortar mixture MT1. The MT2, MT3, MT4 and MT5 specimens attained 6.4 %, 6.9 %, 16.35 %, and 2 % compressive strength of the control mortar mixture. However, MT6 at all cuing time days reached lower compressive strength than a control mortar mixture. Overall, the inclusion of BA in silica sand-based matrices by up to 40 % does not have a tangible adverse impact on the matrix compression power, whereas further substitution decreases the compressive strength.

Table 6 : The compressive strength of concrete containing CBA as cement from previous studied

| Authors (s) | Compressive Strength of concrete contain different Percentage (%) of CBA as cement (N/mm ²) | | | | | | | | | | |
|---------------------------------------|--|------|------|------|-----|-----|-----|-----|-----|-----|------|
| | 0% | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% |
| Khan R[32]- OBA | 26 | 21 | 20 | 19 | - | - | - | - | - | - | - |
| Khan R[32] - GBA | 26 | 19 | 17 | 15 | - | - | - | - | - | - | - |
| Jaturapitakkul and Cheerarot [31]-GBM | 40.8 | 40.5 | 39.7 | 38.3 | | | | | | | |
| Hashemi [33] | 46 | - | 45 | - | 44 | - | 47 | - | 38 | - | 24 |
| Jaturapitakkul and Cheerarot [31]-OBM | 40.8 | 28.4 | 20.1 | 13.6 | - | - | - | - | - | - | - |

4.3 Tensile strength of concrete contains CBA as cement replacement

Result of different size of specimens containing CBA as cement replacement undergo tensile strength test from previous studies.

Mangi [30], reported that the splitting tensile strength was increased by approximately 8% by 10% by replacing Portland cement with ground CBA obtained through 30 hours of grinding time. However, due to the addition of ground CBA to concrete, major improvements in tensile strength were observed. With soil CBA having a 40 hours grinding cycle, the lower values of splitting tensile strength were reported. This is due to more fine particle sizes, which in the concrete mix have absorbed more water. For 10, 20 and 30 % replacement level in concrete mix, the output of ground CBA with 40 hours of grinding duration was evaluated and a substantial decrease of in tensile strength was observed. Concrete containing 10% 30-hour ground CBA grinding gives strong strength growth of about 8% than the control mix.

While, Rafieizonooz [27], investigated fly ash-bottom ash mixes' splitting tensile strength are decrease of 3.55 %, 8.87 %, and 5.32% in tensile strength due to increasd in fly ash bottom ash and an improvement of 1.99 % was observed for the 30% FBA mix at 7 d age curing time with regard to the control mix. Similarly, the decrease for 10%, 20% and 40% mixes was observed at the age of 28 d cure era, with an improvement of 4.96 % for the 30% FBA mix relative to the control mix C0. At the age of 91 d, a decrease for 10% and 20% mixes, with an improvement for 30% and 40% mixes relative to the control mix C0.0. Similarly, a decrease of for 10%and 20% mixes was observed at the age of 180 d healing time, with an improvement of 24.07 % and 12.68 %for 30% and 40% mixes relative to the control mix C0.0.

4.4 Microstructure of concrete containing CBA as cement replacement

The microstructure of CBA concrete detected by scanning electron microscopy (SEM) enables the transition of morphology from the raw material to the hydrated shape to be monitored (C-S-H gel).

Jun Ng [34] reported that a fairly homogeneous morphology in the entire system is shown by the control mortar in Figure 2(a) while a flakier structure is shown by the CBA mortar in Figure 2(b). The OPC appears in Figure 2(a) to form a dense binder in the control mortar, but a less cohesive microstructure is formed by the combination of CBA and OPC as a binder in Figure 2(b), there also tends to be a greater number of CBA mortar pores present, which can be due to a higher percentage of C-H-S. Unlike the spherical voids caused by trapped air, the irregular shape of the pores in Figure 2(b) indicates that they may be capillary voids caused by shrinkage.

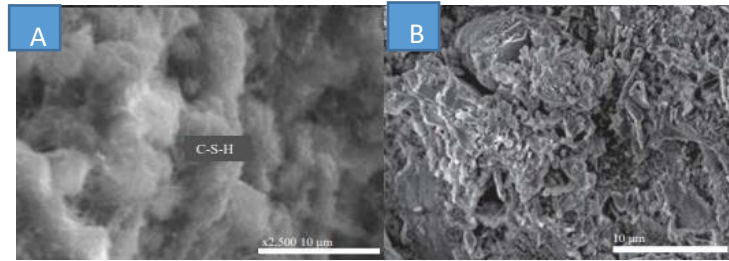


Figure 2: SEM images of a) Control mortar b) mortar with 30% ground CBA as cement replacement [34]

While Mangi [35] reported in Figure 3 are illustrated in the scanning electron microscopy study of concrete containing coal bottom ash (CBA) under water, 5 % sodium sulphate (Na_2SO_4) and 5 % sodium chloride (NaCl) exposure conditions at the overall age of 56 days. 8-10, it should obviously be noted that. At the age of 56 days, the pozzolanic reaction starts and a reaction between calcium hydroxide and CBA has been observed to form C-S-H well. In the concrete containing ground CBA, the formation of C-S-H gel was also noticed. While it was exposed under Na_2SO_4 , inside the concrete, a small portion of ettringite (white, needle-like crystals) was created, which could partially fill the voids in the concrete and contribute to the creation of power. Likewise, C-S-H formation was also found under NaCl solution in CBA concrete, but a sign of crack creation was noticed here. This is the big case of a reduction in compressive strength.



Figure 3: SEM image of concrete containing CBA under a) water condition b) 5% Na_2SO_4 solution c) 5% NaCl solution [35]

Then Oruji [36] conducted the results of the SEM/EDS study of the hydrated 28-day cement pastes Control and FA-4 and PBA(II)-4 (41 % replacement), respectively. PBA(II)-4 blended cement pastes contain smaller and more closely packed C-S-H than both the control mix and FA-4 blended cement mix. A fibrous form of C-S-H was also seen in the control sample. With angular morphology, the PBA(II) hydrated products are irregular in shape, which is to be expected due to the process of high energy pulverization.

4.5 Density of concrete containing CBA as cement replacement

Jun Ng [34] reported the effect of BA replacement on mortar density. The 63 μm samples had densities of 19.33-53.33 g/cm^3 at various BA percentages, the 75 μm samples had densities of 23.78-68.67 g/cm^3 and the 150 μm samples had densities of about 26-79.45 g/cm^3 . In other words, the 63 μm samples were around 4.45-15.34 g/cm^3 and 6.67-26.12 g/cm^3 , respectively, lighter than the 75 μm and 150 μm samples. With an improvement in the amount of BA replacement, the BA-PC mortar density decreased for the various BA sizes almost equally. This is due to the fact that low density particles of low specific gravity are made of BA

Next, Mangi [35] was test the concrete in the hardened at 28 days for density. It can be observed from the graphs in Figure 4 that the effect of ground CBA on concrete is evident both in density and in

the absorption of water. Due to the addition of soil CBA at 28 days, the concrete density continuously decreased. The density of 10% CBA20 and CBA30 comprising concrete was found to be very similar to the control specimen. The density of concrete decrease when the amount of CBA as cement increase.

4.6 Water absorption of concrete containing CBA as cement replacement

Mangi [35] also investigated the water absorption from the **Figure 4** that the effect of ground CBA on concrete in the absorption of water. In concrete containing ground CBA40 grinding time, lower values were reported and contrary behavior in water absorption was observed. The concrete with containing 30 % of CBA had the highest value of water absorption with 5.9% compare to the control concrete at 5.3 %. As the CBA fineness and replacement level improved, water absorption was found to be enhanced.

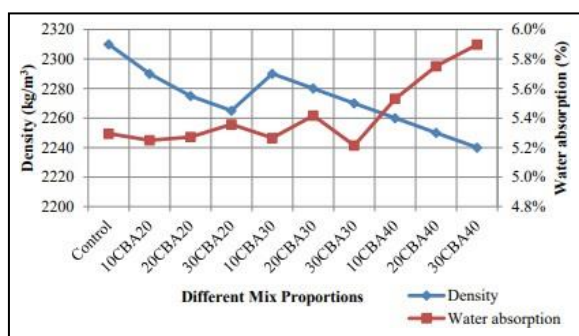


Figure 4: Density and water absorption of concrete containing ground CBA [35]

Then the water absorption test also was conducted by Khan R [32], it has been found that the water absorption potential of concrete is initially improved as the BA content increases. It was noted at 90 days that less water than 28 days is absorbed by BA concrete. The value of water absorption at 10%-30% of OBA at 28 days was greater compare to control concrete with only 6.13%. While the containing 10%-30% of CBA also shows the greater value of water absorption with 6.48%, 6.26% and 6.47%. compare to the control concrete with 6.13 %. For 56 days and 90 days immersion period, the value also greater compare to normal concrete ant 0% of CBA.

According to Martins and Goncalves [37] was conducted on the capillary absorption of concrete. Grinded CBA-containing mixes for various curing times at two different substitution ratios (25 % and 33 % by weight). The observations confirmed that the capillary absorption values of the concrete specimens decreased for both forms of concrete with an increasing binder content. In particular, as opposed to concrete mixes made with FA, the concrete mixes in which PC was substituted by Grinded CBA resulted in a slight decrease in capillary absorption coefficients. As a result of a reduction in overall porosity levels, the predicted decrease in capillary absorption coefficients was noticed.

These studies concluded that the samples' water absorption increased as the content of CBA grew. This is due, in part, to the CBA porosity that enables the absorption of water by CBA particles. Furthermore, CBA grinding and sieving used as a cement substitute or in geopolymers increases its fineness and thus improves the absorption of water.

5. Conclusion

The following conclusion have been made:

- i. Replacing sand for fine aggregate and Portland cement to certain level with CBA cause the decreasing value of slump flow. This situation occurs because CBA has high-water adsorption rate. The slump flow for sand replacement was shows in range of 670mm – 11.2mm, while for cement replacement was 120mm- 35mm.
- ii. The compressive strength and splitting tensile strength of concrete containing CBA as a fine aggregate and cement replacement were found to be decrease with more CBA content in the concrete.

- iii. From the review summarize that the 10% CBA was suitable as cement and fine aggregate replacement materials as it were achieved the target strength for compressive strength and tensile strength.
- iv. The microstructure of concrete with replace the fine aggregate and cement by used CBA was detected by scanning electron microscopy (SEM). All studied enables shows the transition of morphology from the raw material to the hydrated shaped to be monitored (C- S-H gel)
- v. The density and water absorption in hardened concrete is significantly influenced by the introduction of CBA into concrete as fine aggregate and cement. The concrete density is decreased by an increased amount of CBA dirt.

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