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Coal Bottom Ash as an Eco-Friendly Cement Substitute in Self-Compacting Concrete: Properties and Potential

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ABSTRACT

In numerous nations, the utilization of coal as an energy source for thermal power plants and manufacturing operations has increased in recent decades, which has led to an increase in coal consumption. The growth of the world's population is reflected in the increasing use of cement in the construction industry and in the rising production of concrete worldwide. These two occurrences contribute significantly to the increase in carbon dioxide (CO_2) emissions and coal ash discharges, both of which are harmful to the surroundings. Coal-fired power plants produce industrial byproducts such as coal-bottom ash (CBA) that could be incorporated into self-compacting concrete (SCC) to provide sustainable building materials and encourage the use of byproducts. Consequently, the objective of this experimental study is to investigate the effects of CBA as a cement substitute in SCC on the fresh and mechanical properties. Six various mixtures were prepared by replacing the cement used in the production with different amounts of CBA (0%, 10%, 20%, 30%, 40%, and 50%, respectively). The various properties of all mixtures, including fresh and mechanical properties of concrete, were analyzed in accordance with EFNARC and ASTM standards. For the fresh concrete properties of the SCC, a slump flow test, an L-box test, and a V-funnel test were performed. For the mechanical properties, compressive strength, tensile strength, and water absorption tests were performed. The result showed that CBA can be use as cement replacement up to 20% exhibited to improve the strength of SCC Mixture.

1. Introduction

Concrete is the most widely used building material, and most of the essential ingredients needed for its production come from natural resources such as river sand, mountains, mineral deposits, and others [1-3]. Subsequently, cement constitutes one of the majority of vital substances that is employed in the production of concrete [4]. Cement makes up between 10 and 15 % of the total weight of the concrete mixture. The production of cement results in greater emissions of carbon dioxide (CO_2) [5,6]. The production of one tonne of cement releases an estimated 900 kg of CO_2 into the environment [7,8]. This means that the cement sector is responsible for up to 6% of the total CO_2

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emissions that are generated by cement plants worldwide [9,10]. Despite this, the manufacture of cement has a negative effect on the surrounding ecosystem. According to a study by Lehne *et al.,* [11] more than 4 billion tonnes of cement are produced annually. Given the present circumstances, this problem requires considerable attention to achieve the United Nations Sustainable Development Goals, and additional efforts must be made to address both natural resource management and waste utilization problems [12]. The potential application of self-compacting concrete has been highlighted as a possible prospect within this structure [13].

SCC is an innovative concrete technique that has been widely used in Japan for more than two decades [14,15]. Okamura introduced his idea of SCC in the 1980s, and Ozawa built the first model of it at the University of Tokyo in Japan in 1988. This very fluid concrete is practically used for filling heavily reinforced areas and improving the performance of concrete mixture [16,17]. The SCC also known as self-consolidating concrete, is in the limelight for the last two decades in the construction industry. This extremely flowable concrete can be successfully used to cover heavily reinforced areas and increase the efficiency of concrete mixes [18,19]. It is also extremely flowable. The production of a homogenous consistent concrete mix using SCC is possible and has the potential to be developed. Because of its many advantages, there is an increasing trend toward the use of SCC in construction [20]. The design technique includes two aspects, namely setting the total amount of coarse aggregate at 55% of the total volume of the concrete and setting the amount of fine aggregate at 45% of the volume of the concrete mix. The flowability measurements performed on SCC are used to determine the water-binder ratio (W/b) and the slump dose superplasticizer (SP) [21,22]. Tests are performed with these ratios to determine the content of the concrete mix for the end outcome. From the perspective of turning SCC into conventional concrete, ongoing research has been conducted to determine an appropriate mix design procedure and SCC testing methods. In fact, the SCC is considered to be met when specific criteria for workability and flowability of concrete are collected in response to the requirements set in the specifications of the SCC standard [23].

In this context, a possible solution could be to use industrial by-products as complementary raw materials for building components to preserve biodiversity and reduce the negative impact on the environment caused by the disposal of unwanted materials [24-26].

Coal combustion is expected to account for 47% of global electricity generation by 2030 [27]. This is in response to growing energy demand. Fly ash (FA) and CBA are the two primary byproducts of burning coal in a thermal power plant [28,29]. Electrostatic precipitators in the chimney capture the FA. This is a more manageable form of the unburned residue that has just risen from the combustion zone [30]. CBA is a significant residual waste that dissolves and accumulates at the base of the incinerator; 15–25% of the amount of coal ash generated [31,32]. The improper disposal of CBA could pollute groundwater supplies and surrounding soil, resulting in loss of wildlife and greater restrictions on land use. Consequently, CBA characteristics are affected by a number of variables, including the degree of coal grinding, the combustion temperature in the combustion chamber, and the type of burner and location of the thermal power plant [33,34]. Numerous pozzolanic substances, including FA [35], palm oil fuel ash, and rice husk ash [36], was investigated. CBA is characterized by a remarkably high content of silica and an amorphous structure that allows it to be ground into a powder materials that can be utilized either as a pozzolanic substance or as a cement additive [37,38]. These properties are described in the guidelines published by ASTM C618 [39].

There are several studies currently attempting to demonstrate these benefits in a variety of contexts. Among these, the use of SCC in the construction sector as a substitute for cement has attracted considerable interest in recent years. The use of industrial byproducts would be beneficial to both the environment and the health of society, in line with the sustainable economy strategy [40,41]. In addition, based on a previous [42,43] study, this study investigates the possibilities of producing SCC using ground CBA as a substitute for sand in different ratios. The unique aspect of the present experimental study is that it investigates the substitution of CBA for SCC production. In the present study, an SCC mix was prepared with different curing times of 7 and 28 days with a target compressive strength of 35 MPa, and then cement was substituted with 10–50% ground CBA to determine the effects of the substitution ratios on the properties of SCC mixes. The influence of SCC on fresh concrete properties (slump flow, L-box and V-funnel tests) and mechanical properties (compressive strength, tensile strength and water absorption) are examined. This study aims to investigate and promote the use of an environmentally friendly industrial by-product in the production of green concrete.

2. Research Significance

Recent building practices make it necessary to replace cement with environmentally friendly materials that require less fossil fuel to produce. In this case, an industrial by-product can serve as an alternative for conventional Portland cement (OPC) in the production of concrete. Moreover, studies in the improves the fresh and strength properties using industrial waste such as CBA as partial of cement in SCC production still have lack of explored by the researcher and has not explored yet. However, the addition of industrial by-products such as CBA as a partial cement replacement in the production of SCC could improve fresh concrete properties and strength. In addition, the use of CBA as an alternative to cement will reduce the amount of cement required, which in turn will reduce the amount of CO2 released into the environment. The aim of this research is to describe the production of SCC using CBA as an alternative substitute for cement in the production of SCC. The results of this research will help the rapidly expanding construction sector achieve sustainable expansion without depleting the planet's resources. Additionally, the knowledge gained from this research will assist civil engineers in the use of industrial byproducts, which will ultimately promote the implementation of this information in concrete structures to achieve sustainability and safety in such buildings.

3. Experimental Program

The experimental work consists of three stages that involve provision of material used, and preparation of concrete specimens' mixture and, finally with testing of SCC samples. The following subsection will explain in detail. Furthermore, All the testing and mixture design in accordance with EFNARC and ASTM standard was carried out in the experimental work.

3.1 Materials

All substances utilized for this study are readily available in the local area from "Xin Xiang Concrete Sdn. Bhd". Ordinary Portland cement, obtained from a nearby factory, was used for the study. The cement grade is classified as 52.5 N and meets the requirements of the standard MS EN 197-1 [44]. The density, specific gravity, and Blaine surface area of CBA are shown in the Table 1, the values for the density and Blaine surface area of cement are 3.15 and 399.8 m^2/kg, respectively. The combination used for the preparation of the SCC specimens consists of fine and coarse aggregate prepared from readily available river sand. The maximum size of river sand and coarse aggregate was 4.75 mm and 14 mm, respectively. Both fine aggregate and coarse aggregate conformed to ASTM C136 [45]. Both fine aggregate and coarse aggregate have a specific gravity of 2.66 and 2.63 respectively. Furthermore, the water absorption value for fine aggregate and coarse aggregate 2.8% and 2.62% respectively. The original CBA was collected from thermal power plant (Tanjung Bin) in

Johor, Malaysia. It was found that the original form of CBA has a structure that is mostly rougher, more porous, and has the shape of a volcanic substance (as shown in the Figure 1 (a). The CBA was examined by scanning electron microscopy, and the results showed that it had irregular, sharp, rounded pores and a mixture of several textures as shown in Figure 1 (b). Superplasticizer with a trading name 'ViscoCrete®-2044' was used with pH value 3-5 having a specific gravity of 1.09. The amount of SP was determined based on the workability requirements and the range of 1.0 to 2.0% by weight of the cement for the preparation of SCC mixtures.

Table 1
Physical properties of cement and CBA

Physical properties/materials	Cement	CBA
Bulk density (kg/m3)	1440	2350
specific gravity	3.15	2.37
Blaine surface area	0.867	0.494
Fineness modulus	3.38	2.54
Water absorption	--	5.30
Color	Gray	Blackish or dark gray

(a) (b)

Fig. 1. a) Original CBA and SEM b) morphology of original CBA

The CBA was dried in an oven at a temperature of 110±5 ºC for 24 hours, then was sieved through 300-micron sieve, after that was placed in the Los Angeles machine for 7000 cycle, to be suitable pozzolanic materials as recommended guidelines in ASTM C618 [39]. The chemical composition of CBA and OPC are provided in Table 2, which shows that the CBA meet the requirements of ASTM C618 and classified as class F ash [39].

Table 2
Chemical composition of cement and CBA

Chemical composition (%)	Cement	CBA
Silicon Dioxide (SiO_2)	14.4	50.8
Aluminum Oxide (Al_2O_3)	3.55	14.2
Ferric Oxide (Fe_2O_3)	3.10	16.6
Sulphur Trioxide (SO_3)	3.17	0.460
Calcium Oxide (CaO)	63.8	11.2
Magnesium oxide (MgO)	0.693	1.55
Potassium Oxide (K_2O)	0.818	1.66
Titanium Dioxide (TiO_2)	0.228	1.30

3.2 Mix Proportion and Specimen Preparation

The mix design refers to choosing the most suitable and cost-effective components for the SCC mixture and determining their relative proportions for improved fresh and mechanical properties. In this study, the mix designs' ratio is consistent with the EFNARC standard [46]. Most steps for designing the SCC mixes differ significantly from those used for conventional concrete. In the mixture design process, six different mixtures were prepared to consist of a constant proportion of coarse, and fine aggregate water, CBA and SP dosage as shown in Table 3. CBA was employed at 0%, 10%, 20%, 30%, 40%, and 50% as an alternative for cement in the fabrication of SCC. The SCC mixes were prepared using a 0.02 m^3 container rotary mixer. The rotor of a container mixer was then kept spinning for two minutes while two-thirds of the water was introduced with consideration. The mixture was then mixed for another two to three minutes while the water containing the superplasticizer set aside was added. The casting procedure was carried out at an external temperature of 25 to 30 degrees Celsius. Before filling the specimens, the properties of the fresh state were assessed. To prevent the concrete from sticking to the moulds before filling with concrete, demolition oil was added to the moulds beforehand. Following one day, the samples were removed from the moulds and immersed in a tank for curing until the specimens reached the appropriate age for testing. The temperature in the curing tank was kept constant at 28 ± 3 °C. The specimens were then stored in the curing tank until they reached the appropriate age for testing. Table 3 provides the proportions (Kg/m^3) of the SCC mixture design in this work.

Table 3
Mixture design proportion for 1 m3 SCC mixture

Samples ID	Water content (Kg/m^3)	Cement (Kg/m^3)	Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)	CBA content (Kg/m^3)	Superplasticizer (% Binder)
Control	185	550	952	620	0	1.8
CBA 10%	185	495	952	620	55	1.8
CBA 20%	185	440	952	620	110	1.8
CBA 30%	185	385	952	620	165	1.8
CBA 40%	185	330	952	620	220	1.8
CBA 50%	185	275	952	620	275	1.8

3.3 Samples Testing Properties
3.3.1 Fresh state properties of SCC

In order to evaluate the fresh concrete properties of SCC mixes in terms of flowability, passing ability, and viscosity in accordance with the specifications established by EFNARC [46], various workability experiments were conducted. The flow test was used to investigate the flowability of the prepared SCC blends as shown in Figure 2. The viscosity of SCC mixtures was measured using the V-funnel test, and the flow rate was also considered. It refers to the time required for the concrete to flow into the V-shaped device as shown in Figure 3. The slump flow was measured as the mean of greatest diameter (D1) of spread concrete and perpendicular diameter (D2) as shown in Figure 2. The passing ability of the SCC mix was evaluated using the L-box test, which was also used to confirm the flowability of the concrete through small gaps in densely packed reinforcing bars as shown in Figure 4. It is the ratio between the thickness of the concrete at the final point of the section that runs horizontally (H2) and its beginning (H1) in terms of elevation. The Table 4 below gives an overview of the guidelines for SCC mixes.

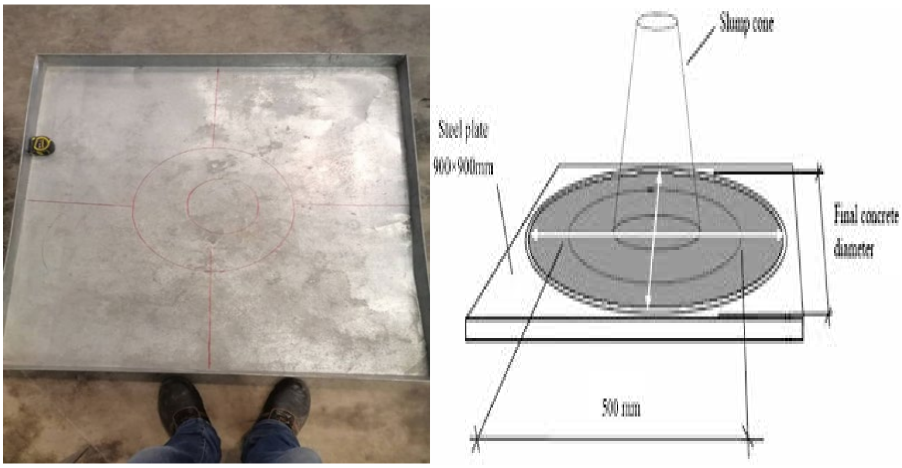

Fig. 2. Slump flow test apparatus

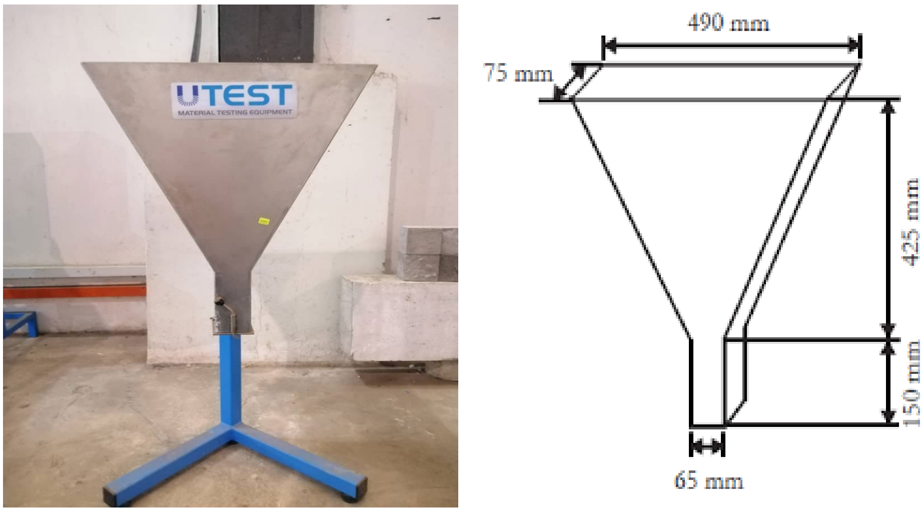

Fig. 3. V-funnel test apparatus

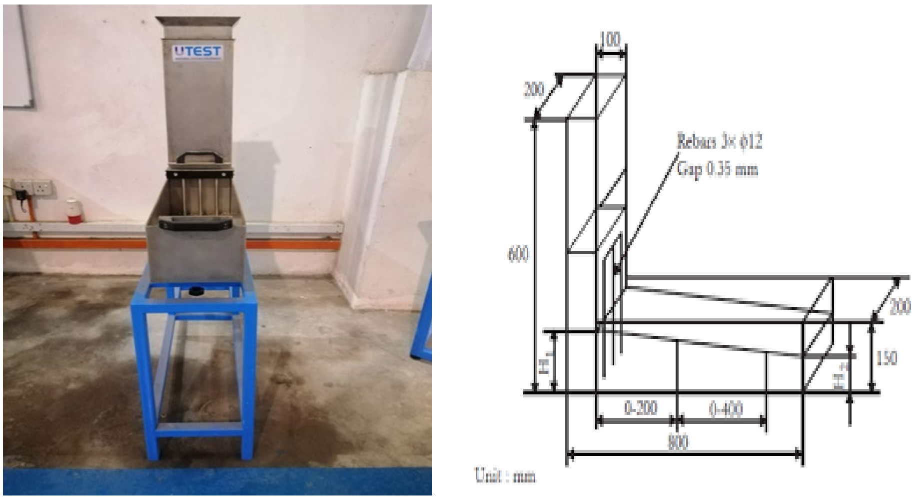

Fig. 4. Apparatus of the L-box test

Table 4
Categories of fresh properties for SCC in accordance with EFNARC standard [46]

Test categories	Class	Limit
Slump flow (SF)	SF1	550–650
	SF2	660–750
	SF3	760–850
V-funnel time (sec)	VF1	≤ 8
	VF2	9 to 25
Passing ability (L-box) categories	PA1	≥ 0,80 with 2 rebars
	PA2	≥ 0,80 with 3 rebars

3.3.2 Hardened properties of SCC

The strength properties of the concrete samples, such as the compressive strength of the concrete specimens evaluated, were determined according to the guidelines of ASTM C-39 [47]. In accordance with the requirements and recommendations of ASTM C78 [48], the flexural strength of the SCC samples was evaluated and the outcomes were determined. For this experimental study, cubes with a size of 100 mm on each of the three sides and beams with a particular size of 100 × 100 × 500 mm were employed to evaluate the compressive strength and flexural strength, respectively. After a curing period of 7 and 28 days, each sample was placed for testing. For each phase of the test, the overall average result for the three samples was determined. The test to determine water absorption was performed in accordance with ASTM C642 [49] on cube specimens of 100 mm in size after the material had cured for 28 days. The concrete samples were maintained in an oven at a temperature of 110.5 °C for 72 hours. After the concrete cubes were removed from the oven, the samples were left to cool down at ambient temperature for 24 hours, and then the weight of each specimen was determined as W1. The concrete samples were then submerged in the curing container for an additional 48 hours, ensuring that at least 50 mm of water stood on the outer surface of each concrete specimen during this time. After the curing process, the samples were removed, any visible water was scraped off the dry area, and the corresponding weights were calculated as W2 for each sample. The following equation can be used to estimate the amount of water that can be absorbed:

$$\text{Water Absorption (\%)} = ((W2-W1)/W1) \text{ X}100)$$

where, W1 = Oven dry weight, W2 = Surface saturated weight

4. Results and Discussion

4.1 Fresh Properties

The Figure 5 displays the results of fresh property tests performed on SCC with CBA as a partial substitute for cement. These tests included slump flow, V-funnel, and L-box. The slump flow test is the most used test because it is the simplest method for evaluating the workability of SCC mixtures. according to the EFNARC standard, slump flow results range from 500 to 680 mm. However, segregation may occur in SCC mixes with a slump of more than 700 mm, while in SCC mixes with a slump of less than 500 mm, the slump is insufficient to pass through densely packed reinforcement. The second reason for the slump flow of more than 700 is the possibility that the concrete mix could segregate during flow. The second explanation for the slump flow of more than 700 is the possibility that the SCC mixture segregates during flow. Additionally, to the flow tests conducted, the V-funnel test was performed to evaluate the flowability and fluidity of the SCC. According to EFNARC [46], a V-funnel test with a duration of less than 25 seconds is recommended for the VF1 to be classified as SCC. This recommendation was made in addition to the flow tests performed. Moreover, according to the EFNARC guideline[46], the proportions of L-box ranged from 0.8 to 1.

Figure 5 shows the results of the slump flow test, indicating the range of values given in the EFNARC specification [27]. The slump flow varies between 675 and 588 mm for SCC containing CBA in a ratio of 10% to 50% as a substitute for partial cement. Nevertheless, the result of the slump flow was within the range considered by the standard as (SF2). The results of the slump flow test showed that the flow rate decreased with an increasing percentage of CBA used as cement replacement in the SCC mix. The observed reduction in slump flow can be attributed to the presence of pores in the SCC mix containing CBA, resulting in greater absorption of fluid associated with a higher percentage of CBA. The second explanation given was the irregular structure of CBA, which leads to less interaction between particles. This property of CBA leads to a decrease in the viscosity of SCC mixes. The optimum flow ratios for (SCC) can be achieved by adding 10% cement replacement with CBA. This phenomenon has been confirmed by several other researchers [50-52].

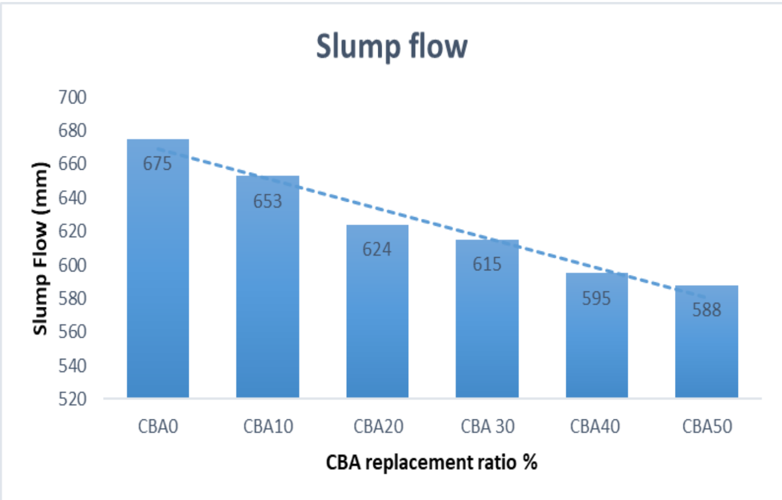

Fig. 5. Results of the Slump flow of SCC containing CBA as cement replacement

V-funnel flow time is the elapsed time in seconds between the opening of the bottom outlet depending upon the time after which opened. According to Figure 6 showed the findings of the V-funnel test , which is the range of the EFNARC standard [46], and the V-funnel ranges from 19 to 24 second for SCC containing CBA range 10% to 50 as partial cement replacement. The results showed that the V-funnel was increased as replacement of CBA increased in SCC mixture. According to Khayat [53] the V-funnel time, which is between 9 to 25 second, is recommended for mixture to qualify as a SCC in confirm with EFNARC specification.

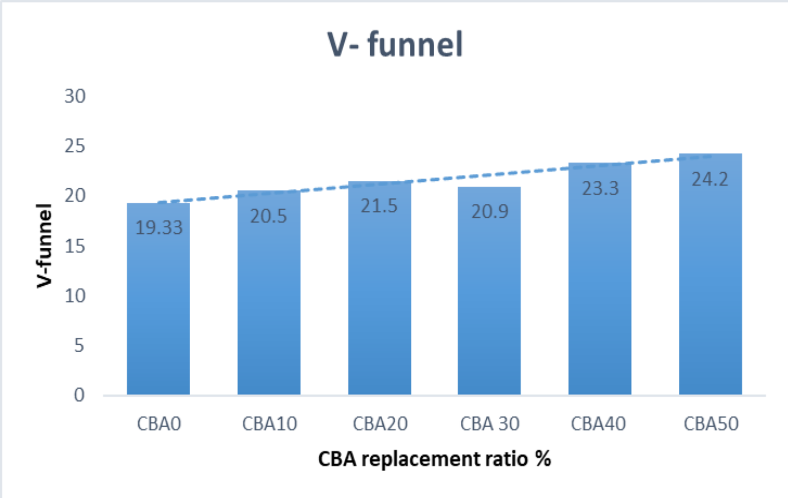

Fig. 6. Results of the V-funnel of SCC containing CBA as cement replacement

The height ratio of the L-box was also determined using the H2/H1 ratio to calculate the suitability of the SCC to pass. The test uses a three-bar L-box that simulates the scenario of a larger amount of reinforcement. The finding of the L-box was found to be decreased as CBA ratio increased in SCC mixture. According to Figure 7 showed the findings of the L-box test , which is the range of the EFNARC standard [46], and the L-box ranges from 0.83 to 0.71 for SCC containing CBA range 10% to 50 as partial cement replacement. The reduction in the L-box due to porous CBA which lead to less interaction between particles. This trend in agreement with previous studies by [54,55].

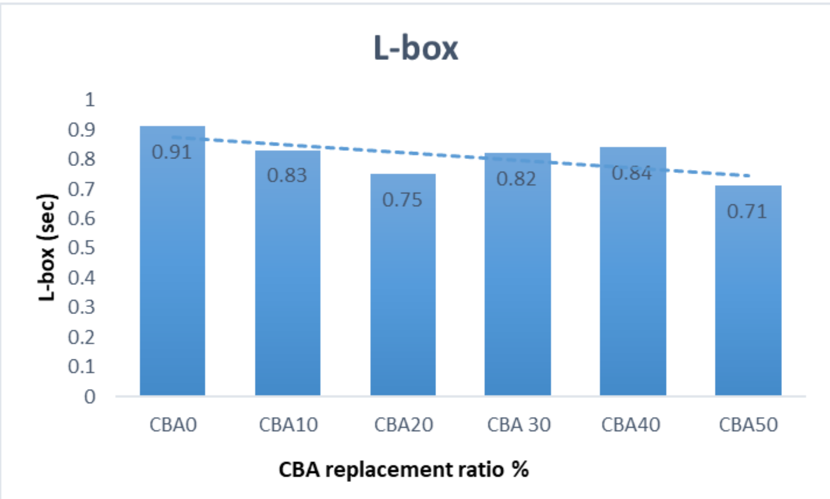

Fig. 7. Results of the L-box of SCC containing CBA as cement replacement

4.2 Mechanical Properties

Figure 8 demonstrates the compressive strength of SCC with CBA as an alternative for cement after 7 and 28 days. All mixes show an increase in compressive strength after 7 and 28 days of curing, respectively. In this experimental study, the range of measured values for compressive strength ranged from 39 MPa to 21 MPa for control specimens to 50% CBA after 28 days of curing. The results show that the differences in the compressive strength values of different substitution ratios depend to some extent on the amount of CBA contained in the SCC mixture. The control specimens of SCC exhibited a range of values ranging from 36.329 MPa to 39.599 MPa at the corresponding curing ages of 7 and 28 days. In addition, it was shown that the optimum amount of CBA as a cement replacement is 20% compared to conventional specimens, which had values ranging from 36.893 MPa to 40.2133 MPa after 7 and 28 days of curing, correspondingly. This could be because of CBA has a late pozzolanic reaction, which is important to make the material denser and thus improve the compressive strength. According to Argiz *et al.,* [56] reported that the pozzolanic properties of fine CBA cause a late pozzolanic reaction that affects the strength properties. According to previous study [57] have shown that concrete mixtures containing 20% finer CBA achieve adequate strength. The results of the current study are consistent with the results of previous research studies [58,59].

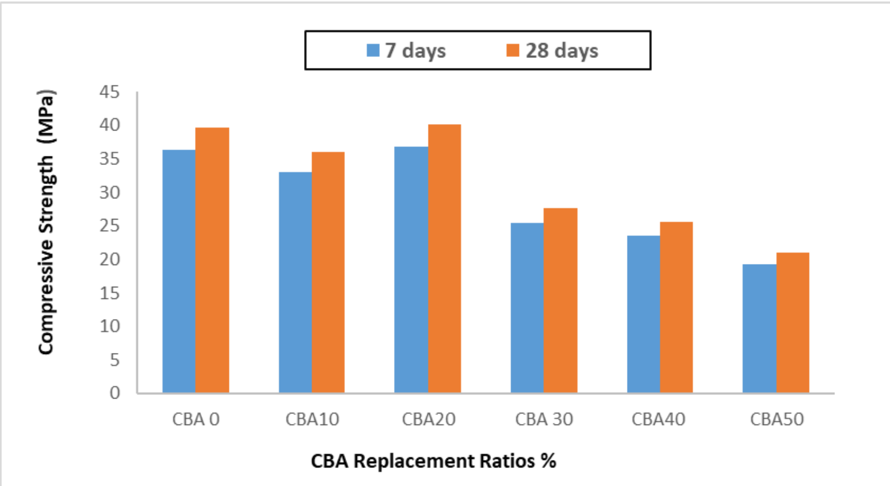

Fig. 8. Result of compressive strength on SCC containing CBA as cement replacement

Figure 9 illustrates the flexural strength of SCC with CBA as a partial cement replacement after 7 and 28 days. The results show that the flexural strength increases with increasing curing age (7 and 28 days, respectively). The flexural strength of all specimens for the control specimens and the specimens with CBA was observed to decrease with increasing percentage of CBA in the SCC mix. At 7 day of curing, for the flexural strength for SCC mixture of CBA10%, CBA20%, CBA30%, CBA40%, and CBA50% gained flexural strength 4.381MPa, 3.896 MPa, 3.894 MPa, 3.432 MPa, 2.869 MPa respectively. At 28-day flexural strength of control mix CBA0 was observed as 5.399 MPa, whereas mixes CBA10%, CBA20%, CBA30%, CBA40%, and CBA50% achieved 5.146 MPa, 4.553MPa 4.047MPa, 3.959MPa. and 3.26MPa, respectively. The decrease in CBA substitution ratios resulting from the effective pozzolanic reaction forming C-H-S in the mixture was not complete after 28 days of curing, delaying the process of hydration. The optimum replacement for the cement ratios with ground CBA was determined to be 10%. The experimental results of this study show comparability with the results of previous studies [60,61].

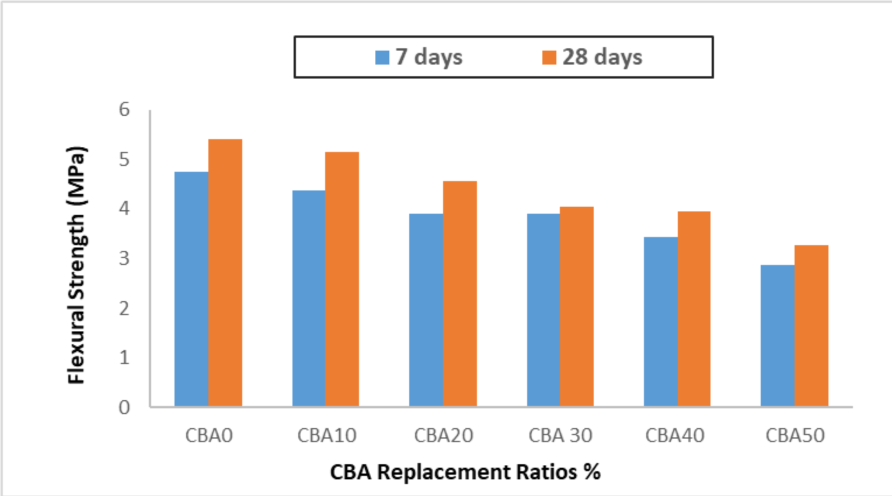

Fig. 9. Result flexural strength on SCC containing CBA as cement replacement

Figure 10 shows the effect of water absorption of CBA as a cement replacement in SCC mixes after 28 days. The water absorption of concrete with CBA as cement replacement 0%, 10%, 20%, 30%, 40% and 50% are 7.1382%, 7.3541%, 5.8757%, 6.5588%, 6.4337% and 6.3958%, respectively. It was observed that the water absorption varied between 7.13 % and 5.87%. It was found that water absorption ranged from 7.13% to 5.87%. also, it was found that all SCC mixtures had lower water absorption (less than 10%). The study found that water absorption was greater at a 10% replacement ratio of CBA, but water absorption decreased with increasing CBA content compared to the traditional specimens in the self-compacting concrete mix. Concrete mixes containing up to 50% CBA are considered high quality due to their favourable water absorption properties. The experimental results of this study show comparability with the results of previous studies [54,62].

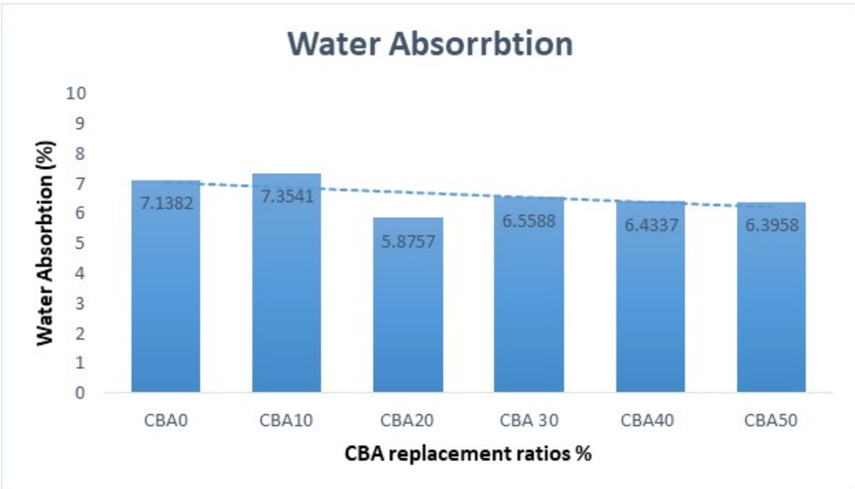

Fig. 10. Result of water absorption on SCC containing CBA as cement replacement

5. Microstructure

Analysis of the hydration products was performed by using FESEM at 7, 28, and 56 days as shown in Figure 11 to determine the main compounds identified in chemical analysis for SCC control and

SCC with CBA10% and CBA20%. At the beginning at 7 days of curing, Figure 11 a) for control and CBA10%, and CBA20% shows various phases using (FESEM) morphologies for SCC samples. For control samples at 7 days showed more homogenous and dense which lead to agglomeration particles for main ingredients and. This is due to inhibiting the mechanism of cement hydration, contributing to weak zones within the matrix. Moreover, for CBA10% and was observed pores and voids for particles, which is due to ground CBA high porosity, and, thus, high absorption rate to these aggregate materials. For SCC contain CBA20% showed the crystallization of new products such as calcium silicate hydrates in the cracks form of the ITZ is directly contributing to the strength of the SCC, besides reducing the amount of calcium hydroxide in the ITZ.

Figure 11 b) observed more $Ca(OH)_2$ crystals, which were large hexagonal plates with massive C-S-H shapes. A large amount of $Ca(OH)_2$ was produced from cement hydration due to the high amount of CaO present in ordinary Portland cement. These crystals are the source of strength for the cement paste. Various ratios (CBA10%, CBA20%) of ground CBA were used as cement replacement at 28 days of curing (as shown in Figure 11 b) and was observed that the C-S-H gel formulation that was developed which lead to improve the pozzolanic properties of the samples. Moreover, the interaction between calcium, sulphate, aluminate, and hydroxyl ions of cement hydration formed needle-shaped prismatic crystal of calcium trisuloaluminate hydrate. Nevertheless, the shape of the CBA20% prismatic crystals of calcium hydroxide and fibrous crystals of calcium silicate hydrates began to fill the void occupied by water previously and the dissolving cement particles. Also, ettringite may decompose into hexagonal-plate known as monosulfoaluminate hydrate due to its unstable state depending on the alumina/sulphate ratio in Portland cement with ground CBA.

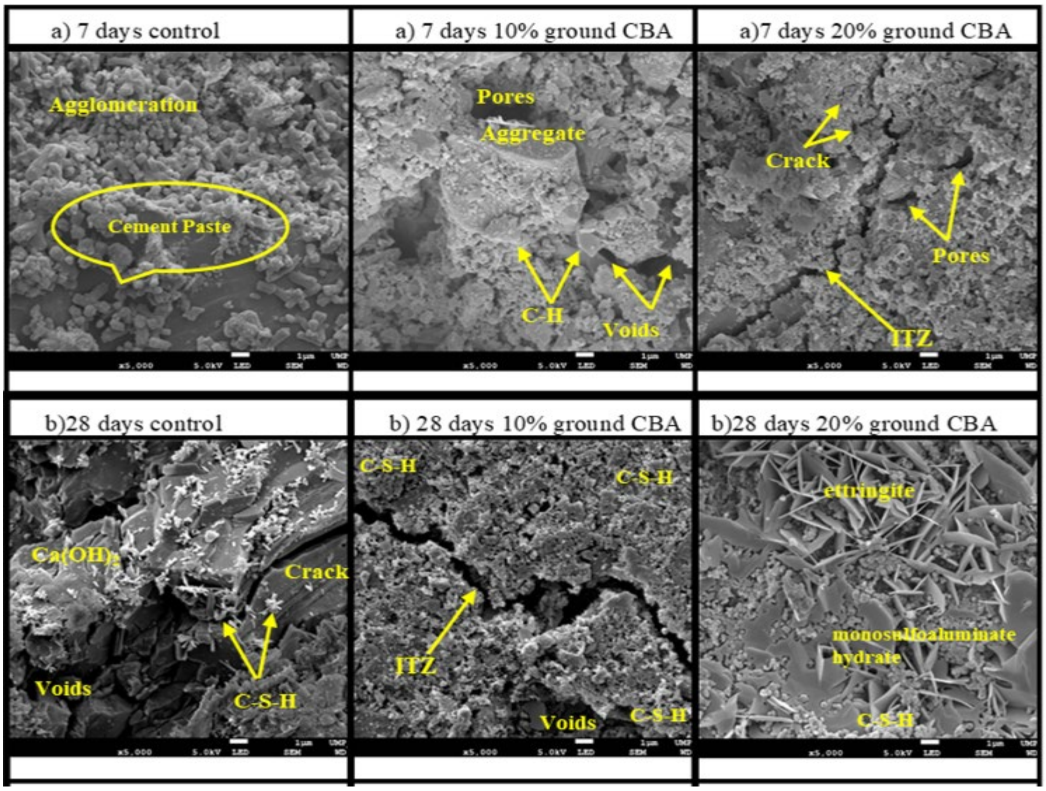

Fig. 11. FESEM micrographs of SCC specimens at a) 7 days, b) 28 days for control and ground CBA 10%, 20% of SCC samples at X5000 magnification

6. Conclusion

In the present study, the fresh concrete properties and the mechanical properties of SCC mixtures containing CBA as a cement substitute are examined and analysed. The following are some conclusions that can be drawn based on the research results and the analysis carried out:

i. The fresh properties of SCC, the slump of CBA was found to be in the range of 675 to 588 mm, which decreased with increasing proportion of CBA in the mix. The V-funnel was observed in the range of 19 to 24 seconds, which is within the range of the standard. The L-box ratio was in the range of 0.9 to 0.71. All fresh properties of SCC with CBA as cement replacement were in the range of EFNARC standard.
ii. The compressive strength of SCC containing CBA as a partial cement replacement was found to be optimum at 20% CBA with a compressive strength value of 36.893 MPa and 40.2133 MPa at 7 and 28, respectively. The compressive strength of the control specimens ranged from 39 MPa to 21 MPa. The compressive strength of the other replacement ratios decreased with the increase of CBA content compared to the control specimens.
iii. The flexural strength of CBA as a partial cement replacement decreased with the increase of the replacement level in the SCC mix. The flexural strength ranged from 5.399MPa to 3.26MPa for the control specimen and the specimens with 50% CBA.
iv. The water absorption exhibited an upward trend as the substitute of CBA increased in the SCC mixture. The control combination has the lowest level of water absorption, while the sample with 10% of CBA displays the maximum water absorption. This could be due to the significant porosity of the CBA particles.
v. The successful use of CBA as a cement substitute in the production of (SCC) facilitates the recycling of waste produced during the manufacture of industrial waste, thus contributing to the production of environmentally friendly building materials. This method is in line with the goal of promoting an environmentally friendly society. In addition, the efficient use of CBA waste would help reduce the natural use of resources and the significant accumulation of waste in landfills, thereby mitigating potentially negative environmental impacts.

7. Recommendations for Future Research

In the investigation conducted, evidence was presented to demonstrate the positive effect of ground CBA as a source material and its role within the SCC framework. For future advancements, various recommendations and proposals can be considered. These insights will assist future researchers in achieving enhanced findings and more precise outcomes. It is suggested that further studies investigate related subject areas as outlined below:

i. The current research indicates that using ground CBA as a partial cement substitute results in self-compacting concrete (SCC) displaying improved strength. However, further investigation into the impact of CBA on the strength’s properties in the long term due to late hydration process for CBA.
ii. Further studies should focus on the chloride resistance, and corrosion is necessary. This should also be applied to various structural elements, such as wells and slabs.

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