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Mechanical Properties of Sustainable Concrete Containing Local Ternary Blended Cement as Cement Replacement

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Abstract

Continuous harvesting of limestone for cement production is increasing to cater to the demand of the construction sector and devastate the natural world. The disposal of shells from the local cockle trade also pollutes the environment. Simultaneously, increasing coal bottom ash (CBA) disposal from the rising consumption of coal in power plants raises severe environmental concerns. The discovery of coal bottom ash as pozzolanic ash that can be utilized as partial cement replacement has paved the way for further exploration. However, the concrete's performance produced using coal bottom ash combined with cockle shell ash (CSA) blended cement has not been reported. This research examines the impact of CBA in CSA blended cement on the mechanical and fresh characteristic of concrete as a cement replacement purposes. Various percentages of CBA as partial cement replacement were integrated into cockle shell ash blended cement concrete. CSA blended cement concrete containing 10% CBA exhibits the highest strength. The utilization of cement formed through the combination of coal bottom ash and cockle shell ash contribute towards the invention of sustainable green concrete with a lesser burden on natural resources and cutting down waste accumulation at the landfill.

1. Introduction

Concrete is used in all types of building construction. The increase in the application of concrete as main construction supplies owing to expanding population demand also results in a flourishing cement manufacturing trade. Production of cement is increasing by 2.5% per year, from 2005 to 2020, 2.3 Gt to 3.5 Gt respectively, and it is anticipated to be between 3.7 and 4.4 Gt by 2050 [1]. Unfortunately, cement industry releases massive quantity of CO_2, accounting approximately 60% of global CO_2 emissions [2]. On overall, the concrete sector is responsible for roughly 10% of worldwide industrial CO_2 emissions, which contribute to climate change [3], [4]. Realizing that cement is increasingly used owing to its role as a sole binder in concrete worldwide, unearthing new alternate material would decrease the reliance on cement and benefit the environment. Thus, investigating alternatives that use materials with a lower carbon footprint and can replace Portland cement in this regard is crucial to promote cleaner industry. Utilization of locally generated industrial waste materials would reduce waste disposed of to the environment. In relation to that, cockle shells which thrown after cockle is consumed as fresh seafood or canned product contribute towards waste generation as the shell of a cockle is not consumable. In 2019, across 13,771.74 metric tonnes of cockles were produced by Malaysian fisheries industry [5]. The cockle industry is generating an increasing quantity of cockle shells which are disposed of as waste at landfills. Cockle shell with their stinking smell is usually thrown as waste and causes environmental pollution [6]. This organic compound, which takes a long time to decompose, also attracts insect pests that increase the risk of diseases spread to the community nearby. The growing quantity of shell waste disposed of resulting from increasing cockle production would consume a larger area at the dump site. Accumulation of cockle shells waste at the landfill also will produce a serious ecological issue since the shells are not well treated [7]. Realization on the unwelcome impact of shell waste dumping on the community's well-being, civil engineering researchers are inspecting the possible usage of this fisheries waste in construction building material development. Past researchers, Othman et al. [8] and Olivia et al. [9] disclosed that the cockle shell ash use at suitable content as partial cement replacement material contributes towards enhancement of concrete properties. Cockle shell ash has a high content of calcium carbonate which is almost equal to the one in limestone and has the potential to be used as cement replacement partly [10]. However, the impact of cockle shell ash as partial cement replacement when combined with pozzolanic ash adopting the approach of ternary mixed cement system towards the properties of concrete is yet to be investigated.

Other than that, coal is one of the resources that generates electricity in many parts of the world. By 2030, approximately 47% of global electricity would be supplied by coal power plants [11]. In order for power plants to operate and generate electricity, an extensive quantity of coal is burned, creating a wide variety of ashes. CBA is one of the largest sources of ash coming from heat-producing plants. CBA from the coal power plant which is disposed at landfills consume space and is unhealthy to the environment. CBA is one of the largest sources of ash from heat-producing plants. As this waste is not utilized, it is dumped into pond over time [12] or landfills [13]. Due to the potential for contamination, the high production of CBA presents a risk to the environment if inadequately discarded as waste. In addition, there will be a risk of leaching due to high levels of toxic elements as reported by other studies [14]-[16]. The consciousness of the importance of recovering this waste for a sustainable environment has enthused researchers to explore and expand the use of CBA which is classified as pozzolanic material in concrete. The utilization of this waste has been tried in plain concrete [17]-[20], high-strength concrete [21], [22], porous concrete [23], [24], self-compacting concrete [25], and even modern concrete such as, geopolymer concrete [26], [27]. However, very little investigation reports the effect of CBA blended with other types of pozzolanic ash towards the properties of concrete. Thus, the present work investigates the workability and mechanical properties of concrete produced by integrating CBA as partial cement replacement in CSA blended cement concrete.

2. Methodology

The experimental work was completed in three consecutive stages beginning from material preparation, mix proportioning and testing of the specimens.

2.1 Materials

The mixing ingredients used for the specimen formation are cement, cockle shell, coal bottom ash, fine aggregate, coarse aggregate and tap water. Granite stone passed the sieve size of 10 mm and retained a sieve size of 5 mm. Sand passing the 2.36 mm strainer was utilized as fine-grained stone. Ordinary Portland cement (OPC) Type 1 in accordance with ASTM C150 [28] was used as a binder. There are two types of waste namely cockle shell ash (CSA) and coal bottom ash (CBA) that were used. The cockle shell (CS) illustrated in Fig. 1(a) has been cleaned via water before subjected to calcining process in a furnace at 650°C for 2 hours. After that, it was finely ground until it became powder. CBA in Fig. 1(b) which acquired from the thermal power station in Malaysia was ground using Los Angeles Abrasion Machine. CSA is made up of CaO (99.44%). As for CBA, the total composition is SiO_2, Al_2O_3, and Fe_2O_3 is more than 70% (93%) enabling it to be classified as pozzolanic ash in accordance with ASTMC618 [29]. The physical and chemical properties of OPC, CSA and CBA are shown in Table 1 and Table 2 respectively. X-Ray Diffraction (XRD) examination of CBA is revealed in Fig. 2.

2.2 Mix Proportion

The derivation of sustainable concrete formed using cement consisting of a combination of CSA and CBA undergoes two processing stages at the laboratory. In the first stage, the optimum amount of CSA as partial cement replacement content in CSA-OPC blended cement is determined by using a trial mix design. In the beginning, control mortar with the targeted flowability, of 60 to 100 mm in diameter from the flow table test and the compressive strength as 20 MPa had been prepared. Then, CSA is integrated at 10, 20, 30, 40, 50, and 60% constitute cement's weight in mortar as tabulated in Table 3. After being cured in water over 28 days, the compressive strength test results show that mix produced using 10% of CSA as a mix performs the best whereas other replacements exhibit strength declination. Previous researchers, Hawkins et al. [30] and Bonavetti et al. [31]

pointed out that limestone is not a pozzolanic material and the incorporation of which percentages higher than 10% always weakens the strength.

In the second stage, plain concrete, cockle shell blended cement concrete and cockle shell blended cement concrete with a combination of various percentages of CBA were used. Normal Concrete (NC) were made using OPC as the sole binder is determined by using the British standard design of normal concrete mixes. The targeted of the 28-day compressive strength is 25 MPa and the concrete slump is set to be in the range of 150 mm to 175 mm. 10% CSA was used to produce cockle shell ash blended cement concrete to form concrete, C-CBA0. Other mixes were produced with the CBA integrated at 10, 20, 30, 40, and 50% by the binder weight in 10% CSA blended cement concrete. The concrete mixes of details are tabulated in Table 4.

(a) **(b)**

Fig. 1 *(a) Cockle shell, and (b) Coal bottom ash*

Table 1 *Physical properties of binders*

Properties	OPC	CSA	CBA (t
Retained on No.325 sieve (%)	1.74	3.21	2.19
Specific gravity	3.15	2.81	2.57
BET surface area (m2/g)	0.56	1.18	2.28

Table 2 *Chemical details of binders*

Oxide	OPC	CSA	CBA (t
CaO	62.21	93.50	3.56
Fe_2O_3	3.79	2.54	13.56
Na_2O	0.10	0.94	-
SiO_2	18.84	0.39	60.14
Al_2O_3	5.39	0.18	19.30
SO_3	3.06	0.13	0.42
K_2O	0.30	0.02	1.19
LOI	3.94	3.97	2.30

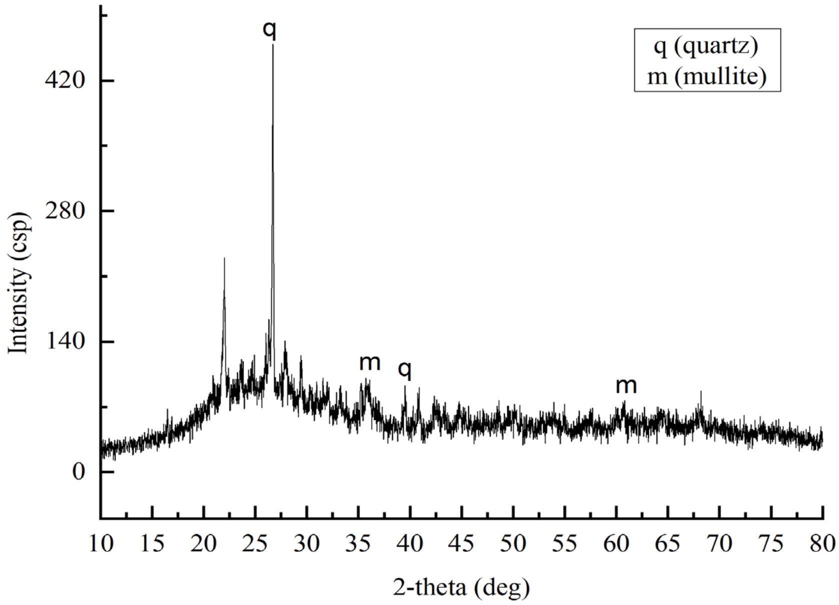

Fig. 2 *X-ray diffraction of ground CBA*

Table 3 *Mix proportion, flowability, and compressive strength of mortar mixes*

Mixes	Mix Proportion				Trial mix result	
	Cement (kg/m^3)	Sand (kg/m^3)	w/c	CSA content (kg/m^3)	Flowability (mm)	Compressive strength (MPa)
CSA	200	600	0.7	0	60	21.39
CSA10	180	600	0.7	20	70	22.34
CSA20	160	600	0.7	40	80	15.10
CSA30	140	600	0.7	60	90	14.76
CSA40	120	600	0.7	80	100	9.79
CSA50	100	600	0.7	100	100	7.30
CSA60	80	600	0.7	120	110	3.50

Table 4 *Mix proportion of concrete mixes*

Mixes	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water binder ratio	CSA content by cement weight (kg/m^3)	CBA content by cement weight (kg/m^3)
NC	400	752	996	0.65	-	-
C-CBA0	360	752	996	0.65	40	-
C-CBA10	320	752	996	0.65	40	40
C-CBA20	280	752	996	0.65	40	80
C-CBA30	240	752	996	0.65	40	120
C-CBA40	200	752	996	0.65	40	160
C-CBA50	160	752	996	0.65	40	200

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2.3 Testing Methods

The test of the slump was carried out based on BS EN 12350-2 [32]. The compressive strength, flexural strength and splitting tensile strength were determined through an experimental test per BS EN-12390-3 [33], ASTM C 496 [34] and ASTM C78-02 [35], respectively. The mechanical strength tests were conducted after the water cured specimen reach the age of 7, 28 and 60 days. The test for water absorption was carried out based on BS 1881- 122 [36].

3. Results and Discussion

Results related to fresh and mechanical properties of concrete produced by blending diverse CTP content are displayed in the following sub-sections.

3.1 Workability

Fig. 3 displays the slump value of normal concrete (NC), cockle shell ash (CSA) blended concrete and CSA blended cement concrete containing coal bottom ash (CBA). All fresh concrete mixes achieved the targeted slump of 150 mm to 175 mm except for CSA blended cement concrete containing CBA by 50% replacement, C-CBA50. The slump value of fresh mix becomes smaller with the higher CBA replacement level. The use of CBA which possesses the highest surface area than OPC and CSA causes rise in water requirement. As a result, the CSA blended cement concrete mixture becomes stiffer as a greater quantity of CBA is utilized into the mix. The results of using finer size particles as an alternative for cement replacement towards workability are noted by past researchers, such as Mangi et al. [37].

3.2 Compressive Strength

The concrete mixes compressive strength result is highlighted in Fig. 4. All mixes experience positive rises in strength as curing age increases. At 7 days, the highest compressive strength was observed at cockle shell ash (CSA) blended cement concrete, C-CBA0, as compared to NC and CSA blended cement concrete containing coal bottom ash (CBA). However, at 28 days the normal concrete (NC), cockle shell ash (CSA) blended cement concrete and CSA blended cement concrete containing 10% CBA achieved the targeted strength of 25 MPa. At a later age, which was from 60 days onwards, CSA blended cement concrete with 10% CBA replacement, (C-CBA10) exhibited the maximum value of compressive strength value amongst all. The silica content in CBA has aided the pozzolanic reaction resulting in a denser internal structure contributing to the enhancement of CSA blended concrete strength after 28 days. The deferred strength development of concrete containing CBA blended cement in comparison to non-CBA-based concrete has been reported by past publications [19], [21], [22]. It can be concluded that CSA blended cement exhibits better long-term strength performance when combined with 10% of CBA.

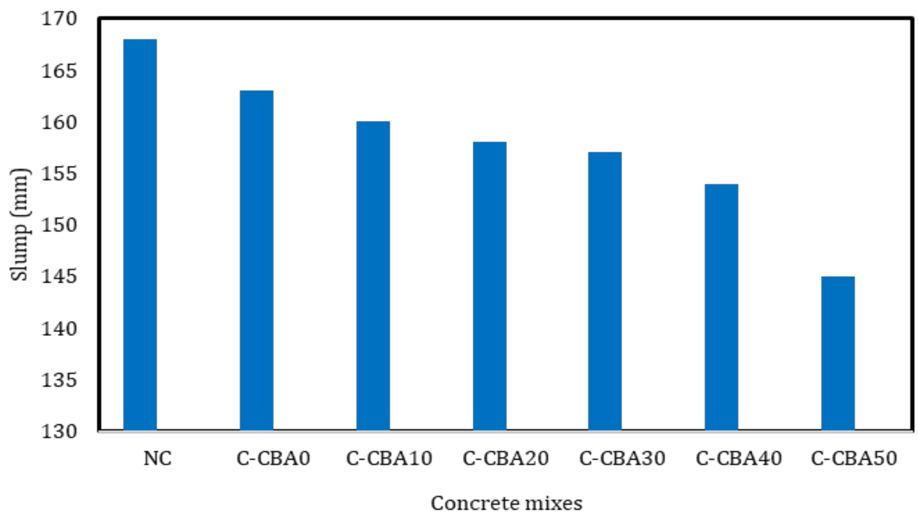

Fig. 3 *Workability results*

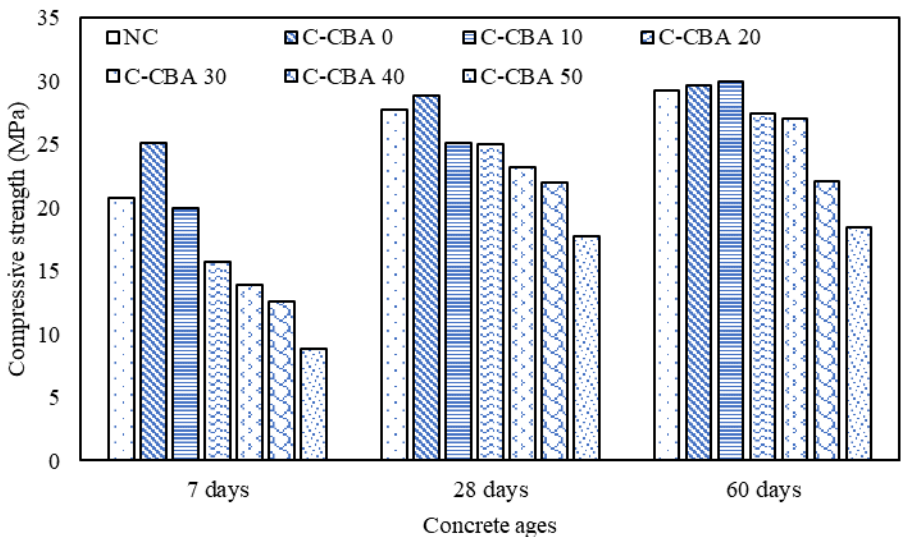

Fig. 4 *Compressive strength results of hardened mixes*

3.3 Splitting Tensile Strength

The tensile strength of concrete with diverse curing ages are displayed in Fig. 5. A similar pattern as compressive strength was noticed for the splitting tensile strength. Maximum split tensile strength was seen to occur at 10% substitution of CSA, irrespective of the CBA content, C-CBA0, at early concrete ages (7 and 28 days). It is also found that even at higher replacement level of CBA, there was no strength increment at 7 and 28 days. However, at later ages, which were at 60 days, it can be observed a slight development in the tensile strength of CSA blended cement concrete with 10% CBA replacement, C-CBA10, as compared to NC and CSA blended cement concrete. The chemical reaction that took place owing to the pozzolanic of CBA and its filler role contributes towards concrete strength improvement after 28 days [38]. Nevertheless, overuse of CBA results in strength declination as a larger percentage of cement has been substituted out with the pozzolanic ash leading towards a lesser C-S-H gel formation from the reduced hydration process.

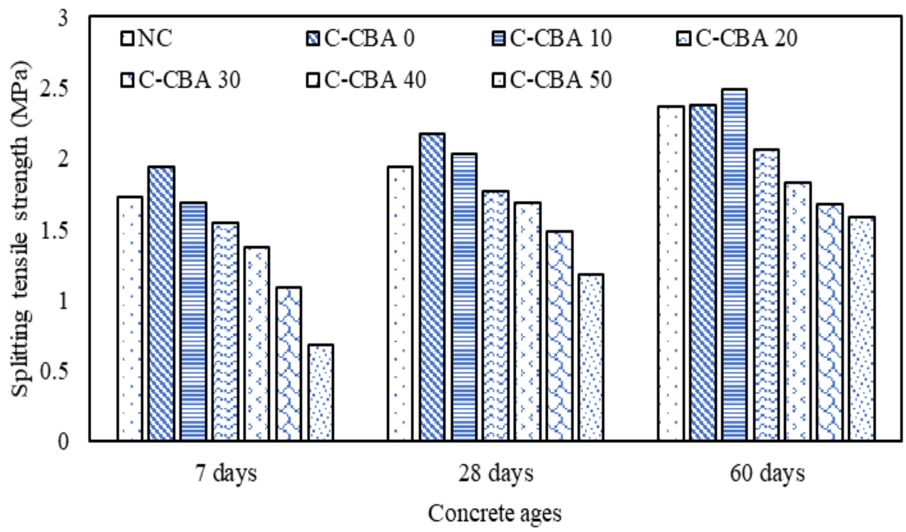

Fig. 5 *Splitting tensile strength results*

3.4 Flexural Strength

The flexural strength of hardened concrete mixes is presented in Fig. 6. The trend of result obtained seems alike as the compressive strength and splitting tensile strength for all concrete ages. The application of water curing enabled a continuous chemical reaction that contributed to the enhancement of binding gel which made the concrete stronger. Similarly, the positive point of prolonged curing for better performance of CBA in concrete has been pointed out by Rafieizonooz et al. [39]. Th present data shows that the use of suitable CBA in CSA blended cement concrete caused it to attain the highest flexural strength of all mixes at 60 days. The use of CBA at 20%

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and more produced concrete with a lower strength than normal concrete, CSA unified cement concrete and CSA blended cement concrete containing CBA with 10% replacement.

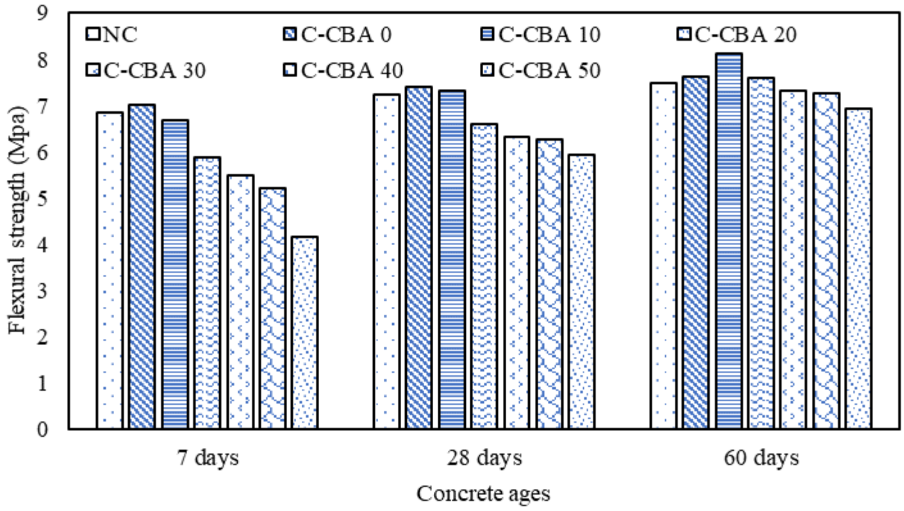


Fig. 6 *Flexural strength results*

3.5 Water Absorption

Based on Fig. 7, it is noted that the incorporation of CBA in CSA blended cement concrete influences the concrete's water absorption. The mix with 10% CBA in CSA blended cement concrete (C-CBA10), generally exhibited the lowest water absorption value owing to the well filled internal structure formed from pozzolanic reaction. The reduction of voids in the interior structure of C-CBA0 (see Fig. 8(a)) upon inclusion of 10% CBA is evident in Fig. 8(b). The water absorption value of C-CBA10 surges when 20% CBA and more were employed. Meanwhile, the highest water absorption of 9.03% is recorded in the concrete when half of the cement is replaced by CBA. The substantial number of gaps that are presence in C-CBA50 shown in Fig. 8(c). Concrete with a greater CBA proportion is more permeable owing to a lesser quantity of CSH gel resulting from a significantly low quantity of cement. The challenges of adding silica content at greater percentages than optimal levels which increases concrete porosity have been noted by Hawkins et al. [30]. Overall, all mixes produced using CBA up to 50% in CSA blended cement can be considered good quality concrete.

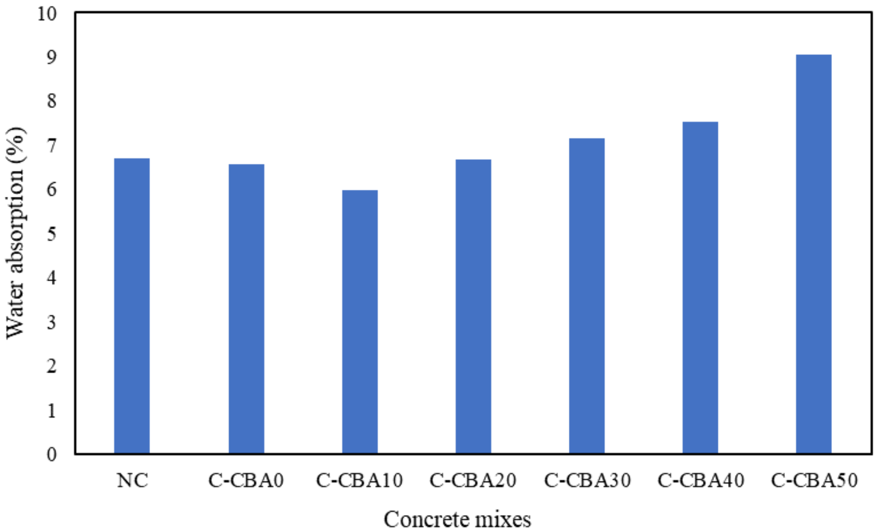
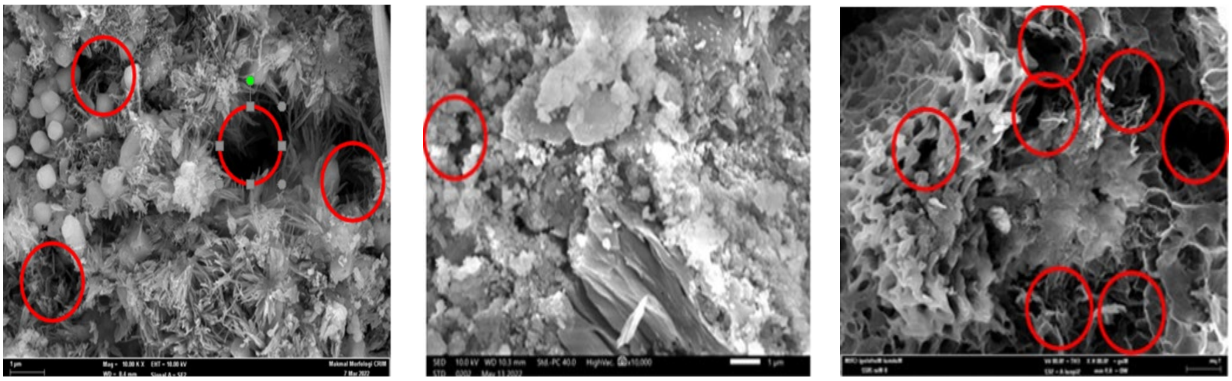


Fig. 7 *Water absorption result*



(a) (b) (c)

Fig. 8 *(a) The presence of voids in C-CBA0 specimens; (b) The presence of fewer voids in C-CBA10 specimens; (c) The presence of many voids in C-CBA50 specimens*

4. Conclusion

The study presents the potential of using CSA blended cement containing CBA as the replacement for cementitious material in the production of concrete. The addition of CSA and CBA to concrete affects its workability. The use of fine powder CBA, which has a larger surface area than OPC particles, results in a stiffer fresh concrete mix. The approach of blending CBA in CSA cement concrete improves the hardened concrete mechanical properties. CSA blended cement concrete containing 10% CBA demonstrated higher compressive strength, tensile strength and flexural strength at later curing ages benefitting from the pozzolanic reaction. By successfully integrating both CBA and CSA as partial cement replacements in concrete, sustainable concrete with enhanced properties and more environmentally friendly would be produced, thus contributing towards a cleaner environment for a healthier community.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Nabilla Mohamad, Khairunisa Muthusamy;* ***data collection:*** *Nabilla Mohamad;* ***analysis and interpretation of results:*** *Nabilla Mohamad, Khairunisa Muthusamy, Fahrizal Zulkarnain;* ***draft manuscript preparation:*** *Nabilla Mohamad, Khairunisa Muthusamy, Sofia Adibah Jasni. All authors reviewed the results and approved the final version of the manuscript.*

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