OPEN ACCESS
The Journal of Engineering and Exact Sciences – jCEC, Vol. 10 N. 06 (2024)
journal homepage: https://periodicos.ufv.br/jcec
eISSN: 2527-1075
ISSN: 2446-9416

Sustainable lightweight self-compacting concrete with coal bottom ash as aggregate and cement replacement

Article Info:
Article history: Received 2024-09-04 / Accepted 2024-10-26/ Available online 2024-10-26
doi: 10.18540/jcecvl10iss6pp20203

Ibtissam Boulahya
ORCID: https://orcid.org/0009-0008-2720-6136
Eco-materials: Innovations & Applications Laboratory, Civil Engineering Department, TAHRI Mohamed University, Bechar, ALGERIA
E-mail: boulahya.ibtissam@univ-bechar.dz
Abdelkadir Makani
ORCID: http://orcid.org/0000-0002-4027-9929
Eco-materials: Innovations & Applications Laboratory, Civil Engineering Department, TAHRI Mohamed University, Bechar, ALGERIA
E-mail: makkani.abdelkadir@univ-bechar.dz
Ahmed Tafraoui
ORCID: https://orcid.org/0000-0002-0278-935X
Eco-materials: Innovations & Applications Laboratory, Civil Engineering Department, TAHRI Mohamed University, Bechar, ALGERIA
E-mail : tafraoui.ahmed@univ-bechar.dz

Abstract
This study aims to examine the impact of utilizing coal bottom ash (CBA) sourced from an inactive power plant on the fresh and hardened properties of lightweight self-compacting concrete (LWSCC). To evaluate the workability of the LWSCC mixtures, slump flow, L-box, and sieve segregation tests were performed. The mechanical and physical properties were assessed through dry density, compressive strength and ultrasonic pulse velocity (UPV) tests. A total of five concrete mixes were developed: a control mix and four additional mixtures in which natural coarse aggregate was fully substituted with coal bottom ash aggregate (CCBA). Additionally, Portland cement was partially replaced with coal bottom ash powder (CBAP) at levels of 15%, 20%, and 25%. The results indicated that the use of CBA as a coarse aggregate enhanced the workability of LWSCC, though workability decreased as the proportion of CBAP increased. Nonetheless, the workability of all mixes remained compliant with the standards specified by the French Association of Civil Engineering (AFGC). Minimal variations in dry density and compressive strength were observed with the incorporation of CBA; however, these values remained within the acceptable limits for structural lightweight concrete. Furthermore, the UPV test demonstrated favorable durability for all LWSCC mixtures. Strong linear correlations were identified among the various measured properties, reinforcing the conclusion that CBA serves as an effective replacement for natural coarse aggregate. Moreover, the use of 15% CBAP as a partial substitute for Portland cement proved to be a feasible option for producing sustainable LWSCC.
Keywords: Coal bottom ash, Lightweight self-compacting concrete, Workability, physical-mechanical performance, Sustainability.

1. Introduction

The growing demand for concrete, driven by population growth and expanding development, is accelerating the depletion of natural resources (Agha *et al*., 2024). The rate at which materials are extracted for concrete production far surpasses the natural replenishment of these resources. This extensive reliance on raw materials within the construction sector poses significant challenges in terms of sustainability and economic efficiency (Ankur & Singh., 2024). In the 21st century, addressing waste reduction and advancing eco-friendly technologies has become imperative. The cement and concrete industries, in particular, face increasing criticism due to their substantial contribution to global CO_2 emissions. These emissions largely stem from the energy-intensive production of Portland cement and the large-scale extraction of natural aggregates (Aygun *et al*., 2024). Such practices not only exacerbate environmental degradation but also raise serious concerns regarding the long-term sustainability of finite natural resources. In response to these challenges, it is crucial to explore alternative materials that promote sustainable development by reducing the consumption of natural resources and safeguarding the interests of future generations. Over the years, various industrial and agricultural wastes have been incorporated into concrete formulations to mitigate environmental impacts and lower production costs (Hamada *et al*., 2022).

These waste materials can function as either binders or aggregates in concrete mixtures. Among these, coal bottom ash (CBA) emerges as a promising by-product available in substantial quantities worldwide, with potential applications in civil engineering (Aygun et al., 2024, Hamada *et al*., 2022, N. Singh *et al*., 2020). CBA is generated as a waste by-product during the combustion of coal in power plants, which produce significant volumes of ash (Zainal Abidin *et al*., 2015). The disposal of this ash presents major environmental challenges, as it is often deposited in landfills, exacerbating ecological concerns.

In Algeria, the issue is particularly pressing due to over 50 years of coal mining, resulting in the accumulation of slag heaps with an estimated volume of approximately 3.7 million cubic meters (Zaouai *et al*., 2020). The incorporation of CBA into concrete production offers a cost-effective and environmentally sustainable solution for waste management. Simultaneously, it helps conserve natural resources and advances efforts toward sustainable development.

The existing literature indicates that coal bottom ash (CBA) can be effectively utilized in concrete, with numerous studies demonstrating satisfactory mechanical properties, including compressive, tensile, and flexural strength (Park *et al*., 2009, Rafieizonooz *et al*., 2016, Kim & Lee, 2011, Ankur & Singh., 2024.; M. Singh & Siddique, 2014; N. Singh *et al*., 2018, Kurama *et al*., 2009, Mangi et al., 2019). However, research exploring CBA's potential as both a lightweight coarse aggregate and a partial cement replacement in self-compacting concrete (SCC) remains limited. Most investigations have concentrated on its application as a fine aggregate (Farhan Hamzah *et al*., 2015; Hamzah *et al*., 2016; Ibrahim *et al*., 2015; Jamaluddin *et al*., 2016.; Zainal Abidin *et al*., 2014a, 2015b , Kumar & Singh, 2020; Meena *et al*., 2024; Raju *et al*., 2022).

Self-compacting concrete (SCC) is characterized by its high workability, allowing it to flow effortlessly through densely reinforced structures under its own weight, filling voids without segregation or material separation. Its stability is achieved through a high paste content and optimized particle distribution, eliminating the need for mechanical compaction (Okamura & Ouchi, 2003). A distinguishing feature of SCC compared to conventional concrete is its increased density, largely due to the high quantities of Portland cement, chemical admixtures, and aggregates used.

To address the environmental and sustainability challenges associated with SCC, the partial or complete replacement of natural aggregates with lightweight aggregates (LWA), along with the incorporation of mineral admixtures from industrial by-products, offers a practical solution. This approach facilitates the development of lightweight self-compacting concrete (LWSCC) (Nahhab & Ketab, 2020; Uysal & Yilmaz, 2011) LWSCC combines the advantages of lightweight materials in the hardened state with the desirable fresh-state properties of SCC (Renukuntla & Murthi, 2024). Replacing normal-weight gravel with lightweight aggregates in SCC formulations is a widely adopted strategy for producing LWSCC (Al-Kabi & Awad, 2024; N. Hilal *et al*., 2024).

Previous studies have extensively explored the incorporation of various natural and artificial lightweight aggregates, as well as industrial and agricultural waste materials, in self-compacting concrete (SCC) (Ting *et al*., 2019). For example, Hwang & Hung, (2005) investigated the use of fine sediment from reservoirs as a replacement for coarse aggregates in SCC. Similarly, Bogas *et al*., (2012) and Nahhab and Ketab (Nahhab & Ketab, 2020) examined the inclusion of expanded clay as a coarse aggregate. Several researchers, including (Topçu & Uygunoğlu, 2010, Uygunoğlu & Topçu, 2009), Kurt et al., 2016), have studied the use of pumice as a lightweight coarse aggregate. Furthermore, Wu *et al*., (2009) and Lo *et al*., (2007) employed expanded shale as a lightweight aggregate (LWA) in SCC.Dolatabad *et al*., (2020) analyzed the effects of incorporating lightweight expanded clay aggregate (LECA), scoria, and perlite on the fresh and hardened properties of lightweight self-compacting concrete (LWSCC). Agricultural waste materials have also been integrated into SCC, as demonstrated by Kanadasan et al. (Kanadasan & Razak, 2014), Ting *et al*., (2020), and Hilal *et al*., (2021), who utilized palm oil clinker, oil palm shell, and walnut shells as aggregate replacements. The use of expanded polystyrene beads as lightweight aggregates has also been investigated by Medher *et al*., (2021) and Hilal *et al*., (2021). Additionally, Kumar *et al*., (2024) explored the application of sintered fly ash aggregate (SFAA) as a complete substitute for natural coarse aggregates to produce environmentally friendly LWSCC mixes.

This study aimed to evaluate the feasibility of utilizing Algerian coal bottom ash (CBA) as a replacement for coarse aggregate and as a partial substitute for cement in the production of lightweight self-compacting concrete (LWSCC). The research focused on both the fresh properties namely, slump flow, filling capacity, and stability and the hardened properties, including compressive strength, dry density and ultrasonic pulse velocity (UPV).

2. Materials and methods

2.1 Materials

<u>Cement:</u> In this study, Ordinary Portland Cement (CEM I 42.5 N), which complies with both the Algerian standard NA 442 and the European standard EN 197-1, was utilized. The chemical composition of the cement is presented in Table 1.

Table 1 - The chemical compositions of the used cement and CBA

Composition (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI
Cement	18.91	4.30	4.74	60.33	3.82	2.29	0.17	0.84	<0.5
CBA	44.78	15.79	22.90	2.47	1.43	4.37	0.16	2.38	1.2

<u>Aggregate</u>: The natural fine aggregate (NFA 0/3) used in this study was river sand sourced from the Bechar region in Algeria. The coarse aggregate (NCA) was obtained from crushed limestone from a quarry in Bechar, available in two size ranges: 3/8 and 8/15 mm. Coal bottom ash (CBA), collected from a decommissioned thermal power plant in Algeria, was manually crushed and further processed using a jaw crusher. After sieving, the CBA was classified into coarse aggregate fractions of 3/8 and 8/15 mm. Additionally, the finer portion of the CBA that passed through an 80 µm sieve (CBAP) was used as a partial replacement for cement (Figure 1).

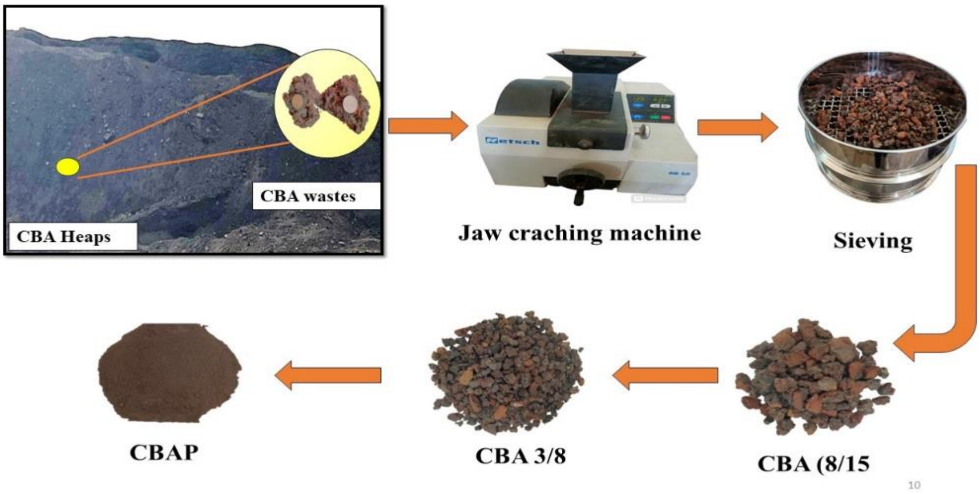

Figure 1 – Production of CBA aggregate.

The physical properties of the aggregates are provided in Table 2, while their particle size distribution is illustrated in Figure 2. The chemical composition of the coal bottom ash (CBA) was determined through X-ray fluorescence (XRF) spectroscopy, with the results summarized in Table 1. The analysis reveals that silica (SiO_2), iron oxide (Fe_2O_3), and alumina (Al_2O_3) are the predominant constituents of CBA, collectively accounting for 83.47% of its total composition. According to the ASTM C618 standard, this composition categorizes CBA as a Class "F" pozzolanic material. A comprehensive overview of the chemical properties of CBA can be found in Table 1.

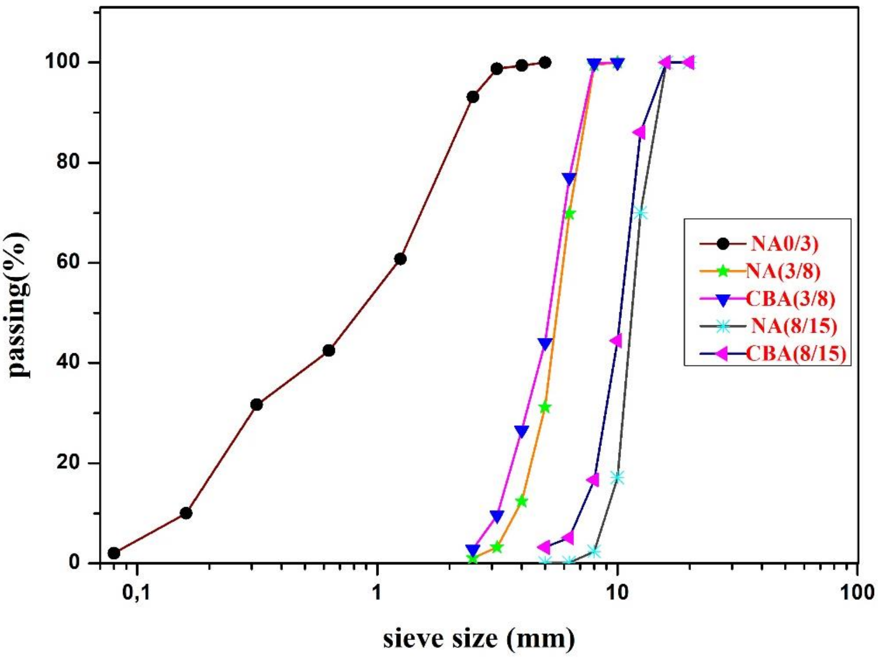

Figure 2 - Aggregates granulometric curves.

Table 2 - Physical and mechanical properties of used aggregate

Properties	**0/3 NFA**	**3/8 NCA**	**3/8 CCBA**	**8/15 NCA**	**8/15 CCBA**
Bulk density (g/cm3)	1.6	1.39	0.70	1.40	0.66
Absolute density (g/cm3)	2.5	2.66	1.93	2.67	1.81
Fineness modulus	2.53	/	/	/	/
Sand equivalent (%)	80.3	/	/	/	/
Water absorption (%)	1.62	0.85	7	0.95	8
Los Angeles coefficient (%)	/	21.56	27.6	20.72	27.9

Figure 3 presents a scanning electron microscopy (SEM) image of the coal bottom ash (CBA), which reveals irregular and porous particles with a complex surface texture. Additionally, energy dispersive spectroscopy (EDS) was employed to analyze the elemental composition of CBA at a microscopic level. As depicted in Figure 4, the primary elements identified in CBA include oxygen, aluminum, and silicon.

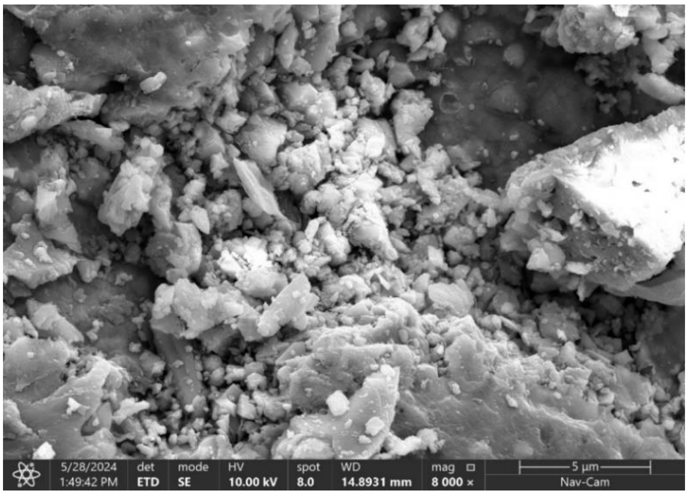

Figure 3 - CBA Scanning electron microscope image.

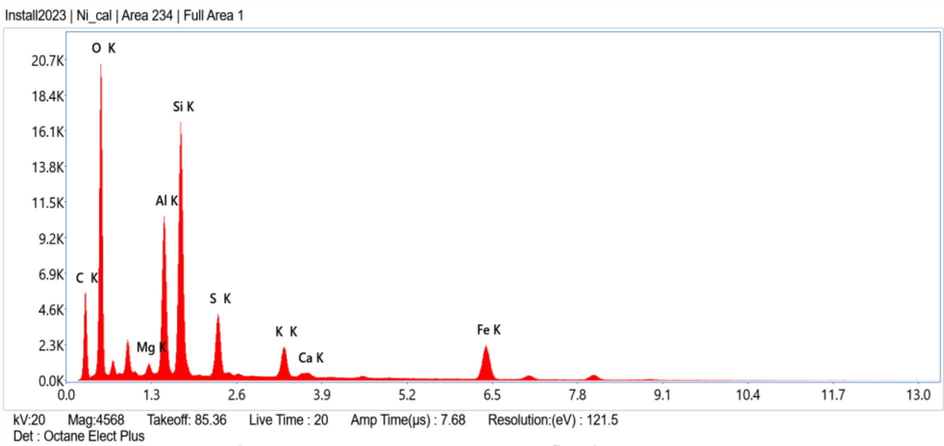

Figure 4 - CBA EDS analysis.

Superplasticizer and mixing water : To achieve optimal workability, the superplasticizer "MAX SUPERFLOW S180," manufactured by the Algerian company "Technachem," was utilized in this study. This superplasticizer complies with NF EN 934-2 standards. The mixing water was obtained from the treated drinking water supply system of Bechar.

2.2. Mix proportion of SCC

Following the guidelines established by (AFGC, 2008), an initial reference mix without coal bottom ash was prepared. Subsequently, the natural coarse aggregate was completely replaced with coal bottom ash (CBA), and coal bottom ash powder (CBAP) was incorporated in varying proportions, ranging from 15% to 25% in 5% increments. The coal bottom ash used in these mixes was in a Saturated Surface Dry (SSD) condition. The different mixes were designated as CSCC-0%, CSCC-15%, CSCC-20%, and CSCC-25%, reflecting the percentage of CBAP replacement. The quantities of materials used in each mix are detailed in Table 3.

Table 3 - SCC composition.

Composition	RSCC	CSCC-0%	CBASCC-15%	CBASCC-20%	CBASCC-25%
Cement (kg/m^3)	520	520	442	416	390
CBAP (kg/m^3)		/	78	104	130
NFA (kg/m^3)	900	900	900	900	900
NCA 3/8 (kg/m^3)	150	/	/	/	/
CCBA3/8 (kg/m^3)	/	111.36	111.36	111.36	111.36
NCA 8/15 (kg/m^3)	580	/	/	/	/
CCBA (kg/m^3)		394.65	394.65	394.65	394.65
Water (kg/m^3)	256	256	260	260	260
Superplasticizer (%)	2%	2%	2.1%	2.3%	2.4%
W/C	0.48	0.48	0.50	0.50	0.50

2.3 Tests on fresh and mechanical properties

To confirm the classification of the concrete mixture as self-compacting concrete (SCC), its fresh properties were assessed, as shown in Figure 5. The evaluations included the slump flow test, the L-box blocking ratio test, and the segregation resistance test. All testing procedures were carried out in compliance with the standards established by the AFGC.

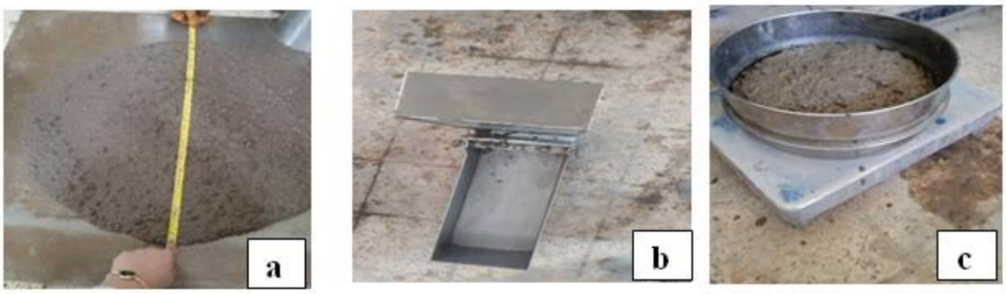

Figure 5 - Fresh state testes: (a) Slump flow test, (b) L-Box test, (c) Sieve stability test.

The hardened properties of the concrete were evaluated by determining the dry density in compliance with EN 12390-7. Compressive strength was measured after 7, 28, and 91 days of curing, in accordance with EN 12390-3 standards. Additionally, ultrasonic pulse velocity (UPV) was assessed using the direct transmission method, as stipulated in EN 12504-4 (Figure 6).

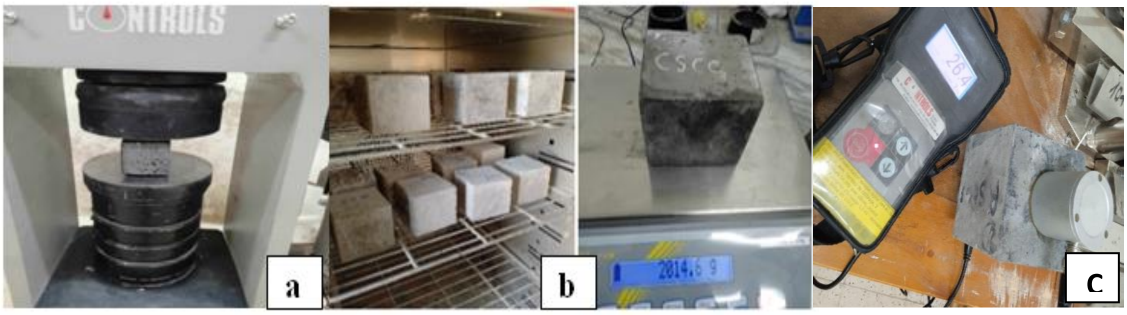

Figure 6 - Hardened state testes: (a) Compressive strength, (b) Dry density, (c) UPV test.

3. Results and discussion

3.1 SCC fresh state results

The experimental results for fresh-state SCC revealed that all concrete mixtures exhibited satisfactory workability and stability, meeting the requirements set by AFGC standards. The slump flow values ranged from 727 mm to 766 mm (Figure 7). The incorporation of coal bottom ash (CBA) as a coarse aggregate in a saturated surface dry (SSD) condition improved the workability relative to the reference mix. Nevertheless, as the proportion of coal bottom ash powder (CBAP) increased, a notable decrease in the flowability of the mixtures was observed. This reduction in slump flow is attributed to the high porosity of CBA, which resulted in increased fluid absorption as its content increased (Zainal Abidin et al., 2014).

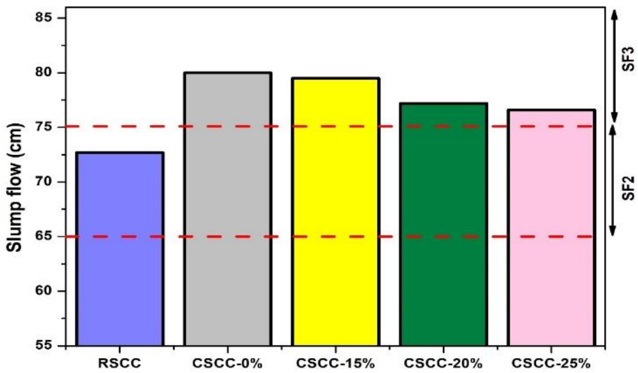

Figure 7 - Effect of CCBA and CBAP on SCC slump flow.

Regarding the passing ability, the L-box blocking ratio ranged from 0.82 to 0.94 (Figure 8), indicating a slight decline with the use of CBA as a coarse aggregate and higher levels of CBAP incorporation. This decrease is primarily due to the irregular shape of the CBA particles, which increases inter-particle friction, consequently reducing the viscosity of the SCC mixtures (Jamaluddin *et al.*, 2016.; Zainal Abidin *et al.*, 2014).

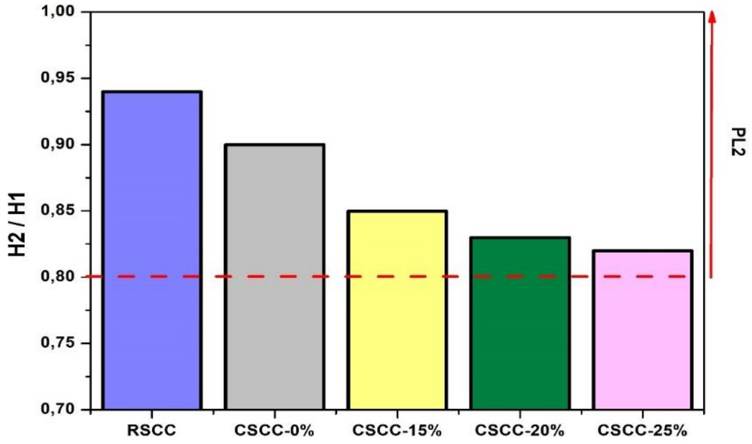

Figure 8 - Effect of CCBA and CBAP on SCC passing ability.

The results of the sieve stability test ranged from 4% to 9.24% (Figure 9), displaying a trend consistent with that observed in the L-box test. Sieve segregation decreased with an increase in the CBA content.

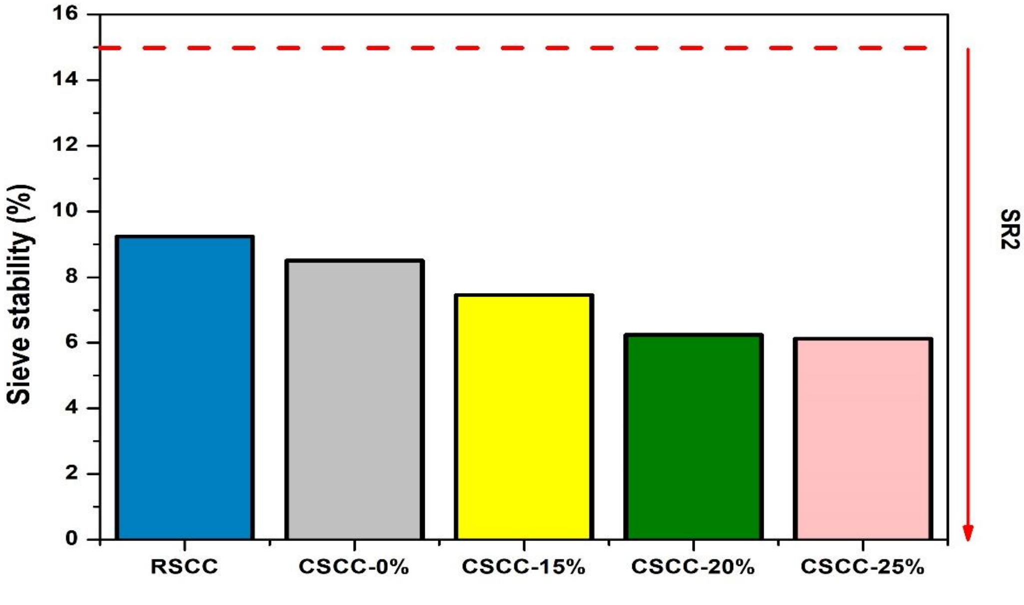

Figure 9 - Effect of CCBA and CBAP on SCC segregation resistance.

3.2 SCC Hardened state results

Compressive strength: The compressive strength results for concrete samples at 7, 28, and 90 days are illustrated in Figure 10. The data reveals that the use of CBA as a coarse aggregate led to more porous concrete, which resulted in an approximate 14% reduction in compressive strength at 28 days. Additionally, an increase in the proportion of coal bottom ash powder (CBAP) in the mix further reduced compressive strength. Notably, at 90 days, the CBASCC-15% mix attained nearly the same compressive strength as the CSCC-0% mix, which may be attributed to the initially slower reactivity of CBAP, with more pronounced strength gains occurring over longer curing durations (Cheriaf *et al*., 1999; N. Singh *et al*., 2020).

These findings align with previous research outcomes (Kim & Lee, 2011; Kumar & Singh, 2020; Meena *et al*., 2024).

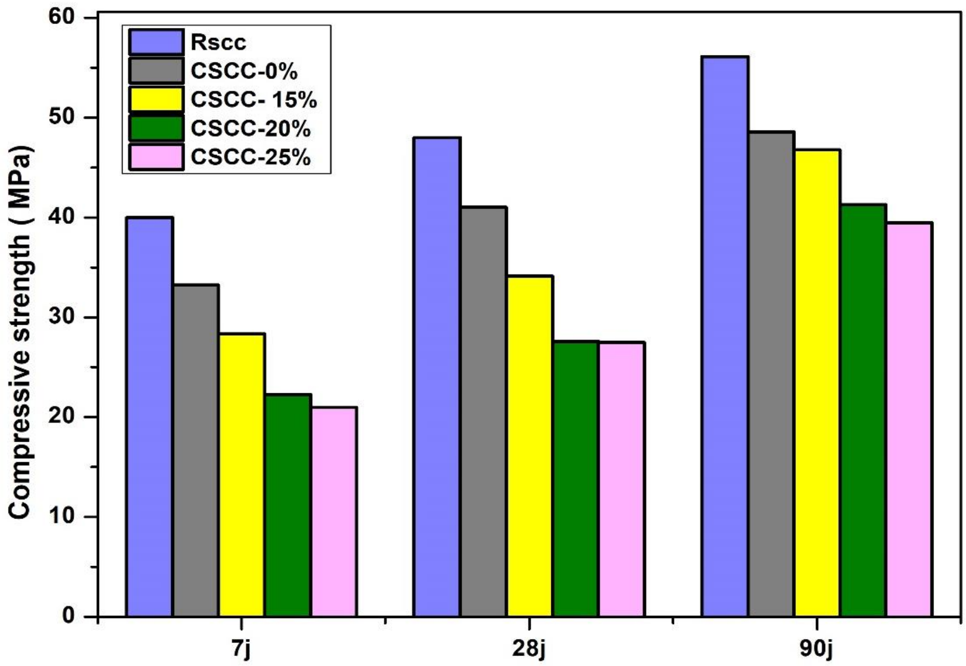

Figure 10 - Effect of CCBA and CBAP on SCC compressive strength.

Dry density: Figure 11 presents the dry density of concrete after 28 days of curing. The results indicate that the incorporation of CBA as both an aggregate and a partial cement replacement in SCC reduces the dry density to 1811.85 kg/m³, which is below the 2000 kg/m³ threshold, thereby classifying it as lightweight self-compacting concrete. This decrease in density is attributed to the lower specific gravity of CBA aggregates compared to conventional aggregates (Raju *et al*., 2022; M. Singh & Siddique, 2014).

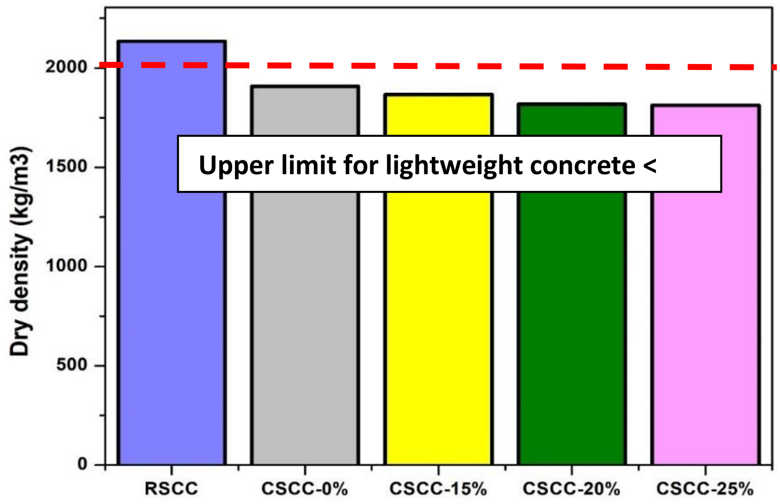

Figure 11 - Effect of CCBA and CBAP on the dry density of SCC.

Ultrasonic pulse velocity: The pulse velocity test results are depicted in Figure 12. After 28 days of curing, the pulse velocity values decreased from 4696 m/s to 3058 m/s when coal bottom ash was used to replace both the coarse aggregate and cement in SCC. These results suggest that the concrete quality conforms to the standards outlined in ASTM C597. The findings are consistent with the compressive strength results observed after 28 days of curing. The reduced pulse velocity values are attributed to the porous nature of the coal bottom ash (Kumar *et al*., 2024; Meena *et al*., 2024).

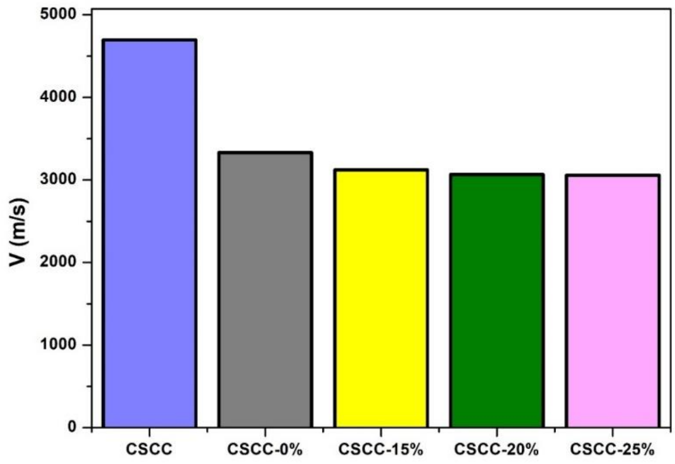

Figure 12 - Ultrasonic pulse velocity of SCC at 28 days.

<u>Dry density, compressive strength and UPV correlations:</u> In this study, a correlation was established between the concrete density and both its compressive strength and ultrasonic pulse velocity (UPV) for SCC mixtures after 28 days of curing, as shown in Figure 13. These relationships were substantiated by high R^2 values of 0.93 for compressive strength and 0.96 for UPV, indicating a strong linear association. The findings reveal that compressive strength decreases as dry density decreases, while it increases with higher density. Additionally, Figure 14 illustrates a linear relationship between dry density and UPV, demonstrating that UPV decreases as the dry density decreases and increases as the density rises (Atyia *et al*., 2021).

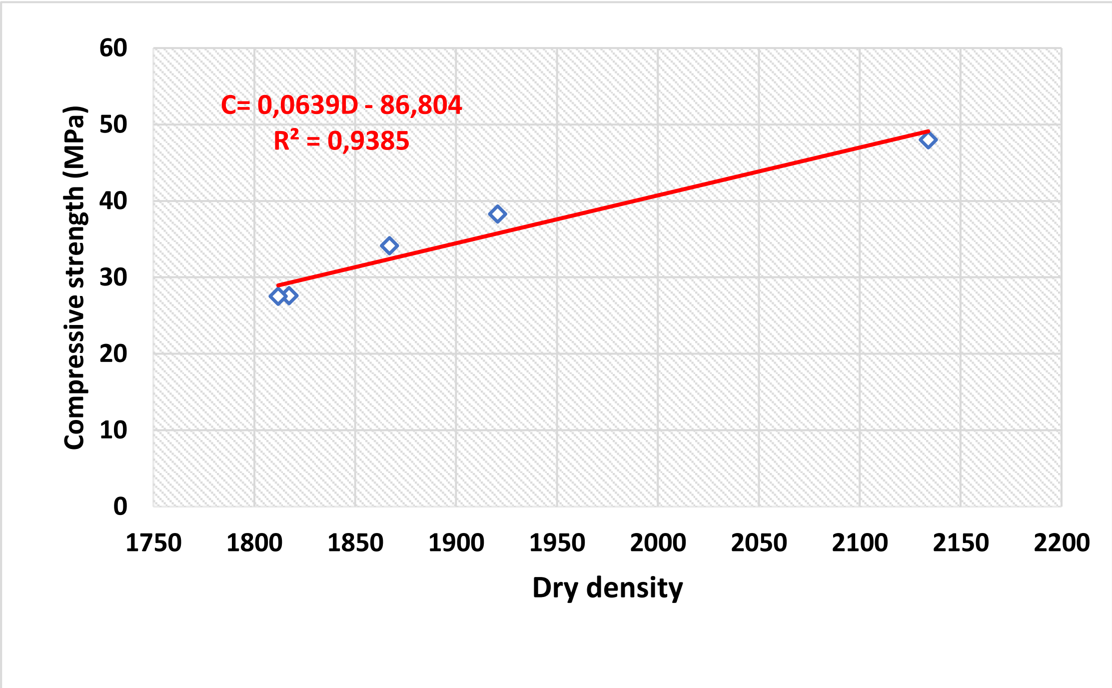

Figure 13 - Dry density and compressive strength correlation.

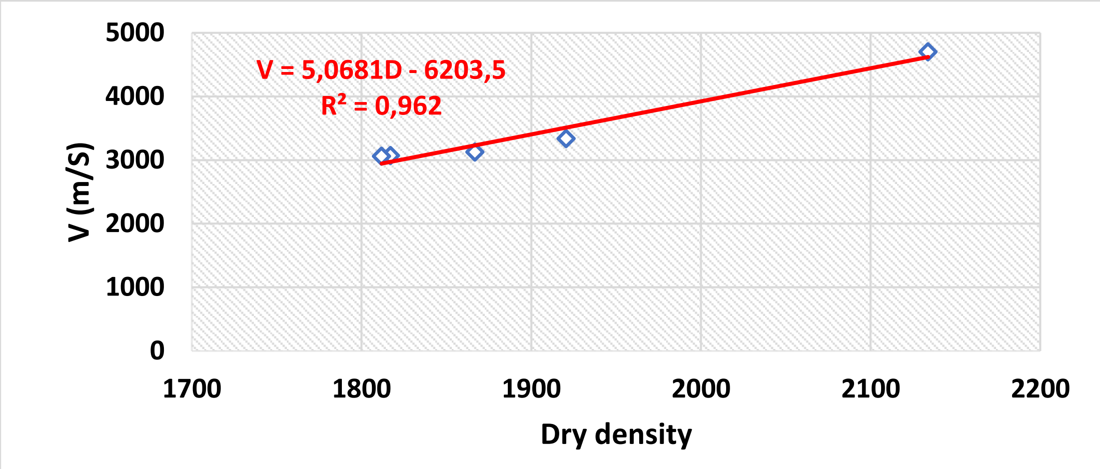

Figure 14 - Correlation between dry density and UPV.

4 Conclusions

This study assesses the influence of coal bottom ash (CBA) on the fresh properties and mechanical performance of self-compacting concrete (SCC). Based on the experimental findings, the following conclusions can be drawn: A) The evaluation of fresh concrete properties indicates that the use of CBA as a coarse aggregate enhances the workability of SCC. However, substituting cement with CBA powder leads to a reduction in workability as the replacement level increases from 15% to 25%. Despite this decline, the resulting workability remains adequate for SCC applications. - Oven dry density measurements demonstrate that incorporating CBA as both a lightweight aggregate and a partial cement replacement reduces the dry density of SCC to below 2000 kg/m³, thereby meeting the classification criteria for lightweight self-compacting concrete as specified by EN 206-1 standards. B) The inclusion of CBA as a lightweight aggregate in SCC led to reductions in both compressive strength and ultrasonic pulse velocity (UPV) after 28 days of curing, primarily due to the porous nature of CBA. However, replacing 15% of Portland cement with CBA powder produced compressive strength values comparable to the control mix (CSCC-0%) over time, which is attributed to pozzolanic activity observed at 90 days. Thus, the reduction in compressive strength and UPV is associated with the reduced density of the concrete. C) A strong correlation was observed between compressive strength and UPV with dry density, as evidenced by R^2 values of 0.93 and 0.96, respectively. This research highlights the potential of reusing CBA waste as both a coarse aggregate and a cement substitute in SCC to mitigate environmental impact. The findings suggest that CBA is a promising material for concrete production; however, further studies are recommended to explore its long-term effects and other mechanical and durability-related properties.

Acknowledgements

The authors would like to express their gratitude to the Directorate General for Scientific Research and Technological Development (D.G.R.S.D.T., Algeria) for providing financial support for this study. Appreciation is also extended to the professors and students of the Laboratory of Eco-Materials: Innovations & Applications (EMIA) for their contributions and assistance

References

AFGC. (2008). *Les BAP : recommandations provisoires pour l'emploi des Bétons autoplaçants, .*

Agha, N., Makani, A., Tafraoui, A., & Zaouai, S. (2024). Effect of recycled concrete aggregate size on physical and mechanical properties of eco-friendly-self-compacting concrete. *Studies In Engineering And Exact Sciences*, *5*(2), e5384. https://doi.org/10.54021/seesv5n2-005

Al-Kabi, W. H., & Awad, H. K. (2024). Investigating Some Properties of Hybrid Fiber Reinforced LECA Lightweight Self-Compacting Concrete. *Journal of Engineering*, *30*(03), 177–190. https://doi.org/10.31026/j.eng.2024.03.12

Ankur, N., & Singh, N. (2024). Shear strength characterization and sustainability assessment of coal bottom ash concrete. Canadian Journal of Civil Engineering.

Atyia, M. M., Mahdy, M. G., & Abd Elrahman, M. (2021). Production and properties of lightweight concrete incorporating recycled waste crushed clay bricks. *Construction and Building Materials, 304*. https://doi.org/10.1016/j.conbuildmat.2021.124655

Aygun, B. F., Bilir, T., & Uysal, M. (2024). Coal bottom ash and its applications in cement and concrete technologies: a review. *Discover Civil Engineering*, *1*(1), 86. https://doi.org/10.1007/s44290-024-00090-y

Bogas, J. A., Gomes, A., & Pereira, M. F. C. (2012). Self-compacting lightweight concrete produced with expanded clay aggregate. *Construction and Building Materials*, *35*, 1013–1022. https://doi.org/10.1016/j.conbuildmat.2012.04.111

Cheriaf, M., Rocha, J. C., & Péra, J. (1999). Pozzolanic properties of pulverized coal combustion bottom ash. *Cement and Concrete Research*, *29*(9), 1387–1391. https://doi.org/10.1016/S0008-8846(99)00098-8

Dolatabad, Y. A., Kamgar, R., & Jamali Tazangi, M. A. (2020). Effects of perlite, leca, and scoria as lightweight aggregates on properties of fresh and hard self-Compacting concretes. *Journal of Advanced Concrete Technology, 18*(10), 633–647. https://doi.org/10.3151/JACT.18.633

Farhan Hamzah, A., Haziman Wan Ibrahim, M., Jamaluddin, N., Putra Jaya, R., Fadzil Arshad, M., Ernida Zainal Abidin, N., Raja, P., Pahat, B., Darul Takzim, J., Alam, S., Darul Ehsan, S., & Kembangan, S. (2015). *Fresh Characteristic and Mechanical Compressive Strength Development of Self-Compacting Concrete Integrating Coal Bottom Ash as Partial Fine Aggregates Replacement I J E N S Fresh Characteristic and Mechanical Compressive Strength Development of Self-Compacting Concrete Integrating Coal Bottom Ash as Partial Fine Aggregates Replacement*. https://www.researchgate.net/publication/281600030

Hamada, H., Alattar, A., Tayeh, B., Yahaya, F., & Adesina, A. (2022). Sustainable application of coal bottom ash as fine aggregates in concrete: A comprehensive review. *Case Studies in Construction Materials*, *16*, e01109. https://doi.org/10.1016/j.cscm.2022.e01109

Hamzah, A. F., Ibrahim, M. H. W., Jamaluddin, N., Jaya, R. P., Arshad, M. F., Zainal Abidin, N. E., Manan, E. A., & Omar, N. A. (2016). Nomograph of self-compacting concrete mix design incorporating coal bottom ash as partial replacement of fine aggregates. *Journal of Engineering and Applied Sciences, 11*(7), 1671–1675. https://doi.org/10.3923/jeasci.2016.1671.1675

Hilal, N., Hamah Sor, N., & Faraj, R. H. (2021). Development of eco-efficient lightweight self-compacting concrete with high volume of recycled EPS waste materials. *Environmental Science and Pollution Research, 28*(36), 50028–50051. https://doi.org/10.1007/s11356-021-14213-w

Hilal, N., Hamah Sor, N., Hadzima-Nyarko, M., Radu, D., & Tawfik, T. A. (2024). The influence of nanosunflower ash and nanowalnut shell ash on sustainable lightweight self-compacting concrete characteristics. *Scientific Reports*, *14*(1). https://doi.org/10.1038/s41598-024-60096-5

Hilal, N. N., Sahab, M. F., & Mohammed Ali, T. K. (2021). Fresh and hardened properties of lightweight self-compacting concrete containing walnut shells as coarse aggregate. *Journal of King Saud University - Engineering Sciences*, *33*(5), 364–372. https://doi.org/10.1016/j.jksues.2020.01.002

Hwang, C. L., & Hung, M. F. (2005). Durability design and performance of self-consolidating lightweight concrete. *Construction and Building Materials*, *19*(8), 619–626. https://doi.org/10.1016/j.conbuildmat.2005.01.003

Ibrahim, M. H. W., Hamzah, A. F., Jamaluddin, N., Ramadhansyah, P. J., & Fadzil, A. M. (2015). Split Tensile Strength on Self-compacting Concrete Containing Coal Bottom Ash. *Procedia - Social and Behavioral Sciences*, *195*, 2280–2289. https://doi.org/10.1016/j.sbspro.2015.06.317

Jamaluddin, N., Farhan Hamzah, A., Haziman Wan Ibrahim, M., Putra Jaya, R., Fadzil Arshad, M., Ernida Zainal Abidin, N., & Huda Dahalan, N. (2016.). *Fresh Properties and Flexural Strength of Self-Compacting Concrete Integrating Coal Bottom Ash*. https://doi.org/10.1051/C

Kanadasan, J., & Razak, H. A. (2014). Fresh Properties of Self-Compacting Concrete Incorporating Palm Oil Clinker. In *InCIEC 2013* (pp. 249–259). Springer Singapore. https://doi.org/10.1007/978-981-4585-02-6_22

Kim, H. K., & Lee, H. K. (2011). Use of power plant bottom ash as fine and coarse aggregates in high-strength concrete. *Construction and Building Materials*, *25*(2), 1115–1122. https://doi.org/10.1016/j.conbuildmat.2010.06.065

Kumar, P., Dinakar, P., & Saravanan, T. J. (2024). Development and Mechanical Performance of Self-Compacting Lightweight Aggregate Concrete Using Sintered Fly Ash Aggregates. *Journal of Materials in Civil Engineering*, *36*(7). https://doi.org/10.1061/JMCEE7.MTENG-17831

Kumar, P., & Singh, N. (2020). Influence of recycled concrete aggregates and Coal Bottom Ash on various properties of highvolume fly ash-self compacting concrete. *Journal of Building Engineering*, *32*, 101491. https://doi.org/10.1016/j.jobe.2020.101491

Kurama, H., Topçu, İ. B., & Karakurt, C. (2009). Properties of the autoclaved aerated concrete produced from coal bottom ash. *Journal of Materials Processing Technology*, *209*(2), 767–773. https://doi.org/10.1016/j.jmatprotec.2008.02.044

Kurt, M., Gül, M. S., Gül, R., Aydin, A. C., & Kotan, T. (2016). The effect of pumice powder on the self-compactability of pumice aggregate lightweight concrete. *Construction and Building Materials*, *103*, 36–46. https://doi.org/10.1016/j.conbuildmat.2015.11.043

Lo, T. Y., Tang, P. W. C., Cui, H. Z., & Nadeem, A. (2007). Comparison of workability and mechanical properties of self-compacting lightweight concrete and normal self-compacting concrete. *Materials Research Innovations*, *11*(1), 16–17. https://doi.org/10.1179/143307507X196239

Mangi, S. A., Wan Ibrahim, M. H., Jamaluddin, N., Arshad, M. F., Memon, S. A., & Shahidan, S. (2019). Effects of Grinding Process on the Properties of the Coal Bottom Ash and Cement Paste. *Journal of Engineering and Technological Sciences*, *51*(1), 1–13. https://doi.org/10.5614/j.eng.technol.sci.2019.51.1.1

Medher, A. H., Al-Hadithi, A. I., & Hilal, N. (2021). The Possibility of Producing Self-Compacting Lightweight Concrete by Using Expanded Polystyrene Beads as Coarse Aggregate. *Arabian Journal for Science and Engineering*, *46*(5), 4253–4270. https://doi.org/10.1007/s13369-020-04886-9

Meena, A., Singh, N., & Singh, S. P. (2024). Shear strength and microstructural investigation on high-volume fly ash self-compacting concrete containing recycled concrete aggregates and coal bottom ash. *Materiales de Construcción*, *74*(353), e333. https://doi.org/10.3989/mc.2024.354623

Nahhab, A. H., & Ketab, A. K. (2020). Influence of content and maximum size of light expanded clay aggregate on the fresh, strength, and durability properties of self-compacting lightweight concrete reinforced with micro steel fibers. *Construction and Building Materials*, *233*, 117922. https://doi.org/10.1016/j.conbuildmat.2019.117922

Okamura, H., & Ouchi, M. (2003). Self-Compacting Concrete. *Journal of Advanced Concrete Technology*, *1*(1), 5–15. https://doi.org/10.3151/jact.1.5

Park, S. B., Jang, Y. Il, Lee, J., & Lee, B. J. (2009). An experimental study on the hazard assessment and mechanical properties of porous concrete utilizing coal bottom ash coarse aggregate in Korea. *Journal of Hazardous Materials*, *166*(1), 348–355. https://doi.org/10.1016/j.jhazmat.2008.11.054

Rafieizonooz, M., Mirza, J., Salim, M. R., Hussin, M. W., & Khankhaje, E. (2016). Investigation of coal bottom ash and fly ash in concrete as replacement for sand and cement. *Construction and Building Materials*, *116*, 15–24. https://doi.org/10.1016/j.conbuildmat.2016.04.080

Raju, K., Ramanjaneyulu, N., & Rao, M. V. S. (2022). Strength and Durability Studies on Lightweight Self-Compacting Concrete Partially Replacing Coarse Aggregate with Sintered Fly Ash Aggregate. *CVR Journal of Science and Technology*, *23*. https://doi.org/10.32377/cvrjst2302

Renukuntla, A., & Murthi, P. (2024). Bibliometric analysis on Characterization of Sustainable lightweight Self Compacting Concrete with Recycled Aggregate. *E3S Web of Conferences*, *559*. https://doi.org/10.1051/e3sconf/202455904001

Singh, M., & Siddique, R. (2014). Strength properties and micro-structural properties of concrete containing coal bottom ash as partial replacement of fine aggregate. *Construction and Building Materials*, *50*, 246–256. https://doi.org/10.1016/j.conbuildmat.2013.09.026

Singh, N., M., M., & Arya, S. (2018). Influence of coal bottom ash as fine aggregates replacement on various properties of concretes: A review. *Resources, Conservation and Recycling*, *138*, 257–271. https://doi.org/10.1016/j.resconrec.2018.07.025

Singh, N., Shehnazdeep, & Bhardwaj, A. (2020). Reviewing the role of coal bottom ash as an alternative of cement. *Construction and Building Materials*, *233*, 117276. https://doi.org/10.1016/j.conbuildmat.2019.117276

Ting, T. Z. H., Rahman, M. E., & Lau, H. H. (2020). Sustainable lightweight self-compacting concrete using oil palm shell and fly ash. *Construction and Building Materials*, *264*. https://doi.org/10.1016/j.conbuildmat.2020.120590

Ting, T. Z. H., Rahman, M. E., Lau, H. H., & Ting, M. Z. Y. (2019). Recent development and perspective of lightweight aggregates based self-compacting concrete. In *Construction and Building Materials* (Vol. 201, pp. 763–777). Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2018.12.128

Topçu, I. B., & Uygunoğlu, T. (2010). Effect of aggregate type on properties of hardened self-consolidating lightweight concrete (SCLC). *Construction and Building Materials*, *24*(7), 1286–1295. https://doi.org/10.1016/j.conbuildmat.2009.12.007

Uygunoğlu, T., & Topçu, I. B. (2009). Thermal expansion of self-consolidating normal and lightweight aggregate concrete at elevated temperature. *Construction and Building Materials*, *23*(9), 3063–3069. https://doi.org/10.1016/j.conbuildmat.2009.04.004

Uysal, M., & Yilmaz, K. (2011). Effect of mineral admixtures on properties of self-compacting concrete. *Cement and Concrete Composites*, *33*(7), 771–776. https://doi.org/10.1016/j.cemconcomp.2011.04.005

Wu, Z., Zhang, Y., Zheng, J., & Ding, Y. (2009). An experimental study on the workability of self-compacting lightweight concrete. *Construction and Building Materials*, *23*(5), 2087–2092. https://doi.org/10.1016/j.conbuildmat.2008.08.023

Zainal Abidin, N. E., Wan Ibrahim, M. H., Jamaluddin, N., Kamaruddin, K., & Hamzah, A. F. (2014). The effect of bottom ash on fresh characteristic, compressive strength and water absorption of self-compacting concrete. *Applied Mechanics and Materials*, *660*, 145–151. https://doi.org/10.4028/www.scientific.net/AMM.660.145

Zainal Abidin, N. E., Wan Ibrahim, M. H., Jamaluddin, N., Kamaruddin, K., & Hamzah, A. F. (2015). The Strength Behavior of Self-Compacting Concrete Incorporating Bottom Ash as Partial Replacement to Fine Aggregate. *Applied Mechanics and Materials*, *773–774*, 916–922. https://doi.org/10.4028/www.scientific.net/amm.773-774.916

Zaouai, S., Tafraoui, A., Makani, A., & Benmerioul, F. (2020). Hardened and transfer properties of self-compacting concretes containing pre-coated rubber aggregates with crushed dune sand. *Journal of Rubber Research*, *23*(1), 5–12. https://doi.org/10.1007/s42464-019-00030-x