Mehran University Research Journal of Engineering and Technology

https://doi.org/10.22581/muet1982.0226

2025, 44(4) 58-67

Effect of Activated Carbon Content Derived From Coconut Shell and Water to Binder Ratios on The Workability of Mortar Mixtures

Ahmed Tahir Yousef Omar [a], Azman Mohammed [a,*], Nur Hafizah A. Khalid [a] and Milad Hafezolghorani [b] Muhammad Akbar Caronge[c]

[a] *Faculty of Civil Engineering, University Teknologi Malaysia, Johor*

[b] *Dura Technology Sdn. Bhd., Chemor, Perak, Malaysia*

*Corresponding author: Azman Mohammed, Email: azmanmohamed.kl@utm.my

Received: 02 May 2025, Revised: 15 September 2025, Accepted: 29 September 2025, Published: 01 October 2025

KEYWORDS

Workability

Cement

Activated Carbon

Water Binder Ratios

Mortar Components

ABSTRACT

This study analyzes the workability and compressive strength of mortar with activated carbon (AC) at 0%, 5%, 10%, 15%, and 20% cement substitution. XRF analysis shows that AC includes silica (SiO_2: 6.39%), calcium oxide (CaO: 9.64%), magnesium oxide (MgO: 29.20%), potassium oxide (K_2O: 46.60%), and somewhat less iron oxide (Fe_2O_3: 2.06%) and aluminium oxide (Al_2O_3: 3.34%), which improves pozzolanic reactivity and its initial stage AC has a finer particle size distribution than cement, with a high specific surface area (1,016.38 m^2/g) and pore size (2.71 nm), suggesting potential advantages in particle packing and hydration kinetics. The flow table test indicated that workability increased with greater water-to-binder (W/B) ratios for all AC concentrations, from 13.54% for the control to 14.84% for 10% AC at W/B = 0.50 and to 22.74% to 23.70% at W/B = 0.65. These findings imply AC inclusion had no impact on fresh mortar flow. In testing, the 5% AC mix at W/B = 0.55 exhibited a maximum strength of ≈38 MPa, 8% greater than the control. AC increased modest strength losses. AC can augment cementitious materials to increase mechanical performance and workability at suitable replacement levels, saving cement consumption costs and benefiting the environment.

1. Introduction

Workability is a fundamental property of mortar that influences its ease of mixing, placing, and finishing while ensuring proper cohesion and bonding. Various additives have been introduced into mortar mixtures to enhance workability, durability, and overall performance[1]. Among these, some materials have emerged as a potential modifier due to its unique surface properties and porous structure [2, 3]. This makes it an interesting alternative to traditional additives such as fly ash, silica fume, and met kaolin, which are commonly used to improve the rheological properties of mortar and concrete [4, 5]. Several studies have investigated the impact of different additives on mortar and concrete workability [6]. Fly ash, for instance, is widely known for its ability to improve fluidity and reduce water demand [7, 8]. However, silica fume enhances cohesion but can increase the need for superplasticizers due to its fine particle size. Another commonly used additive, refines the pore structure and enhances early strength development [9, 10].

Some studies indicate that the porous nature of some materials can lead to increased water absorption [6, 11]. This could result in stiffer mixes unless water content is adjusted accordingly [12]. Therefore, optimizing the water-to-cement ratio in the presence of admixtures are crucial to achieving the desired

© Mehran University of Engineering and Technology 2025

balance between workability and strength [13]. Comparing materials workability-enhancing materials highlights its potential advantages and challenges [14]. Unlike superplasticizers, which improve flow ability without significantly affecting hydration, some materials may influence both the physical and chemical interactions within the cement matrix [15, 16]. This dual effect makes it a unique addition to mortar and concrete mixtures, requiring precise adjustments to mix design parameters [17]. The effectiveness of material in modifying workability also depends on factors such as particle size, surface treatment, and compatibility with other admixtures [18]. These variables must be considered when incorporating material into mortar formulations to achieve consistent and reliable results [19].

This study aims to explore the influence of AC on the workability of mortar while considering its interaction with water and cementitious materials. By comparing its effects to those of other widely used additives, this research seeks to provide a comprehensive understanding of how AC functions within the mix. The findings will contribute to the ongoing development of innovative and sustainable construction materials, offering insights into how AC can be effectively utilized to optimize mortar workability.

2. Materials and Methods

2.1 Experimental Materials

The main ingredients employed to prepare the mortar for mortar blocks are shown in Figure 1; water, fine aggregate (sand), activated carbon (AC), which can partially substitute cement, and cement (binding agent). We chose ACA, ACB, ACC, and ACD (various AC kinds) to illustrate their production techniques and physical characteristics, including chemical composition, surface area, and particle size distribution. We anticipated that ACB, due to its reduced ash and elevated fixed carbon content, would improve mechanical stability. Conversely, we expected that the finer particle size of ACA would enhance water retention and workability. The balanced pore structure of ACC was anticipated to enhance paste cohesion while maintaining flow integrity. Finally, we evaluated ACD, noted for its elevated mineral residue concentration, for its impact on setting time and fresh-state consistency. These distinctions facilitated our ability to forecast and analyze performance trends.

The ideal workability is achieved by carefully balancing these components. The AC is used to improve heat absorption properties and is visible as a black powder. The finished result created by combining these components is shown by the mortar block on the right. In order to assess their impact on the mechanical and physical performance of the mortar blocks which are often produced in standardized cuboid shapes designed for construction applications the study investigates different cement replacement levels with AC at 0%, 5%, 10%, 15%, and 20% as covered in the work of [20, 21].

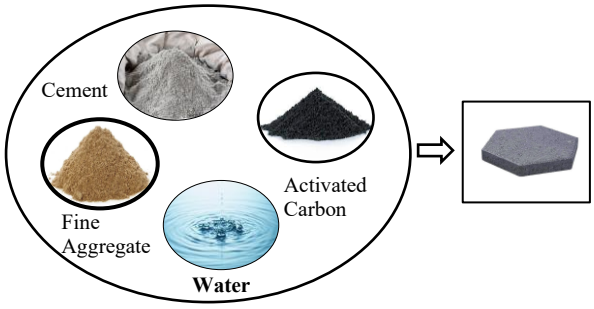

Fig. 1. Type of materials to used prepare the mortar

2.2 Synthesizing and characterization activated carbon from Coconut Shells

The preparation guidelines for four different kinds of AC samples ACA, ACB, ACC, and ACD all made from coconut shells are shown in the Table 1 and Figure 2. The physicochemical characteristics of the final AC are significantly influenced by the samples' varying chemical treatments and processing settings [22]. In particular, different quantities of hydrochloric acid (HCl) and sodium hydroxide (NaOH) were applied to the samples in relation to the volume of water used for activation. ACC received the greatest NaOH (24%) and HCl (10%) concentrations, indicating a more aggressive chemical activation step, possibly designed to improve pore formation and surface area. The lowest quantities of HCl (6%), and NaOH (10%), were found in ACA, indicating a gentler activation condition, as covered in the work of [23].

Based on prior optimization studies on carbonaceous and pozzolanic cement replacements, AC replacement levels of 5%, 10%, 15%, and 20% were chosen because levels below 5% have little effect on fresh and hardened properties, while levels above 20% often reduce workability and compressive strength due to cementitious phase dilution. The water-to-binder (W/B) ratio range of 0.50–0.65 is popular in mortar manufacture and complies with ASTM C109 norms, allowing the assessment of stiff to highly flowable mixes. This range also allows

© Mehran University of Engineering and Technology 2025

comparison with earlier research and keeps findings relevant to lab and construction studies. The samples are further distinguished in terms of preparation intensity by the drying and soaking times. We observed that ACC necessitated the lengthiest soaking and drying periods (24 hours each), in addition to the high chemical doses, suggesting that its construction sought to optimize activation efficiency. To balance activation strength and process efficiency, ACB, which had moderate chemical concentrations (15 percent NaOH and 8 percent HCl), also underwent extended drying (20 hours) and soaking (12 hours). However, although having a relatively high acid concentration (12%), ACD had the shortest drying (8 hours) and soaking (6 hours) times, which could lead to a less porous yet chemically functional surface [8]. The shells undergo pyrolysis, a thermal breakdown process carried out at 700°C in an inert atmosphere for two hours, after they have completely dried. The technique does not permit any gases to enter the furnace in order to preserve the inert atmosphere. This makes them appropriate for a variety of industrial or environmental applications [24, 25].

Table 1

Description of activated carbon derived from coconut shell

Sample ID	Amount of NaOH (to the volume of the water)	Amount of HCl (to the volume of the water)	drying procedure Hours	Soaked time Hours
ACA	10%	6%	12	8
ACB	15%	8%	20	12
ACC	24%	10%	24	24
ACD	13%	12%	8	6

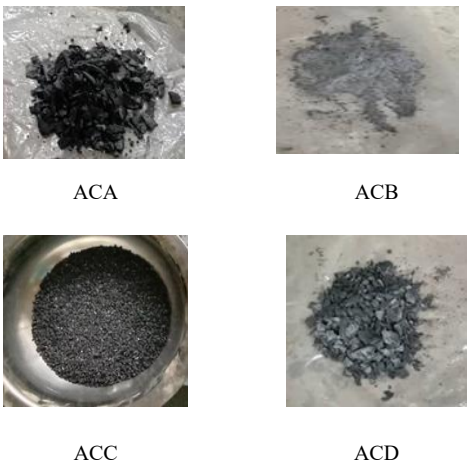

Fig. 2. Shown comparison of different activated carbon samples: ACA, ACB, ACC, and ACD.

2.2.1 Grinding and sieving

After synthesizing, the granular chunks of AC were produced which was further grinded to form the powder [26]. For this purpose, the ball mill Figure 3 machine has been used. About 700g of the AC were fed into the cell of the mill with 1kg steel balls of variable sizes [27, 28]. Over the course of five days, we ran the machine at regular intervals, rotating it for three hours and then resting for an hour. To make sure the AC powder was finely ground, we sieved it through a 75 µm sieve once the grinding operation was finished.

With the goal to simulate the ball mill grinding based on the Box-Bhenken design technique utilizing DX software, the d80 and the amount of 37 µm fraction in the product were defined as process responses. Ball mill solid content, grinding time, and ball size were chosen as model variables to enable accurate elemental analysis, as covered in the work of [29].

Fig. 3. AC material and grinding equipment

2.3 Result and discussion

2.3.1 X-Ray Fluoresces (XRF) Test

According to the XRF results, Table 2 shows the chemical composition of the AC samples (ACA, ACB, ACC, and ACD) in relation to Portland cement (PC). PC is mostly composed of CaO (68.16%), SiO_2 (20.54%), and Al_2O_3 (3.83%), and is necessary for hydration and strength development. However, the high proportions of K_2O (42.4%) and Fe_2O_3 (2.06–27.3%) in the AC samples suggest that these compounds possess alkali activated or pozzolanic properties. Mortar's mechanical properties and durability can be impacted by replacing cement with 5%, 10%, 15%, and 20% AC. At lower replacement levels (5%–10%), AC may enhance the pore structure and contribute to improved durability due to its wide surface area and potential adsorption properties. However, because of the increase in K_2O and Fe_2O_3 and the decrease in CaO concentration, higher replacement levels (15–20%) may alter the hydration process and change the workability and compressive strength. Through encouraging secondary hydration mechanisms, SiO_2 (6.39%) in ACC may enhance long-term strength gain. Test results can exceed parts per million ppm. as discussed in the work of [30, 31].

Table 2

Chemical Composition of NaOH-synthesized AC with Different ratios

© Mehran University of Engineering and Technology 2025

Oxide	ACA w%	ACB w%	ACC w%	ACD w%	BC w%
SiO_2	1.42	-	6.39	-	20.54
CaO	25	22.5	9.64	33.6	68.16
Fe_2O_3	27.3	8.15	2.06	-	0.149
Al_2O_3	0.481	-	3.34	-	3.38
MgO	-	-	29.2	-	1.67
K_2O	42.4	64.3	46.6	65.8	0.08
ZrO_2	0.667	0.549	2.27	0.658	0.002
SrO	.0174	0.594	0.0669	-	0.031
P_2O_5	0.580	0.406	-	-	0.11

For this study, we choose to use ACC (Activated Carbon from Coconut Shell) because of its beneficial oxide composition, which is in line with the performance goals for cementitious applications.

Reactive oxides like SiO_2 (6.39%) and AlO_3 (3.34%), which are both necessary for pozzolanic activity and help mortar gain strength, are present in balanced amounts in ACC. Additionally, its comparatively low FeO_3 level (2.06%) reduces the possibility of color change and unfavorable chemical interactions, while its moderate CaO content (9.64%) improves compatibility with cement hydration. Notably, ACC has a high K_2O content (46.6%), which could affect early strength increase and setting time. Because of these combined qualities, ACC is an effective and appropriate supplemental material for enhancing durability, mechanical qualities, and workability.

On the other hand, the compositional issues with ACA, ACB, and ACD limit their applicability in mortar. Both ACA and ACB have abnormally high K_2O levels (42.4% and 64.3%, respectively), which can impair cement matrix stability, raise the likelihood of efflorescence, and interfere with hydration. Additionally, ACA has an unusually high amount of FeO_3 (27.3%), which could cause coloring and possible chemical instability. ACD has a high CaO content (33.6%), but its pozzolanic potential is unknown due to a lack of information on reactive silicates and aluminates. Furthermore, essential oxides like SiO_2 and AlO_3 are absent in detectable quantities from ACB and ACD. Therefore, ACC provides the best balanced and dependable profile for improving cement performance, supporting its selection above the other variations, according to the thorough oxide analysis.

The increased Fe_2O_3 content in ACA may engage in hydration reactions through interactions with C_3S and C_2S phases, potentially affecting the kinetics of C–S–H formation and contributing to the development of ferrite phases, which may alter early-age strength characteristics[1,2] .

2.3.2 Scanning Electron Microscopy SEM test activated carbon

At 400x magnification, the SEM image in the Figure 4 shows the AC sample's porous structure. The material's high surface area and microporous characteristics are demonstrated by the apparent interconnected network of pores. Because they give fluid or gas molecules a way to enter and interact with the interior structure, these pores which come in a variety of sizes and shapes are essential for adsorption applications. Maintaining durability under mechanical or chemical stressors requires structural integrity, which is indicated by the well-defined pore walls. This microstructure plays a significant role in the effectiveness of AC in improving the adsorption and temperature regulation of composite materials, such concrete, permitting accurate elemental analysis, as covered in the work of [32, 33].

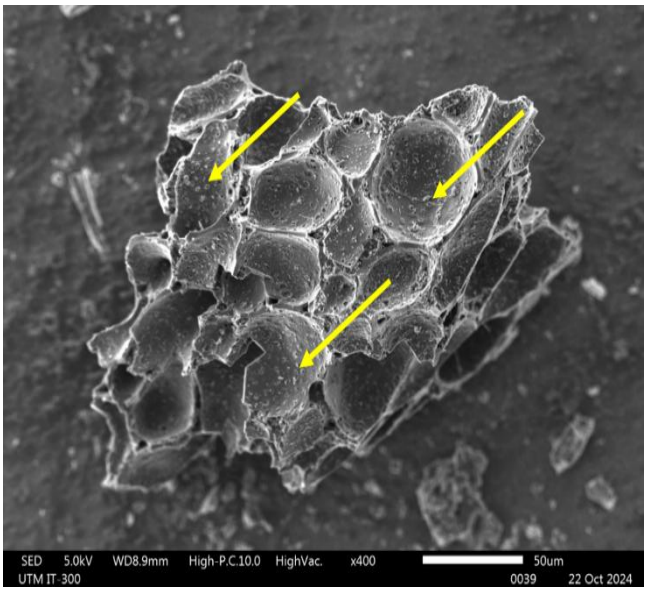

Fig. 4. Scanning electron microscopy SEM test AC

2.3.3 Brunauer-Emmett-Teller BET Test

The Table 3 provided the results of the BET study, AC made from coconut shells is extremely porous and suitable for adsorption applications. With a huge BET surface area of 1,016.38 m^2/g, the material shows a large quantity of surface area that is available for adsorption operations. The sample's strong microporosity is demonstrated by the t-Plot micropore volume, which is measured at 0.3216 cm^3/g. The material is classified as mesoporous based on the average pore widths of 2.4465 nm and 2.9676 nm obtained from the BJH adsorption and desorption investigations, respectively, and the overall average pore size of 2.70705 nm. Because of these characteristics, this AC is perfect for uses including gas storage, water purification, and thermal regulation in composite materials that call for high adsorption efficiency, enabling exact elemental analysis, as covered in the work of [34, 35].

Table 3

Brunauer-Emmett-Teller BET Test

© Mehran University of Engineering and Technology 2025

Sample	Activated carbon coconut shell	Unit	Value
Surface Area	BET Surface Area	m^2/g	1,016.38
Pore Volume	t-Plot micropore volume	cm^3/g	0.321637
Pore Size	BJH Adsorption average pore width (4V/A)	nm	2.4465
	BJH Desorption average pore width (4V/A)	nm	2.9676
	average pore size	nm	2.70705

2.3.4 Particle size analysis PSA of AC and cement

The Figure 5 shows the fraction of finer particles against particle diameter, the PSA graph contrasts the particle distributions of cement and AC. In contrast to cement, AC has curve moves to the left, suggesting that the former has a finer particle size distribution. This implies that when used as a partial cement substitute, AC particles may affect the overall workability, setting time, and strength development of mortar because they are typically smaller and more evenly distributed than cement particles, permitting accurate elemental analysis, as covered in the work of [36-38].

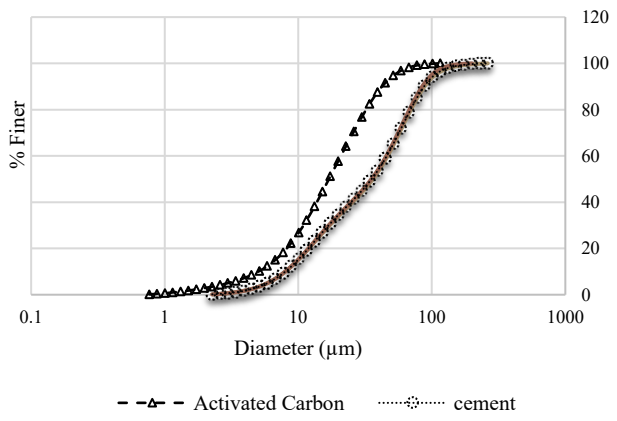

Fig. 5. Particule size analysis for cement & AC

2.3.5 Grain size distribution of fine aggregate

The Fineness Modulus (FM) of the fine aggregate is 3.43, indicating its coarseness. The cumulative percentages retained are used to calculate the fine aggregate's average particle size, a higher FM denotes a coarser material. This Table 4 Granular gradient of fine aggregate might be improved by Figure 6 Grain size distribution of fine aggregate, which visually represents the grain size distribution and illustrates how particle size varies within the fine aggregate sample.

Table 4

Granular gradient of fine aggregate

Sieve Size (mm)	Weight of Material Retained [39]	% of Material Retained	Cumulative % of Material Retained	% Finer
4.75	77.5	7.67	7.67	92.33
2.36	219.5	21.73	29.41	70.59
1.18	208	20.59	50.00	50.00
0.6	210	20.79	70.79	29.21
0.3	214.5	21.24	92.03	7.97
0.15	10	0.99	93.02	6.98
Pan	70.5	6.98	100.00	0.00
Total	1010			
Fineness Moduls (FM)			3.43	

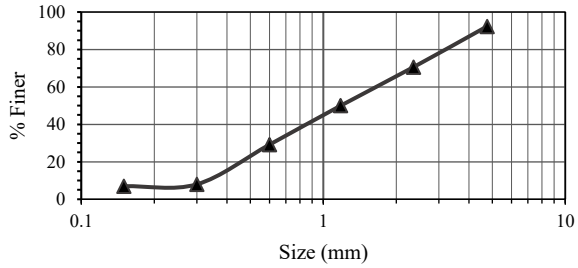

Fig. 6. Grain size distribution of fine aggregate

In Figure 7, we illustrated the process of grain size distribution for the fine aggregate using a series of photos. Every stage, from sifting to weighing, corresponds to figuring out the total proportion of particles smaller than each sieve size. Particle size (mm) is plotted on a logarithmic x-axis, while cumulative % finer is plotted on the y-axis in the accompanying graph of grain size distribution of fine aggregate. A tiny quantity of extremely fine particles (<0.1 mm) are shown by the curve's beginning close to the origin. The cumulative percentage steadily increases with particle size, demonstrating consistent grading. Around 50% of the particles pass through the sieve at 1 mm, whilst almost all of the particles have done so by 10 mm, indicating a well graded distribution and enhancing the quality of the mix as a whole, as discussed in the work [40, 41].

A B C D E

Fig. 7. Processing of Grain size distribution of fine aggregate

2.4 Workability test of mortar samples and statistical Analysis

© Mehran University of Engineering and Technology 2025

The flow table test is used to assess the workability of the mortar after it has been mixed. On the flow table, the mortar is poured into a conical mold, making sure to fill it in layers and gently compact it to eliminate any air spaces. Once the mold is filled, it is lifted off, allowing the mortar to spread out on the flow table. The diameter of the spread is then measured to determine the flowability, which indicates the mortar's consistency and suitability for use in construction. As Figure 8, the table is lifted and lowered 25 times in 15 seconds after the mold has been removed. This process allows the mortar to flow uniformly across the surface of the table, providing a clear indication of its workability. The diameter of the spread is then measured to evaluate the consistency and quality of the mortar mix. The measured diameter is compared to established standards to determine if the mortar meets the necessary specifications for construction use. This assessment is crucial for ensuring that the mortar will perform effectively in its intended application, providing both strength and durability. In addition, workability critically determines the strength of mortar by enabling adequate mixing, placing, and compaction. By reducing permeability and voids, it also improves durability. Therefore, enhancing workability especially with supplementary materials AC modification is critical to preserve structural integrity and long-term performance. Two perpendicular measurements of the spread diameter are made, and the average is noted as the flow value. For every blend with different W/B ratios and additive percentages, this procedure is repeated.

Table 5

Proportion materials of workability test of mortar

Activated Carbon Replacement (%)	Cement (g)	Fine Aggregat (g)	Activated Carbon (g)	W/B			
				0.5	0.55	0.6	0.65
				Water (g)			
0%	1630	2258	0.00	815	897	978	1060
5	1549	2258	82	815	897	978	1060
10	1467	2258	163	815	897	978	1060
15	1386	2258	245	815	897	978	1060
20	1305	2258	326	815	897	978	1060
Total	7337	11288	815	4,076	4,484	4,891	5,299

The results indicate that increasing the water ratio can enhance the workability to a certain extent, but excessive amounts may lead to a decrease in strength. Similarly, variations in AC content also play a crucial role, as higher concentrations tend to improve the material's properties, yet may compromise its consistency if not balanced properly. As demonstrated in Table 5, these insights help optimize the mix design for specific applications where workability and performance are critical, enabling accurate elemental analysis as covered in the work of [8, 42].

Fig. 8. Shows process workability test of mortar (A, B, C, D, E and F)

To determine how AC concentration and W/B ratio affected critical qualities, we ran an ANOVA. There was a substantial relationship between the W/B ratio and compressive strength ($p = 0.0017$) and workability ($p < 0.001$), as well as a significant relationship between the AC content and water absorption ($p = 0.0036$).

2.4.1 Workability analysis of mortar

Figure 8 illustrates the flowability of mortar at various water-to-binder (W/B) ratios, specifically 0.50, 0.55, 0.60, and 0.65. In contrast, Figure 9 depicts the flowability corresponding to different percentages of content (AC) replacement. Increasing the W/B ratio results in a modest enhancement of flow, indicating that elevated water content improves workability. This percentage has been established as discussed in the work of [43] .The differences observed between the control sample (0% AC) and those with 5%, 10%, 15%, and 20% AC are minimal, suggesting that the incorporation of AC does not significantly alter mortar consistency within the tested ranges. The results for all W/B ratios are consistent, indicating stable workability characteristics with the incorporation of AC as a partial cement replacement. The control sample (C) and the samples with 5%, 10%, 15%, and 20% AC replacements, however, differ very little, indicating that adding AC does not substantially

© Mehran University of Engineering and Technology 2025

change the mortar's flow properties. Furthermore, the results stay within a small range for all W/B ratios, suggesting that AC has little effect on the mixture's consistency. The overlapping data points indicate that the effect of varying percentages of AC is rather consistent, suggesting that the replacement amounts employed in this experiment keep mortar workability within reasonable bounds. However, Components Workability is greatly impacted by the kind and quantity of aggregates used, such as crumb rubber and palm shell ash. For example, because crumb rubber absorbs water, ECC mortars containing it had less flow ability than regular ECC mortars [5, 44]. The flow measurements for various AC replacement levels exhibited considerable overlap; however, two-factor ANOVA without replication indicated that both AC content ($p = 0.0054$) and W/B ratio ($p = 0.0017$) significantly affected workability. The observed effects were minimal, suggesting that although slight variations occurred among mixtures, the overall workability remained acceptable across all replacement levels and water-to-binder ratios. This finding supports the observation that the incorporation of AC, even at elevated replacement levels, preserves acceptable fresh-state properties while facilitating potential sustainability advantages by decreasing cement consumption.

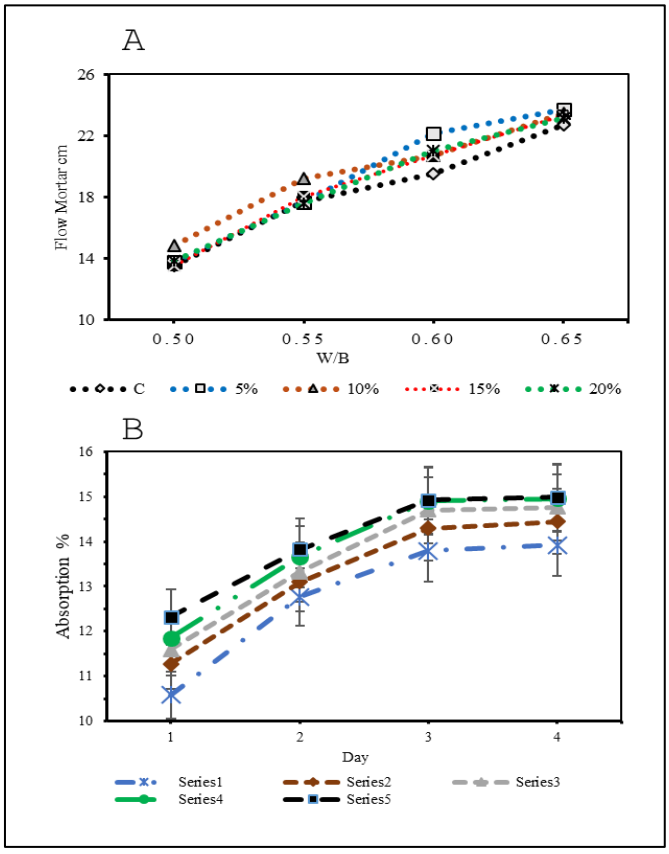

Fig. 9. Results workability test of mortar (A) and absorption/ water retention test (B) of the samples.

The activated carbon (ACC) sample had a porosity of 2.71 nm, a high surface area of 1,016.38 m²/g, and was dominated by K_2O (46.6%), MgO (29.2%), and CaO (9.64%), with minimal SiO_2, Fe_2O_3, Al_2O_3, and negligible. Higher ACC replacement levels improved workability at W/B ratios 0.50 – 0.65. With increasing W/B ratio, flow climbed from 13.54 to 22.74 at 0% ACC, whereas workability improved with ACC contents (5 – 20%), culminating at 23.7 at 5% ACC and 0.65 W/B. ACC improved paste fluidity without impacting consistency due to its tiny particle size and large. The main findings have been summarized in Table 6.

Table 6

Summary of Properties of Activated Carbon (ACC) and Workability at Varying W/B Ratios

Samples	Porosity	Surface	Oxides Content		ACC	Workability W/B			
						0.50	0.55	0.60	0.65
Activated carbon (ACC)	2.705 nm	1,016.38 m²/g	SiO_2	6.39	0%	13.54	17.72	19.52	22.74
			CaO	9.64					
			Fe_2O_3	2.06	5%	13.80	17.66	22.16	23.7
			Al_2O_3	3.34	10 %	14.84	19.2	20.7	23.48
			MgO	29.2	15 %	13.6	18	20.7	23.33
			K_2O	46.6					
			ZrO_2	2.27	20 %	13.86	17.6	21.02	23.16
			SrO	0.067					

3. Compression strength of mortar cubes with different W/B ratio

The Figure 10 depicting the results of the 28-day compressive strength test shows a distinct interaction between the W/B and the proportion of cement replaced with AC. Compressive strengths of the control mix and mixes with 5–10% AC reached up to 38 MPa at lower W/B ratios (0.5 to 0.55), indicating that limited AC incorporation can preserve structural performance on par with conventional mortar. But as the W/B ratio reached 0.65, we saw a little drop in compressive strength across the board for all blends; this lines up with the improved flowability we saw in the workability testing. This balance draws attention to a significant study innovation: mild AC replacement up to 10% can improve sustainability by using less cement while maintaining proper workability and strength performance. These results support AC's viability as a partial cement alternative that offers environmental advantages without sacrificing crucial engineering qualities.

© Mehran University of Engineering and Technology 2025

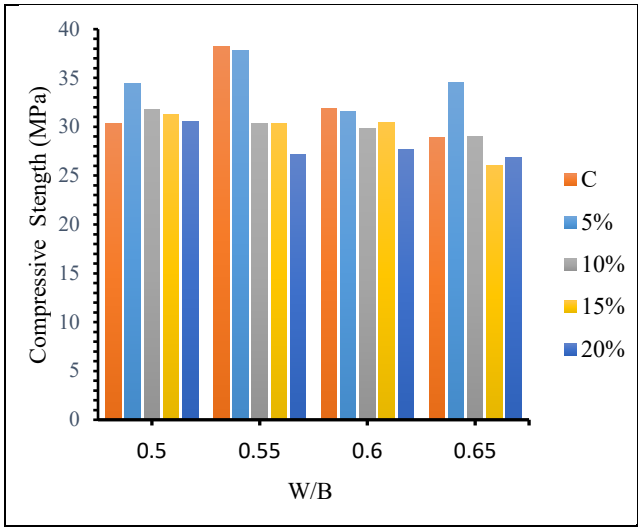

Fig.10. Compression test of mortar at 28 days for various W/B ratio

4. Conclusion

This study demonstrated the viability of utilizing activated carbon (AC) derived from coconut shells as a partial substitute for cement in mortar applications. The study aimed to develop sustainable and high-performing construction materials by integrating chemical and physical characterization with the evaluation of fresh-state properties. Replacement levels of AC at 5%, 10%, 15%, and 20% were evaluated in conjunction with W/B ratios of 0.50, 0.55, 0.60, and 0.65, facilitating the analysis of the effects of material composition and mix proportions. Analytical results indicate that AC exhibits a finer and more uniform particle dispersion compared to cement, a characteristic that may improve hydration kinetics. XRF analysis revealed compositional variations, particularly in Fe_2O_3 content, which may influence silicate phase hydration and early strength development. Flow testing indicated a steady enhancement in workability corresponding to an increase in the water-to-binder ratio, yielding improvements of about 22 – 26%. Conversely, the proportion of aggregate replacement exhibited minimal influence on mix consistency within the examined parameters. These findings indicate that AC can be integrated into mortar without affecting fresh-state performance and may offer microstructural and chemical advantages.

The study demonstrates that converting waste biomass into a functional cement substitute can effectively reduce clinker demand and lower CO_2 emissions, while providing a sustainable method for producing durable, environmentally friendly mortar. The findings endorse the incorporation of AC into mortar production as a viable measure for attaining sustainability goals within the construction industry, applicable to both structural and non-structural components under comparable conditions to those evaluated. Under the examined conditions, the performance in the fresh state was preserved, while also presenting opportunities for decreased cement consumption, reduced CO_2 emissions, and the promotion of sustainable construction practices.

5. References

[1] E. Paul, "Influence of superplasticizer on workability and strength of ambient cured alkali activated mortar," *Cleaner Materials,* vol. 6, p. 100152, 2022.

[2] A. M. Zeyad, "Sustainable concrete Production: Incorporating recycled wastewater as a green building material," *Construction and Building Materials,* vol. 407, p. 133522, 2023.

[3] P. V. Mane, R. M. Rego, P. L. Yap, D. Losic, and M. D. Kurkuri, "Unveiling cutting-edge advances in high surface area porous materials for the efficient removal of toxic metal ions from water," *Progress in Materials Science,* p. 101314, 2024.

[4] Z. Pan, M. Tan, G. Zheng, L. Wei, Z. Tao, and Y. Hao, "Effect of silica fume type on rheology and compressive strength of geopolymer mortar," *Construction and Building Materials,* vol. 430, p. 136488, 2024.

[5] A. Lubis, M. Aswin, and G. C. R. Hasibuan, "WORKABILITY INVESTIGATION ON THE FRESH MIX OF ECC MORTAR AND CRUMB RUBBER (CR)-ECC BASED ON VARIATIONS OF PALM SHELL ASH, RIVER SAND, AND CEMENT," *Journal of Syntax Literate,* vol. 9, no. 5, 2024.

[6] S. Mehmood and F. Butt, "Effect of steel fibers on heat of hydration and mechanical properties of concrete containing Fly Ash," *Mehran University Research Journal of Engineering & Technology,* vol. 38, no. 1, pp. 83-94, 2019.

[7] G. Jia, Y. Wang, and F. Yang, "A review on the application of circulating fluidized bed fly ash in building materials," *Advances in Materials Science and Engineering,* vol. 2022, no. 1, p. 7099430, 2022.

[8] A. Aspiazu-Méndez, N. A. Cisneros-Cárdenas, C. Pérez-Rábago, A. M. Pat-Espadas, F. Manzini-Poli, and C. A. Estrada, "Analysis of the solar pyrolysis of a walnut shell: insights into the thermal behavior of biomaterials," *Energies,* vol. 17, no. 6, p. 1435, 2024.

[9] S. Zhang, X. Qi, S. Guo, L. Zhang, and J. Ren, "A systematic research on foamed concrete: The effects of foam content, fly ash, slag, silica fume and water-to-binder ratio," *Construction and Building Materials,* vol. 339, p. 127683, 2022.

[10] J. Xi *et al.*, "Role of silica fume on hydration and strength development of ultra-high

© Mehran University of Engineering and Technology 2025

performance concrete," *Construction and Building Materials,* vol. 338, p. 127600, 2022.
[11] S. Zhuang, Q. Wang, and M. Zhang, "Water absorption behaviour of concrete: Novel experimental findings and model characterization," *Journal of Building Engineering,* vol. 53, p. 104602, 2022.
[12] S. Ali, M. O. R. Siddiqui, and H. Ali, "Performance evaluation of flexible pavement using polyethylene terephthalate (PET)," *Mehran University Research Journal Of Engineering & Technology,* vol. 43, no. 3, pp. 126-135, 2024.
[13] H. Wu *et al.*, "Effects of binder component and curing regime on compressive strength, capillary water absorption, shrinkage and pore structure of geopolymer mortars," *Construction and Building Materials,* vol. 442, p. 137707, 2024.
[14] M. A. Khan, A. Javed, and M. A. Choudhry, "Strength comparison of accelerated cured and normal cured fly-ash based concrete," *Mehran University Research Journal of Engineering & Technology,* vol. 39, no. 1, pp. 21-30, 2020.
[15] T. O. Ofwa, "Evaluating Superplasticizer Compatibility With Portland Pozzolana Cement CEM II/BP in Production of High Performance Concrete," University of Nairobi, 2022.
[16] O. Heinz and H. Heinz, "Cement interfaces: Current understanding, challenges, and opportunities," *Langmuir,* vol. 37, no. 21, pp. 6347-6356, 2021.
[17] N. Bazregar, Z. Garkani-Nejad, S. Maghsoudi, and M. Amiri, "Investigating the performance of silica fume as a supplementary cementitious material in the production of pozzolanic cement with the aim of achieving the maximum compressive strength," *Asian Journal of Civil Engineering,* vol. 25, no. 4, pp. 3747-3761, 2024.
[18] N. A. Jokhio, B. A. Memon, S. A. Mallah, M. Oad, M. A. Memon, and R. Bhanbhro, "Workability and strength of recycled aggregate concrete reinforced with nylon fibers," *Mehran University Research Journal Of Engineering & Technology,* vol. 43, no. 2, pp. 34-45, 2024.
[19] J. F. Gonzalez-Sanchez, B. Taşcı, J. Fernández, I. Navarro-Blasco, and J. Alvarez, "Improvement of the depolluting and self-cleaning abilities of air lime mortars with dispersing admixtures," *Journal of Cleaner Production,* vol. 292, p. 126069, 2021.
[20] M. A. Keerio, S. A. Abbasi, A. Kumar, N. Bheel, K. u. Rehaman, and M. Tashfeen, "Effect of silica fume as cementitious material and waste glass as fine aggregate replacement constituent on selected properties of concrete," *Silicon,* vol. 14, no. 1, pp. 165-176, 2022.
[21] E. El-Seidy, M. Chougan, Y. A. Al-Noaimat, M. J. Al-Kheetan, and S. H. Ghaffar, "The impact of waste brick and geo-cement aggregates as sand replacement on the mechanical and durability properties of alkali–activated mortar composites," *Results in Engineering,* vol. 21, p. 101797, 2024.
[22] P. Borisut, C. Tangsathitkulchai, and A. Nuchitprasittichai, "Dynamic of CO2 adsorption in a fixed bed of microporous and mesoporous activated carbon impregnated with sodium hydroxide and the application of response surface methodology (RSM) for determining optimal adsorption conditions," *Environmental Science and Pollution Research,* vol. 31, no. 9, pp. 13833-13855, 2024.
[23] Y. K. Verma, A. K. Singh, S. K. Singh, S. Dutta, and M. Paswan, "Comprehensive analysis of enhanced thermal and mechanical properties in vacuum pressure impregnated (VPI) treated Chimono bamboo fibers through surface treatment with sodium hydroxide and graphene oxide: in-depth characterization and insights into the performance of graphene oxide-based natural hybrid composites," *Journal of Wood Chemistry and Technology,* pp. 1-20, 2025.
[24] J. O. Ighalo *et al.*, "Biochar from coconut residues: an overview of production, properties, and applications," *Industrial Crops and Products,* vol. 204, p. 117300, 2023.
[25] J. Fu *et al.*, "Effects of temperature, oxygen and steam on pore structure characteristics of coconut husk activated carbon powders prepared by one-step rapid pyrolysis activation process," *Bioresource technology,* vol. 310, p. 123413, 2020.
[26] A. A. Jhatial, "Thermomechanical evaluation of sustainable foamed concrete incorporating palm oil fuel ash and eggshell powder," *Journal of Engineering Research,* vol. 9, no. 3A, 2021.
[27] s. shahidan, s. mangi, m. s. senin, s. mohd zuki, and m. wan ibrahim, "Characterization of tyre rubber ash and crumb as fine aggregate resource," *Journal of Engineering Science and Technology,* vol. 16, no. 1, pp. 510-526, 2021.
[28] E. Partlan *et al.*, "Effect of bead milling on chemical and physical characteristics of activated carbons pulverized to superfine sizes," *Water research,* vol. 89, pp. 161-170, 2016.
[29] A. Ebadnejad, H. Dehghani, M. Hadizadeh, K. Ghorbani, and M. Sanaie, "Optimisation of the size distribution of ball mill product by modelling grinding variables using DX8 software," *Mineral Processing and Extractive Metallurgy,* vol. 130, no. 1, pp. 42-49, 2021.

© Mehran University of Engineering and Technology 2025

[30] M. F. González, N. Saadatkhah, and G. S. Patience, "Experimental methods in chemical engineering: X-ray fluorescence—XRF," *The Canadian Journal of Chemical Engineering,* vol. 102, no. 6, pp. 2004-2018, 2024.

[31] M. Bhatia *et al.*, "Portable X-ray fluorescence as a rapid determination tool to detect parts per million levels of Ni, Zn, As, Se, and Pb in human toenails: a South India case study," *Environmental Science & Technology,* vol. 55, no. 19, pp. 13113-13121, 2021.

[32] P. Muthuswamy, "Influence of powder characteristics on properties of parts manufactured by metal additive manufacturing," *Lasers in Manufacturing and Materials Processing,* vol. 9, no. 3, pp. 312-337, 2022.

[33] S. H. Abro, "Effect of Niobium and Titanium addition on formation of second phase particles in CHQ steel using transmission electron microscope," *Mehran University Research Journal Of Engineering & Technology,* vol. 40, no. 1, pp. 31-37, 2021.

[34] N. Heinemann *et al.*, "Enabling large-scale hydrogen storage in porous media–the scientific challenges," *Energy & Environmental Science,* vol. 14, no. 2, pp. 853-864, 2021.

[35] Q. Khan, U. Imran, J. L. Ullman, and W. A. Khokhar, "Turbidity removal through the application of powdered azadirachta indica (neem) seeds," *Mehran University Research Journal of Engineering and Technology,* vol. 42, no. 1, pp. 1-8, 2023.

[36] K. Nwachukwu, N. Mmonwuba, and E. Ogunjiofor, "Compressive Strength Investigation of PSA–MSA-Cement Concrete [PMCC] Using Kings-Scheffe's (6, 2) Model," 2025.

[37] A. A. Aghajari *et al.*, "Effect of multi-walled carbon nanotube/Porous Carbon/SiO2 on reinforcing of cement mortar matrix: Modeling studies of effective parameters," *Journal of Building Engineering,* vol. 78, p. 107758, 2023.

[38] W. Mahmood, A. Mohammed, K. Ghafor, and W. Sarwar, "Model technics to predict the impact of the particle size distribution (PSD) of the sand on the mechanical properties of the cement mortar modified with fly ash," *Iranian Journal of Science and Technology, Transactions of Civil Engineering,* vol. 45, pp. 1657-1684, 2021.

[39] S. Na, S. Lee, and S. Youn, "Experiment on activated carbon manufactured from waste coffee grounds on the compressive strength of cement mortars," *Symmetry,* vol. 13, no. 4, p. 619, 2021.

[40] B. Li, S. Hou, Z. Duan, L. Li, and W. Guo, "Rheological behavior and compressive strength of concrete made with recycled fine aggregate of different size range," *Construction and Building Materials,* vol. 268, p. 121172, 2021.

[41] M. Shahpari, P. Bamonte, and S. J. Mosallam, "An experimental study on mechanical and thermal properties of structural lightweight concrete using carbon nanotubes (CNTs) and LECA aggregates after exposure to elevated temperature," *Construction and Building Materials,* vol. 346, p. 128376, 2022.

[42] M. N. Azhar, L. A. Qureshi, and M. U. Rashid, "Investigating the strength and durability properties of one-way slabs incorporating marble dust as cement replacement material," *Mehran University Research Journal Of Engineering & Technology,* vol. 40, no. 4, pp. 775-792, 2021.

[43] J. Chen, P. L. Ng, A. Kwan, and L. Li, "Lowering cement content in mortar by adding superfine zeolite as cement replacement and optimizing mixture proportions," *Journal of Cleaner Production,* vol. 210, pp. 66-76, 2019.

[44] M. Aziminezhad, E. Mohamedelhassan, and M. Mahdikhani, "Multi-property response and optimisation of lightweight self-consolidating mortar containing silica fume and nano silica," *European Journal of Environmental and Civil Engineering,* vol. 28, no. 5, pp. 1163-1182, 2024.

© Mehran University of Engineering and Technology 2025