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Effects of Coal Ash and Walnut Shell on the Impact Resistance and Mechanical Properties of Eco-Efficient Self-Compacting Concrete

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ABSTRACT

This study investigated the effects of incorporating up to 20% coal ash (CA) by weight and 25% walnut shell (WS) by volume of coarse aggregate on the fresh and hardened properties of self-compacting concrete (SCC). A total of 12 SCC mixtures were designed, divided into two groups, with a constant water-to-binder (w/b) ratio of 0.309 and a total binder content of 550 kg/m³. In the first and second groups, cement was replaced with 10% and 20% CA by weight, respectively. Mixtures in both groups utilized WS as a partial replacement for coarse aggregate at ratios ranging from 0% to 25% in 5% increments by volume. The results indicated that increasing CA and WS content adversely impacted the fresh properties of SCC, though the mixtures still met the necessary requirements. The slump flow diameter decreased by up to 13%, while the time to reach 50% flow (T50) increased. A notable reduction in the H2/H1 ratio was observed as WS content increased. Additionally, the segregation ratio experienced a 75% increase. A decline in compressive strength was recorded at a 25% WS replacement level, amounting to 29.2% and 17.6% for 10% and 20% CA mixtures, respectively. However, 20% CA mixtures exhibited higher compressive strength than 10% CA mixtures at the same WS replacement level, with a 21.7% increase observed at 25% WS substitution. Flexural strength exhibited similar trends. With increasing WS content for the same CA replacement level, the first fracture impact energy was found to decrease. The first crack impact energy results remained unaffected by CA replacement levels. Failure impact energy demonstrated analogous outcomes.

1. INTRODUCTION

Self-compacting concrete (SCC) is a specialized type of concrete that offers complete form filling due to its high flowability, even in the presence of limited reinforcement spacing. Cohesiveness is critical for the flowability of fresh SCC [1, 2]. The cost of SCC usage can be reduced by incorporating mineral admixtures, which can often improve workability and slump of concrete mixes. It has been observed that when fly ash (FA) is used as a partial cement replacement, it enhances the properties of concrete and reduces the need for chemical admixtures to control viscosity levels [3]. Furthermore, these admixtures can be used to decrease cement consumption and carbon dioxide emissions, thus mitigating global warming [4].

Agricultural waste disposal through burning or landfill techniques can be detrimental to the environment. A more sustainable approach would involve using these waste products to create new materials for manufacturing other products. For instance, these waste products can be used to produce building materials, such as concrete. Numerous studies have investigated the effects of using such materials as partial replacements for cement or aggregates in concrete, focusing on properties like density, porosity, workability, and durability, in addition to strength [5].

Walnuts are commonly used in sweets and supplementary foods in cities across Iraq. Depending on their size, walnut shells (WS) make up 43% to 65% of a walnut's total weight and require a significant amount of land for disposal. A safe method of disposing of WS waste is to use it in the production of industrial materials, such as construction materials. Researchers have explored the effects of using various agricultural wastes in cement and concrete [6]. Globally, there is a focus on reducing the self-weight of structures. One effective way to achieve this is by using lighter ingredients in concrete compositions, especially by replacing aggregate types with lighter alternatives. Many waste materials can be recycled and used as aggregate. The authors have previously examined the recycling of waste materials as aggregate and powder replacements for cement in SCC [7-11].

Some studies have investigated the use of WS and coconut shells in concrete production, examining their influence on fresh and hardened properties [12, 13]. Adebakin et al. [12] studied the fresh properties of self-compacting lightweight concrete (SCLWC) made with various amounts of cement combined with fly ash (0% to 25% by weight) and coconut shell as coarse aggregate, maintaining constant w/b and superplasticizer ratios of 0.33 and 1.75% by weight of the binder, respectively. According to their findings, the SCLWC with fly ash and coconut shell aggregate met the requirements for viscosity, flowability, and passing ability. Fly ash ratios of 15% and 20% yielded the most favorable results. Moreover, Hilal et al. [14] used WS as a replacement for gravel in SCC production. Their findings indicated that the mechanical properties of SCC decreased due to WS usage. They recommended using 35% to 50% WS to create lightweight SCC. In another study by Hilal et al. [5], WS was used as a substitute for both gravel and sand in concrete. They examined compressive, flexural, and splitting strengths, absorption ratio, and dry density across three groups: the first group replaced sand with WS, the second replaced gravel with WS, and the third replaced both sand and gravel with WS. The third group exhibited the best overall properties, with the optimal WS ratio being 15%. Cheng et al. [15] produced lightweight wet-mix shotcrete (LWMS) by substituting WS for conventional coarse aggregate. To enhance the properties of LWMS, polypropylene (PP) and polyethylene terephthalate (PET) fibers were added. Increasing WS content led to a significant reduction in compressive and splitting strengths and a decrease in slump and pressure drop. Furthermore, fiber addition reduced the slump and flowability of fresh LWMS, decreased compressive strength, and increased splitting tensile strength and shootability, as evidenced by reduced rebound amounts.

Husain et al. [16] investigated the use of powdered walnut shells (WSP) as a substitute for fine aggregate in concrete production at three different levels: 10%, 20%, and 30%. With higher WSP content, a slight reduction in compressive strength was observed, with the best results obtained at 20% WSP content. At 28 days, the maximum compressive strength of 29.3 MPa was achieved for concrete specimens fully cured in water and manufactured using WSP, meeting the requirements for lightweight structural concrete. Kamal et al. [17] suggested that WS could be used as a substitute for fine aggregate up to 30% with a w/c ratio of 0.38. Their results demonstrated no significant difference in the compressive strength of concrete, indicating that WS could be used in concrete production due to its structural and environmental advantages.

From the literature review, it is apparent that few studies have investigated the recycling of WS in concrete production, particularly the combined use of coal ash and WS in SCC. Therefore, the present experimental investigation aims to examine the influence of coal ash up to 20% as a cement replacement and WS as a partial replacement for coarse aggregate up to 25% on the impact resistance, impact energy, fresh, and hardened properties of SCC.

2. MATERIALS

2.1 Cement

This investigation utilised Type I Ordinary Portland Cement (OPC) that complied with Iraqi standards IQS No.5/1984 [18]—chemical and physical properties presented in Table 1.

2.2 Coarse aggregate

Natural coarse crushed aggregate with a nominal size of 9.5 mm and a specific gravity of 2.66 satisfies IQS No.45 1984 [19]. The physical characteristics are listed in Table 2.

Table 1. The chemical compositions and physical properties associated with the OPC are investigated in this work

Oxide Composition		Content (%)	Iraqi Standard No. 5/1984 Limits
Fe_2O_3		3.8	---
SO_3		2.6	2.8% Max.
MgO		2.8	5% Max.
Al_2O_3		4.5	---
SiO_2		20.4	---
CaO		62.6	---
Insoluble residue		0.32	1.5% Max.
Loss on ignition		2.8	4% Max.
C_3A		5.1	---
C_3S		56.6	---
C_2S		15.4	---
LSF		0.92	---
AM		1.16	---
SM		2.44	---
Physical Properties			
Initial Setting (min)		186	≥ 45
Final Setting (min)		308	≤ 600
Fineness (m^2/kg)		354	≥ 230
Compressive Strength (MPa)	3 Days	19	≥ 15
	7 Days	28	≥ 23

Table 2. The gravel's physical characteristics were investigated in this experimental study

Sieve Size (mm)	Passing %	Limits of IQS No. 45
12.50	100.00	100
9.50	99.08	85 to 100
4.75	1.25	0.25
2.36	0.00	0 to 5
Deleterious Substance		
SO_3 (%)	0.048	≤ 0.1
≤ 0.075 mm	1.300	≤ 3.0

2.3 Sand

Sand having a specific gravity of 2.65 was shipped from the AL-Habnya area for use in this investigation. There is a 2.96 fineness modulus. As shown in Table 3, the physical characteristics and grading of used sand were carried out in accordance with IQS No. 45/1984 [19].

Table 3. Physical properties and grading of utilized sand

Sieve Size	Passing %	Limits of IQS No.45/1984
4.75	99.67	90-100
2.36	87.24	75-100
1.18	67.89	55-90
0.6	39.98	35-55
0.3	9.59	8-30
0.15	1.00	0-10
Deleterious Substance		
SO_3 (%)	0.031	≤ 0.1
≤ 0.075 mm	1.400	≤ 3.0

2.4. Superplasticizer (SP)

Superplasticizer utilized for SCC is Sika® ViscoCrete®-5930 L IQ. The properties of SP are listed in Table 4. Many trial mixes were performed to obtain the optimum dosage [20].

Table 4. Properties Sika® ViscoCrete®-5930 L IQ superplasticizer

Technical Data	Results
Form	Viscous liquid
Colour	Brownish liquid
Specific gravity	1.085 ± 0.01 g/cm^3
pH	4 to 6

2.5 Coal ash (CA)

As a supplementary cementitious ingredient, CA was employed to replace cement partially. The chemical composition of CA is revealed in Table 5. Figures 1 and 2 demonstrate SEM image analysis and XRD of CA. The CA powder was sieved through a sieve measuring 75 μm after being collected from several restaurants.

Table 5. Chemical compositions of CA

Chemical Analysis (%)	CA
SiO_2	2.098
CaO	31.29
Fe_2O_3	0.807
Al_2O_3	0.159
MgO	4.37
SO_3	5.454
K_2O	4.77
Na_2O	-
P_2O_5	2.406

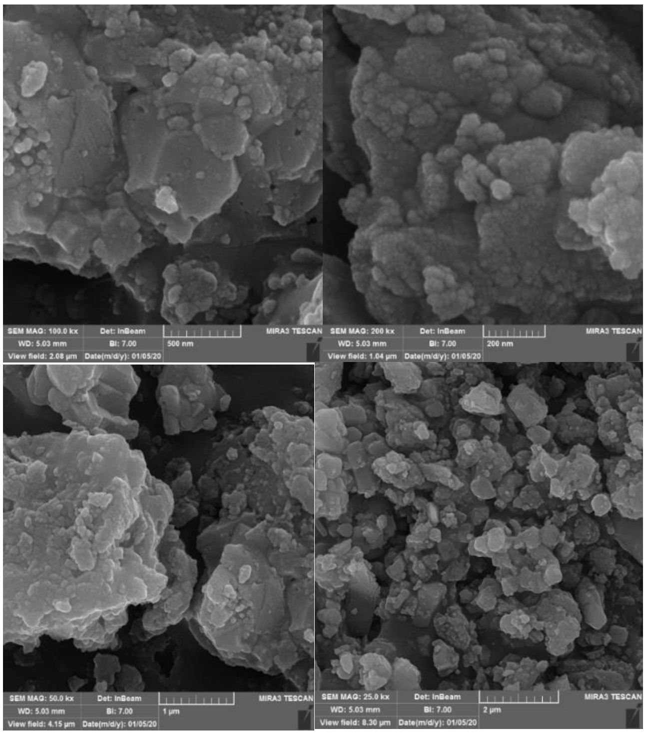

Figure 1. Scan electron microscope (SEM) of CA

2.6 Walnut shells

The waste from consumed walnuts at the Anbar government was collected, along with the WS. The WS particles were washed with water, and after drying for at least a week in the sun, they were permitted to dry. The dried SW particles had been sieved, and their grading matched the coarse aggregate employed in this investigation (Figure 3).

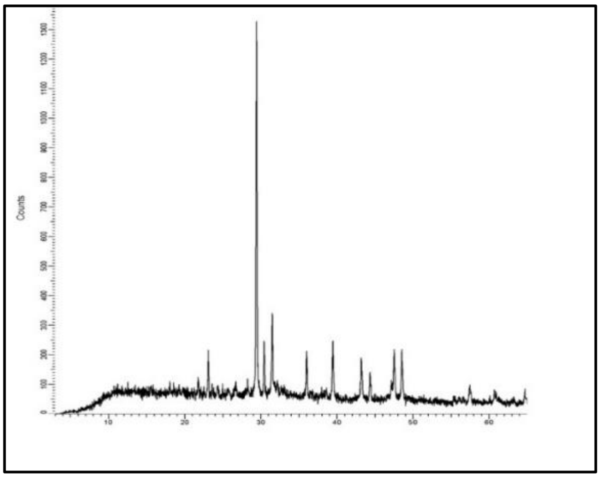

Figure 2. X-ray diffraction (XRD) of CA

Figure 3. A walnut shell was used in this work

3. MIX PROPORTIONS AND TESTING PROCEDURE

3.1 Mix proportions

For estimating the performance of SCC, an overall number of 12 SCC mixes divided into two groups were intended with a constant (w/b) ratio of 0.309 and total binder content of 550 kg/m^3. In the first group, the cement was replaced by 10% CA; in the second group, the replacement level was 20% by weight. Each group containing a reference mix was produced using 100% coarse aggregate without SW. Then, other blends were prepared with 5 to 25% of an SW to replace coarse aggregate by volume partially. The mixture proportions of SCC are shown in Table 6.

After mixing, the fresh concrete was discharged into the moulds and compacted by a vibrating table. Then, the moulds were enclosed with nylon sheets and leftward at ambient temperature for 24 hours. After that, concrete specimens were extracted from the molds and cured in water (22 ± 2)℃ until the age test.

Table 6. Mixture proportions of SCC mixes

Mix ID	Cement Kg/m^3	CA Kg/m^3	Sand Kg/m^3	Gravel Kg/m^3	WS Kg/m^3	Water Kg/m^3	SP Kg/m^3
C10W0	495	55	880	873	0	170	10
C10W5	495	55	880	815	41	170	10
C10W10	495	55	880	760	71	170	10
C10W15	495	55	880	679	95	170	10
C10W20	495	55	880	613	114	170	10
C10W25	495	55	880	560	131	170	10
C20W0	440	110	880	873	0	170	10
C20W5	440	110	880	514	41	170	10
C20W10	440	110	880	480	71	170	10
C20W15	440	110	880	445	95	170	10
C20W20	440	110	880	415	114	170	10
C20W25	440	110	880	390	131	170	10

3.2 Testing procedures

This section explains the procedure utilized to test the SCC mixes of fresh and hardened characteristics following the standard's requirements for each test.

3.2.1 Fresh properties

All fresh properties tests were performed in this study following the method described by EFNARC (2005) [21]. The slump flow diameter test calculates the SCC's free flat flow when no obstacles are present. After lifting the slump cone and ultimately stopping the flow of concrete, the average diameter of the flowing concrete is measured to assess the SCC's filling capacity. Another flow indicator, T50, is the time required to produce concrete flows with diameters of 500 mm.

The L-box test evaluated SCC's passing ability. SCC was poured into the L-vertical box's section, and then the gate was raised to allow the SCC to flow into the L-horizontal box's section. H2 and H1 respectively stand for the height of the SCC at the conclusion of the horizontal component and the remaining SCC in the vertical segment. The H2/H1 ratio is a predictor of passing ability.

Workability traits including segregation resistance, passing and filling prowess are seen as key traits for SCC. The V-funnel test, in which the funnel is approximately filled with 12 L of SCC and the time it takes for SCC to flow inside the devices is recorded, can be used to determine the flowability of SCC.

3.2.2 Hardened properties

The compression strength test was accomplished on the average of three (150*300) mm cylinders according to ASTM C39 [22] and the fresh concrete powerd in the mould in three layers after compacting each layer then left in the laboratory room for 24 hr then demolded and immersed in water for curing until the testing date at the age of 28 days using of 2000 KN hydraulic machine.

The three-point bending test was carried out on the average of three (100*100*500) mm prisms to determine the flexural strength of the specimens, and the loading rate was set at 1.0 (MPa/min) according to ASTM, C78 [23]. While the impact resistance test was performed according to ACI 544 [24] using this formula.

$$EI = N \times m \times g \times h \tag{1}$$

where, *EI:* The impact energy (N.m); *N:* Number of blows; *m:* The mass of the drop hammer (kg)=4.57 kg; *g:* Gravitational acceleration (N/kg); *h:* Height of the drop hammer (m)=0.455 m.

4. RESULTS AND DISCUSSION

4.1 Fresh properties

The results of SFD for SCC made with different WS and CA are presented in Figure 4. It is noted from this Figure that the results of SFD decreasing with increasing the WS content comparing with control mix. The decrease reached 13 and 11% for 10 and 20% of CA, respectively. The major cause of this decrease in SFD may be due to WS's irregular form and increased capacity for absorption compared to natural coarse aggregate [14]. On the other hand, for the same WS replacement level, the SFD results decreased with increasing the CA content from 10 to 20%. According to the EFNARC [21] the mix C10W0 lies in SF3 class, but all other mixes lies in SF2 class.

The results of T50 showed that the T50 increased with increasing the WS replacement level from 2 to 5.4 sec at 10% CA and from 7 to 14 sec at 20% CA and for the same WS content the T50 increased with increasing the CA content from 10 to 20% Figure 5. The results of T50 showed that the mix C10W0 lies in VS1/ VF1, but all other mixes lie in VS2/ VF2 class.

As for the passing ability of SCC in terms of the L-box height ratio, the results showed that all mixes conformed to the EFNARC (2005) [21]. The results also showed that the H2/H1 ratio was considerably reduced by amplifying the WS content. Due to the uneven, convex, and concave nature of the surface of the WS particle and the water that was absorbed by it, the H2/H1 ratio values decreased, which decreased the mixture's passing ability [14], but for the exact replacement level of WS, increasing the CA content from 10 to 20% was slightly affected on the results of L- box as demonstrated in Figure 6.

The ability of the fresh concrete composition to remain homogeneous segregation resistance was tested. The results in Figure 7 showed that the segregation ratio increased with increasing the replacement level of WS. The increasing reached to 75 and 73.3% with 10 and 20% of CA replacement level respectively. This is may be due to random shape of WS particles.

Figure 8 displays the outcomes of the V-funnel test. It is evident that a rise in the values of V-funnel time was caused by an increase in the WS volume fraction. At 10% CA the time increased from 7 sec for 0% WS to 12 sec for 25% WS, and for 20% of CA the time reached to 17 sec. Moreover; it can also be observed that mixtures C10W0 and C10W5 confirms to viscosity class VS1/VF1, While the other mixes meet the EFNARC [21] criterion for viscosity class VS2/VF2. The rough surface, irregular form, and water absorption of the WS particles are the causes of the decreased flowability of SCC combined with WS [6, 13, 14].

The overall results of fresh properties clarified that increment of CA from 10 to 20% comprises a negative influence on behavior of SCC, but the results still meet the requirement for the fresh properties of SCC. This is apportioned to the nano-scale of CA particles compared with micro-scale of cement particles, consequently due to the higher surface area of CA particles, this necessities more water quantity to dampen all surface area of the particles [7, 13].

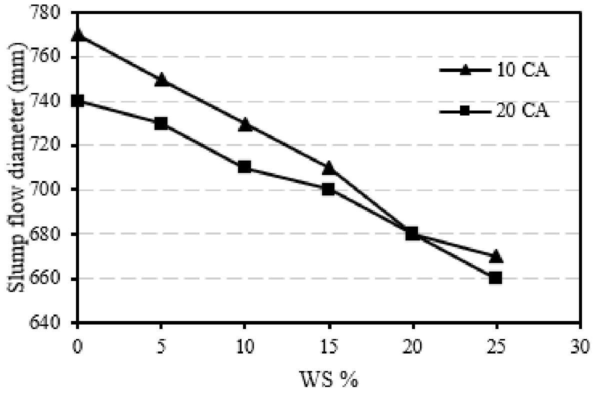

Figure 4. Slump flow diameter of SCC

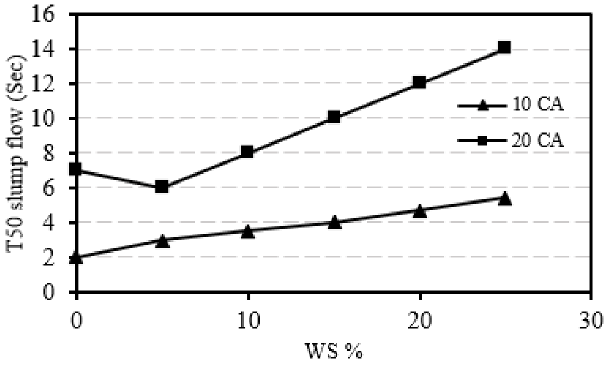

Figure 5. T50 slump flow of SCC

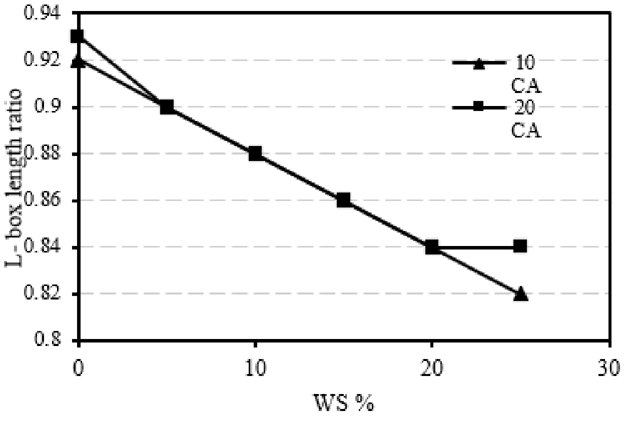

Figure 6. L- box length ratio of SCC

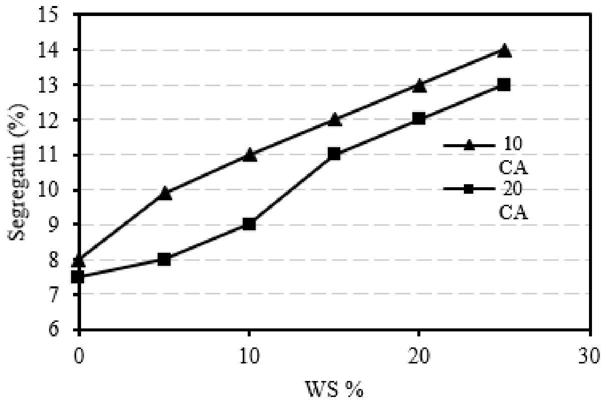

Figure 7. Segregation ratio of SCC

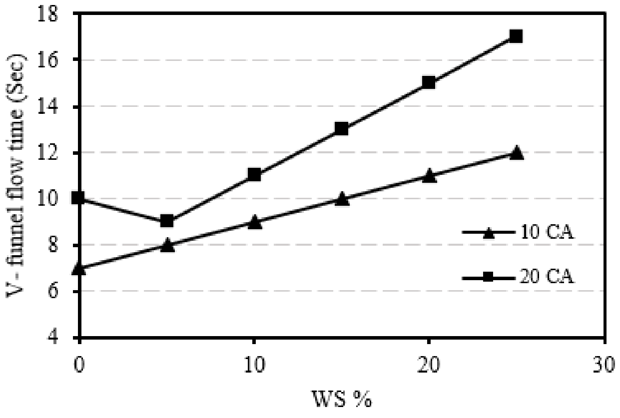

Figure 8. V- funnel flow time of SCC

4.2 Hardened properties

4.2.1 Compressive strength

The results of Compressive strength at 28 days made with different WS and CA are presented in Figure 9. Results showed that increased WS content for the same CA replacement level reduced compressive strength. The decrease reached a 25% replacement level of WS to 29.2 and 17.6% for 10 and 20% CA, respectively. Weak bonding between WS particles and surrounding cement paste is the primary cause of this reduction. additionally, because there wasn't enough cement paste to fill up the concave sides of the WS particles and produce voids, as well as another reason related to WS lightweight compared to normal aggregate [6, 7, 13, 14].

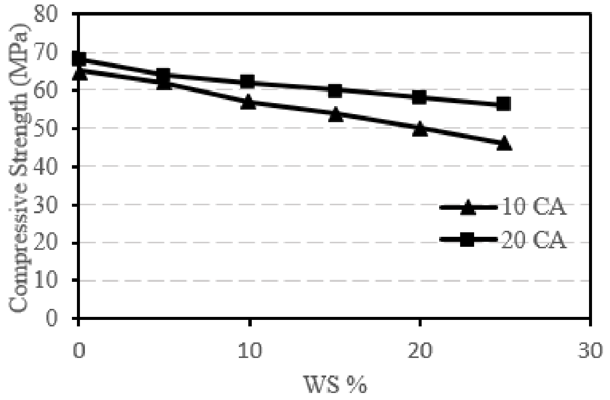

Figure 9. Compressive strength of SCC

The results also showed that for the same WS replacement level the mixtures containing 20% CA gives higher compressive strength comparing with the mixtures containing 10% CA. the increasing in compressive strength reached to 21.7% at 25% WS replacement level. Increasing the compressive strength with the increasing of CA from 10 to 20% can be attributed to the particles' much smaller diameters and greater surface area, which improved the ITZ and matrix microstructure [25].

4.2.2 Flexural strength

The results of flexural strength at 28 days made with different WS and CA are presented in Figure 10. Results showed that for the same CA replacement level the flexural strength decreased with increasing WS content. The flexural strength decreased from 5.3 to 1 MPa and from 6.5 to 2 MPa for 10 and 20% of CA respectively.

The results also showed that for the same WS replacement level the mixtures containing 20% CA gives higher flexural strength comparing with the mixtures containing 10% CA. For example the mix C20W0 gives 6.5 MPa comparing with 5.3 MPa for the mix C10W0. This is because of the microstructure of the matrix and ITZ was well enhanced with the increasing the addition of CA.

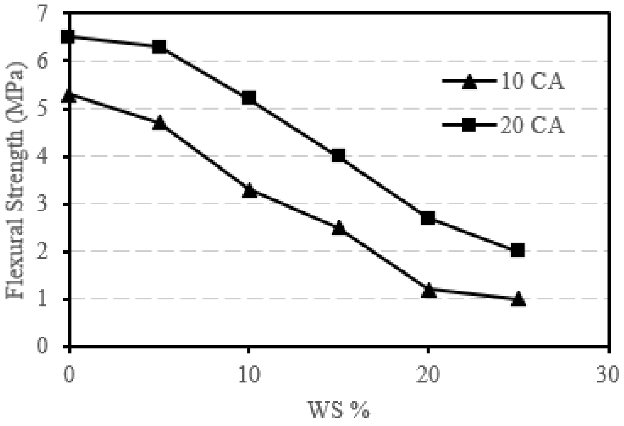

Figure 10. Flexural strength of SCC

4.2.3 Impact resistance

Table 7. Results of impact resistance for SCC

Mix ID	No. of Blows for First Crack	No. of Blows for Failure	Impact Energy First Crack (N.m)	Impact Energy Failure (N.m)
C10W0	900	905	18358.581	18460.573
C10W5	875	878	17848.620	17909.815
C10W10	855	859	17440.652	17522.245
C10W15	825	830	16828.699	16930.691
C10W20	800	803	16318.738	16379.934
C10W25	760	763	15502.801	15563.997
C20W0	890	895	18154.596	18256.589
C20W5	880	886	17950.612	18073.003
C20W10	850	855	17338.659	17440.652
C20W15	830	835	16930.691	17032.683
C20W20	800	804	16318.738	16400.332
C20W25	775	778	16088.778	15869.973

For each type of concrete specimen, the number of impact strikes needed to cause the first visible crack and ultimate failure is indicated in Table 7. The results of the first crack impact energy made with different WS and CA are presented in Figure 11. Results showed that the first crack impact energy decreased with increasing WS content for the same CA replacement level. The decrease reached a 25% replacement level of WS to 15.5 and 7% for 10 and 20% CA, respectively. In comparison, the CA replacement level not much affected the first crack impact energy results. On the other hand, the same behaviour was noted in the results of failure impact energy, as shown in Figure 12.

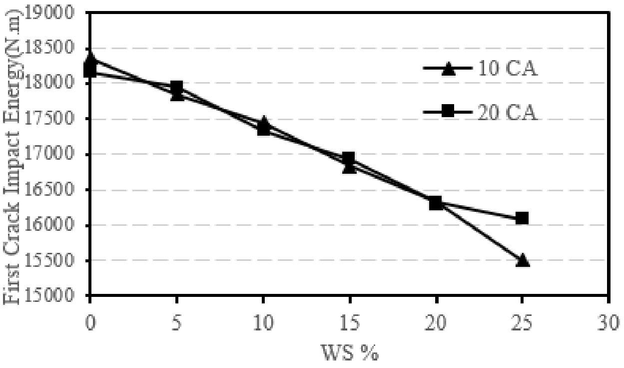

Figure 11. First crack impact energy of SCC

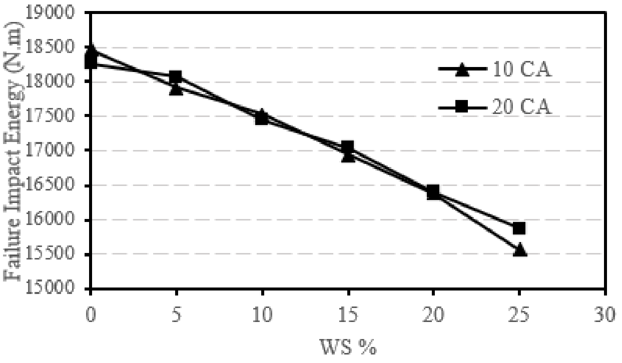

Figure 12. The failure impact energy of SCC

5. CONCLUSIONS

The main conclusions from the study of the effect of CA and WS on the properties of SCC can be drawn as follows:

1. The overall results of fresh properties clarified that an increment of CA from 10 to 20% comprises a negative influence on the behaviour of SCC. However, the results still meet the requirement for the fresh properties of SCC. Increasing the replacement of coarse aggregate by WS from 5 to 25% leads to reduce the fresh properties of SCC. The slump flow diameter decreased to 13% and increased T50. The results also showed that the H2/H1 ratio was considerably reduced by amplifying the WS content. The increase in the segregation ratio reached 75%.

2. Results showed that the compressive strength decreased with increasing WS content for the same CA replacement level. The decrease reached a 25% replacement level of WS to 29.2 and 17.6% for 10 and 20% CA, respectively. The results also indicated that for the same WS replacement level, the mixtures containing 20% CA gives higher compressive strength compared with the mixtures containing 10% CA. The compressive strength increased to 21.7% at 25% WS replacement level.

3. Results showed that the flexural strength decreased with increasing WS content for the same CA replacement level. The flexural strength decreased from 5.3 to 1 MPa and from 6.5 to 2 MPa for 10 and 20% of CA, respectively. The results also showed that the mixtures comprising 20% CA give greater flexural strength for the same WS replacement level than those containing 10% CA. For example, the mix C20W0 gives 6.5 MPa compared with 5.3 MPa for the mix C10W0.

4. The first crack impact energy results showed that for the same CA replacement level, the first crack impact energy decreased with increasing WS content. The decreasing reached at 25% replacement level of WS to 15.5 and 7% for 10 and 20% CA, respectively. In comparison, the CA replacement level not much affected the first crack impact energy results. The same behaviour was noted in the results of failure impact energy.

REFERENCES

[1] Zhu, C., Niu, J., Li, J., Wan, C., Peng, J. (2017). Effect of aggregate saturation degree on the freeze–thaw resistance of high performance polypropylene fiber lightweight aggregate concrete. Construction and Building Materials, 145: 367-375. https://doi.org/10.1016/j.conbuildmat.2017.04.039

[2] Öz, H.Ö., Gesoglu, M., Güneyisi, E., Sor, N.H. (2017). Self-consolidating concretes made with cold-bonded fly ash lightweight aggregates. ACI Materials Journal, 114(3). https://doi.org/10.14359/51689606

[3] Bilodeau, A., Sivasundaram, V., Painter, K.E., Malhotra, V.M. (1994). Durability of concrete incorporating high volumes of fly ash from sources in the USA. Materials Journal, 91(1): 3-12. https://doi.org/10.14359/4411

[4] Golewski, G.L. (2018). Green concrete composite incorporating fly ash with high strength and fracture toughness. Journal of Cleaner Production, 172: 218-226. https://doi.org/10.1016/j.jclepro.2017.10.065

[5] Hilal, N., Mohammed Ali, T.K., Tayeh, B.A. (2020). Properties of environmental concrete that contains crushed walnut shell as partial replacement for aggregates. Arabian Journal of Geosciences, 13: 1-9. https://doi.org/10.1007/s12517-020-05733-9

[6] Mohammed, A.S., Hilal, N.N., Ali, T.K.M., Sor, N.H. (2021). An investigation of the effect of walnut shell as sand replacement on the performance of cement mortar subjected to elevated temperatures. In Journal of Physics: Conference Series, 1973(1): 012034. https://doi.org/10.1088/1742-6596/1973/1/012034

[7] 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

[8] Hamah Sor, N., Hilal, N., Faraj, R.H., Ahmed, H.U., Sherwani, A.F.H. (2022). Experimental and empirical evaluation of strength for sustainable lightweight self-compacting concrete by recycling high volume of industrial waste materials. European Journal of Environmental and Civil Engineering, 26(15): 7443-7460. https://doi.org/10.1080/19648189.2021.1997827

[9] Aadi, A.S., Sor, N.H., Mohammed, A.A. (2021). The behavior of eco-friendly self–compacting concrete partially utilized ultra-fine eggshell powder waste. In Journal of Physics: Conference Series, 1973(1): 012143. https://doi.org/10.1088/1742-6596/1973/1/012143/meta

[10] Bheel, N., Awoyera, P., Tafsirojjaman, T., Sor, N.H. (2021). Synergic effect of metakaolin and groundnut shell ash on the behavior of fly ash-based self-compacting geopolymer concrete. Construction and Building Materials, 311: 125327. https://doi.org/10.1016/j.conbuildmat.2021.125327

[11] Abed, J.M., Khaleel, B.A., Aldabagh, I.S., Sor, N.H. (2021). The effect of recycled plastic waste polyethylene terephthalate (PET) on characteristics of cement mortar. In Journal of Physics: Conference Series, 1973(1): 012121. https://doi.org/10.1088/1742-6596/1973/1/012121

[12] Adebakin, I.H., Gunasekaran, K., Annadurai, R. (2018). Mix design and rheological properties of self-compacting coconut shell aggregate concrete. ARPN Journal of Engineering and Applied Sciences, 13(4): 1465-1475.

[13] Bheel, N., Ali, M.O.A., Liu, Y., Tafsirojjaman, T., Awoyera, P., Sor, N.H., Bendezu Romero, L.M. (2021). Utilization of corn cob ash as fine aggregate and ground granulated blast furnace slag as cementitious material in concrete. Buildings, 11(9): 422. https://doi.org/10.3390/buildings11090422

[14] Hilal, N.N., Sahab, M.F., Ali, T.K.M. (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

[15] Cheng, W., Liu, G., Chen, L. (2017). Pet fiber reinforced wet-mix shotcrete with walnut shell as replaced aggregate. Applied Sciences, 7(4): 345. https://doi.org/10.3390/app7040345

[16] Husain, M.S., Ahmad, A., Huda, S., Asim, M. (2017). Cost optimization of concrete by replacing fine aggregate with walnut shell powder. International Journal of Civil Engineering and Technology, 8(3): 82-89.

[17] Kamal, I., Sherwani, A.F., Ali, A., Khalid, A., Saadi, L., Harbi, A. (2017). Walnut shell for partial replacement of fine aggregate in concrete: Modeling and optimization. Journal of Civil Engineering Research, 7(4): 109-119.

[18] Specification, I.S. (1984). Portland cement. Central Organization for Standardization & Quality Control (COSQC), Baghdad, Iraq.

[19] IQS and No 45. (1984). Aggregate From Natural Sources for Concrete and Building Construction.

[20] Sor, N.A.H.. (2018). The effect of superplasticizer dosage on fresh properties of self-compacting lightweight concrete produced with coarse pumice aggregate. Journal of Garmian University, 5(2): 190-209. https://doi.org/10.24271/garmian.336

[21] EFNARC. (2005). The european guidelines for self-compacting concrete: Specification, production and use. European Guidelines for Self Compacting Concrete, pp. 68.

[22] ASTM C39. (2018). Standard test method for compressive strength of cylindrical concrete specimens: C39/C39M-18. American Society for Testing and Materials, 8.

[23] ASTM C78/C78M. (2002). Standard test method for flexural strength of concrete (Using simple beam with third-point loading). ASTM International, 1–3.

[24] ACI 544. (1996). Measurement of properties of fiber reinforced concrete. ACI Materials Journal, no. West 481 Conshohocken, Pennsylvania, United States.

[25] Rathi, V.R., Modhera, C.D. (2014). An overview on the influence of nano materials on properties of concrete. International Journal of Innovative Research in Science Engineering and Technology, 3(2): 9100-9105.