Fresh behavior and hardened properties of self-compacting concrete containing coal ash and fly ash as partial replacement of cement

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Abstract

Due to higher price of cement compared to other concrete ingredients, the problems associated to greenhouse gases emissions during its production and its high popularity contributed to the concern of replacing it by other complementary cementitious constituents. In this regard, the current research has been accomplished to examine both the fresh and hardened performance of self-compressing concrete (SCC) made with coal ash (CA) and fly ash (FA) which can be regarded as partial material replacement of cement. Consequently, this paper aims to make use of the remaining CA from the barbecue process of the restaurants from Fallujah city, Iraq. We have totally designed 7 concrete mixtures with a constant (w/b) ratio of 0.37 and total binder content of 450 kg/m^3. Control mixture was produced by using 100% cement without FA or CA. Then, other mixtures were prepared with 10%, 20% and 30% (by weight) replacement of cement by FA and CA, respectively. The results illustrated that, in contrast to the FA, the CA has negative influences on the fresh properties of SCC but the results still meet the criteria for the fresh behavior of SCC. From the other hand, CA which has been added was significantly improved the strength of SCC. Sustainable high strength SCC can be produced due to the addition of CA.

Keywords: *Self-compacting concrete; Coal ash; Fly ash; Fresh properties; Hardened properties*

1. Introduction

Due to high demand for cement as a main construction material, its higher prices compared to certain (other) cement constituents and the problems associated to the emissions of greenhouse gases during its production made a huge interest to replace them by pozzolanic powders as.complementary cementitious resources. As mineral admixtures, there has been numerous waste materials have been used in concrete in order to protect the environment. However, by using pozzolanic mineral admixtures, mechanical properties and the stability of the concrete have been improved. In addition, they can also be utilized as a way for decreasing the consumption of cement and the emission of carbon dioxide which causes global warming and waste of raw materials. The term green concrete can be used for these types of concretes (Golewski, 2018).

In the previous literature a huge amount of studies can be found regarding incorporation of different pozzolanic materials into the concrete to partially replace Portland cement (Al-Jumaily et al. 2015), these pozzolanic materials include: FA (Adak et al. 2017; Güneyisi et al. 2016; Al-Hadithi, & Hilal, 2016), silica fume (Faraj et al. 2019; Mastali & Dalvand, 2018), rice husk ash (Ahsan & Hossain, 2018; Chakraborty & Goswami, 2015), palm oil fuel ash (Mujah, 2016; Zeyad et al. 2016), coconut shell ash (Oyedepo, 2015), shell sun flower ash and shell pumpkin ash (Shahbazpanahi & Faraj, 2020).

From the chemical point of view the pozzolan materials are siliceous or siliceous-aluminous in their nature. They have little inherent cementitious value alone, while during their reaction with saturated calcium hydroxide (C-H) extra calcium silicate hydrates ((C-S-H)) was produced. Thus, calcium silicate and calcium hydroxide represents the major products of cement hydration (Omrane et al. 2017). Therefore, the pozzolanic materials can have the ability to form additional C-S-H during hydration by which the matrix can be improved. The pozzolanic reactivity of mineral admixtures would have impact on the strength and durability of concrete. Burning and grinding of waste materials are the best ways to produce pozzolan materials (Shahbazpanahi & Faraj, 2020).

From methodological point of view, we can pour and vibrate the SCC regarding it as a high performance and special concrete under its self-weight without any compaction effort assures complete filling of formworks even when access is delayed by constricted gaps between reinforcement bars. Therefore, the cohesiveness along with flow ability of fresh concrete is highly crucial for SCC (Güneyisi & Gesoğlu, 2008).

2. Research significance

Due to the large number of restaurants especially in the touristic places and in the city centers a large amount of remaining coal ash (CA) from the barbecue process is generated. This ash can be regarded as waste material and may be hazardous to the environment. Thus, in this paper an attempt was made to use the remaining CA from the barbecue process of the restaurants from Fallujah city, Iraq, which their number is more than 20 restaurants. The researches regarding the influence of the CA on the performance of SCC is limited. Therefore, this article mainly aims to make a comparison between the effects of CA and FA as partial spare of cement on the fresh and some hardened features of SCC.

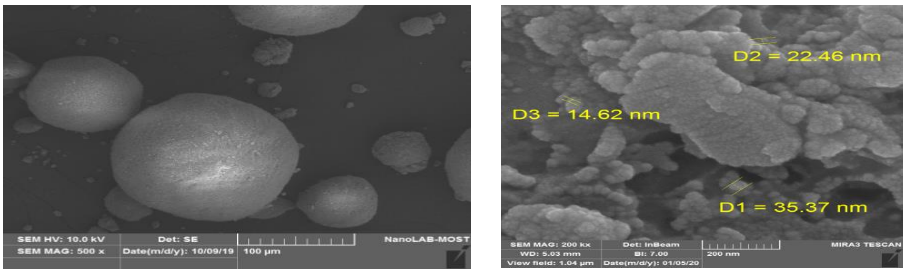
3. Experimental program

3.1 Materials

The main material which has been used as cementitious material in this study is that of Ordinary Portland cement from Al-mass Company. While the supplementary cementitious material used for partially replacing the cement is Class F FA and CA. The chemical composition of CA, FA and cement is shown in Table 1. Moreover the physical characteristics of cement are noted in Table 2. Also, figure 1 demonstrates both SEM images analysis of FA and CA respectively. The CA powder which was obtained from different restaurants was sieved through sieve 75 µm. The Grading properties of used coarse aggregate and natural river sand utilized in this study with specific gravities of (2.7) are given in figure 2. Thus, for the sake of accomplishing the intended and adequate workability of SCCs, high performance super plasticizer known commercially as (ViscoCrete - 5930) was used with specific gravity of (1.08).

Table 1. Chemical compositions of PC, FA and CA

Chemical analysis (%)	PC	FA	CA
SiO_2	20.9	68.67	2.098
CaO	63.22	1.926	31.29
Fe_2O_3	3.85	1.725	0.807
Al_2O_3	4.89	0.43	0.159
MgO	2.82	2.49	4.37
SO_3	2.73	0.758	5.454
K_2O	0.92	2.488	4.77
Na_2O	0.22	-	-
P_2O_5	-	0.69	2.406



(a) **(b)**

Figure 1. SEM image of (a) FA and (b) CA

3.2 Mix proportions

As a methodological procedure for evaluating the performance of SCC containing CA and comparing its effects with FA, an overall number of 7 SCC mixtures were designed with a constant (w/b) ratio of 0.37 and total binder content of 450 kg/m^3. Control mixture was produced by using 100% cement without FA or CA. Then, other mixtures were prepared with 10%, 20% and 30% (by weight) replacement of cement by FA and CA, respectively. The mixture proportions of SCC are shown in Table 3.

Table 3. Mixture proportions (Kg) of SCC for 1 m^3 of concrete

Mix ID	Cement	Sand	Gravel	Water	SP	FA	CA
C	450	915	885	170	8	0	0
M1	405	915	885	170	8	45	0
M2	360	915	885	170	8	90	0
M3	315	915	885	170	8	135	0
M4	405	915	885	170	8	0	45
M5	360	915	885	170	8	0	90
M6	315	915	885	170	8	0	135

3.3. Mixing procedure and Preparation of the samples

Mixing procedure is actual significant stage in SCC production that depends on the quantity of elements comprising of binders, coarse and fine aggregates, furthermore the water and admixtures. The procedures set by EFNARC (2005) as a methodology for the production of SCC as well as the direct technique proposed by Kheder et al. (2010) were followed in this study. Mixtures of SCC were prepared by adding a small quantity of water with the half of aggregates (sand + gravel) to the mixing pan. The mixer was rotated for 1 minute, then partial of the cementitious materials (the cement or cement + FA or CA) were supplemented to the mixture plus partial amounts of sand. The mixture rotated for another 1 minute. Next, quantitatively, half of (water plus super plasticizer) that has been added to the mixture and the process of mixing were continued for about 2 minute till materials became homogenous, finally remaining constituents including (sand and gravel, superplasticizer and water) added to the mixer. At this stage, the mixing was continued for extra 3.0 minute.

3.4. Testing procedures

3.4.1 Fresh properties

For measuring slump flow diameter (SFD) and the slump flow time (SFT), a cone with an ordinary slump flow was chosen and then it was filled up with concrete without being leveled and compacted. After lifting the cone and the concrete being spread, the averages diameters of the spread concrete has been subsequently measured as shown in Figure 2. As proposed by EFNARC (2005), three typical classes of slump flow have been regarded to identify the range of applications. The typical application areas and various boundaries, lower and upper, of the different classes are provided in Table 4. However, the test of slump flow was conducted and its time (T_{50}), the determinant that identified the time in which the concrete reached the 500 mm spread circle, was also calculated. EFNARC suggests T_{50} of 2 to 5 seconds for SCC.

Figure 3. Measurement of SFD and SFT for SCCs.

Figure 4 illustrates the process of evaluating the flowability and the viscosity of the mixture in which the experiment was accomplished. The determination of time has been done by using a simple methodology in which the funnel has been entirely filled with a material of fresh concrete. Additionally, the time flow has been measured during the opening of the orifice until the funnel being drained completely. An adequate and stable concrete would have been consuming short time for flowing out. Two kinds of viscosity classes in the EFNAC (2005) SCC guide according to the measured V-funnel time (VFT) and T_{50}. Thus, the viscosity classification was also shown in Table 4.

Figure 4. Photographic view of VFT measurement

3.4.2 Hardened properties

As for the compression strength, it has been found that the experiment of compressive strength has been accomplished by using a 100 mm cubes at the age of 7 and 28 days. This experiment was performed by using of 2000 KN hydraulic machine. The stress rate of compression has been measured in terms of dividing the maximum capacity load of the cubes by the face zone and the average of three cubes are reported (Standard, B 1983).

For detemining the flexural strength of the specimens the three point bending test was performed and the loading rate was designated to be 1.0 ($N/mm^2/min$) (ASTM, C78. 2010).

4. Results and discussion

4.1 fresh properties

4.1.1 SFT and T_{50} SFD

It has been found in this study that the SFD and T_{50} for SCC containing different percentages of FA and CA as it evident in both Figures 6 and 7. It is noted from Figure 6 that as a result of increasing the FA content, the flowability of SCC has been increased too remarkably. Increasing FA content from 0% to 30% resulted in the increase of SFD from 700 mm to 770 mm. On the other hand, the addition of CA into the SCC resulted in the opposite behavior as it is compared to FA. The addition of 30% CA into the SCC reduced the slump flow diameter by about 14% compared to the control mixture. Moreover, the mixture that contains 30% FA has 22% higher SFD as compared to the mixture containing the same percentage of CA. Adding 30% FA shifted the mixture class from SF2 to SF3, while adding the same percentage of CA shifted the mixture class from SF2 to SF1. All produced mixtures containing either FA or CA satisfied the fresh criteria for SCC proposed by EFNARC (2005), but the classes were remarkably different for mixtures made with FA or CA.

Regarding the time of slump flow, as it is shown in below, the addition of CA also increases the T_{50} time, which means higher time is essential for SCC to reach 500 mm diameter, thus the flowability decreased. However, the inclusion of FA slightly decreased T_{50} time. The mixture containing 30% FA has 77% lower T_{50} time compared to the same mixture but contained 30% CA.

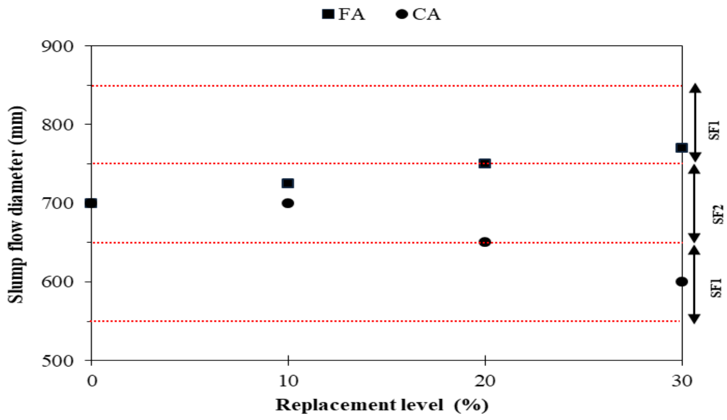


Figure 6. SFD of SCC containing FA and CA

4.1.2 V-funnel flow time

Figure 8 shows the VFT versus the partial replacement of FA and CA with cement. It is obvious from the results that the addition of CA significantly amplified the VFT, thus the filling ability of SCC has been decreased. Increasing the CA content from 0% to 30% amplified the VFT form 8 seconds to 17 seconds. In contrast, the addition of FA gradually decreased the VFT. The mixtures containing CA can be categorized as VF2, while the mixtures containing FA can be classified as VF1 according to EFNARC (2005).

On the other hand, the VFT versus T_{50} flow time for SCC made with FA and CA as it is shown in Figure 9. This figure can be used to identify the viscosity classes of SCC. As can be seen from Figure 9 mixtures containing FA can be regarded as VS1/VF1 class whereas the mixture that contains CA should be regarded as VS2/VF2 class.

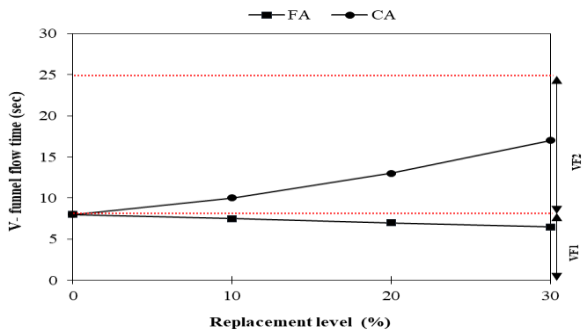


Figure 8. VFT of SCC containing FA and CA

4.1.2 L-box ratio

As for the passing ability of SCC in terms of L-box height ratio, it was significantly reduced by amplifying the CA content as demonstrated in Figure 10. Moreover, contrasting other fresh properties the addition of FA also decreased the passing ability of SCC but with a small range compared to CA. The inclusion of 30% CA resulted in the 37% reduction in the L-box height ratio. The mixtures containing CA cannot meet the fresh criteria for SCC regarding the passing ability

The overall fresh results illustrated that the CA involves negative impact on the fresh behavior of SCC, but the majority of the results still meet the criteria's required for fresh behavior of SCC. The main reason behind decreasing the fresh properties with increasing the CA content is assigned to the fact that those particles of CA was in the nano-scale compared with particles of cement and FA which in the micro scale, thus the CA particles has higher surface area and needs more quantity of water to wet all surface area of the particles (Shahbazpanahi & Faraj, 2020).

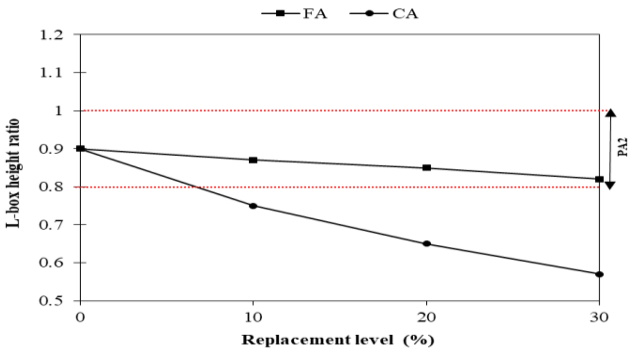


Figure 10. L-box height ratio of SCC containing FA and CA

4.2 Hardened properties

4.2.1 Dry density

The dry density of SCC containing different percentages of FA and NFA is presented in Figure 11. Mixtures with CA had higher dry density compared to those containing FA at all testing ages. The inclusion of CA leads to the surge of the dry density of SCC at 7 and 28 days. This may be accredited to the fact that, because the CA particles had greater surface area when compared with cement and FA particles, thus during the hydration process more water was converted to the hydration products, made the micro structure less porous, more packed and increased the density of the produced concrete. The mixture containing 20% FA had a dry density about 7% and 9.5% lower than that containing the same percentage of CA at 7 and 28 days, respectively.

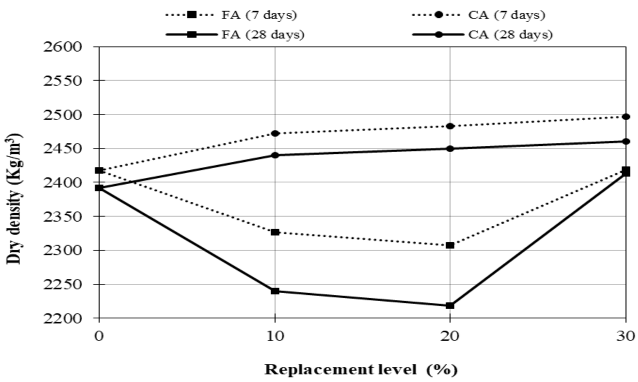


Figure 11. Dry density of SCC containing FA and CA

4.2.2 Compression strength

As for the results about the compression, the compressive strength of SCC has remarkably been increased with increasing CA content up to 20% at 7 and 28 days, as shown in Figure 12. Nevertheless, this behavior was different for SCC containing FA. The compressive strength was decreased with the inclusion of 10% FA, and then it was increased with the addition of 20% and 30% of FA at both testing ages. The mixtures containing 10% and 20% of CA and 30% of FA might be considered as self-compacting high strength concrete (SCHSC), because the strengths higher than 60 MPa were obtained at 28 days (Faraj et al. 2019; ACI 363R-10). The .compressive .strength of SCC was increased by about 30% and 46% with the inclusion of 20% and 30% of CA and FA, respectively. Increasing the compressive strength with the addition of CA can be assigned to the highly lower diameters and higher surface area of the particles that enhanced the ITZ and microstructure of the matrix (Al-Jumaily et al. 2015)

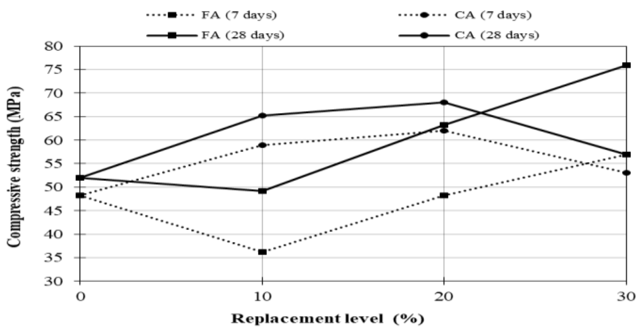


Figure 12. Compressive strength of SCC containing FA and CA

4.2.3 Flexural strength

It has been also found that flexural strength of SCC containing various percentages of FA and CA at 28 days are illustrated in Figure 13. It is obvious from the findings that the flexural strength of SCCs involving different percentages of FA and CA were lower than the control sample. However, the lowest flexural strength of SCC was achieved for the mixture containing 10% FA which was 46% lower than that of the control mixture. However, the highest flexural strength was gained for the mixture that contains 30% CA which was about 8% higher than the reference sample. Moreover, the mixtures containing CA had higher flexural strength of the mixes containing FA, because the microstructure of the matrix and ITZ was better improved with the addition of CA compared to the FA.

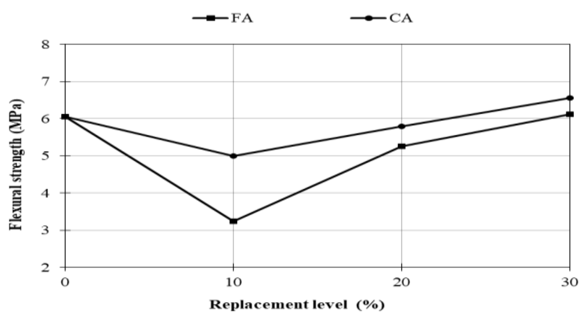


Figure 13. Flexural strength of SCC containing FA and CA at 28 days

4.2.4 Absorption

The water absorption test results of SCC comprising different ratios or percentages of FA and CA as they are shown in Figure 14. Generally, the process of water absorption of SCC was dramatically increased with the inclusion of FA and CA. The negative impact of FA on the water absorption was more obvious especially at 10% and 20% replacements. However, the addition of 30% of FA resulted in the similar water absorption compared to the control specimen.

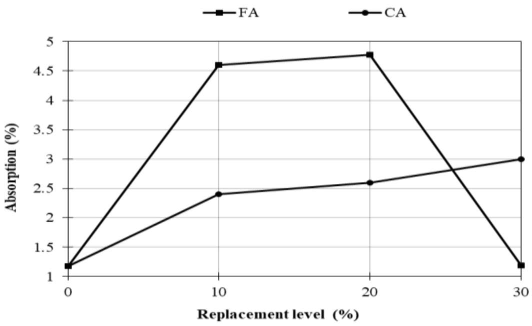


Figure 14. Water absorption of SCC containing FA and CA

5. Conclusions

According to the outcomes reached at through this study, some conclusions can be drawn:

1- First, the waste material resulted from the barbecue process was gained and used as a partial replacement with cement to produce sustainable SCC. Moreover, the influence of CA on the SCC fresh as well as the hardened properties were studied and compared with the FA effects.

2- Generally the fresh behavior of SCC has been negatively impacted by the CA but the majority of the results still meet the criteria's required for fresh behavior of SCC.

3- The fresh properties of SCC have been improved by the FA addition terms of flowability, filling ability and passing ability.

4- The dry density of SCC has been increased along with the increase of CA content starting from 0% to 30% and it was reduced with increasing the FA content.

5- There has been a significance enhancement in the compressive strength of SCC that has been significantly improved when the CA content up increased to 20% and then decreased with further increase of the CA content.

6- The CA is a significant element for producing SCHSC with compressive strength higher 60 MPa.

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