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Durability and Strength of Sustainable Self-Consolidating Concrete Containing Fly Ash

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Abstract. In this paper, the durability and strength of self-consolidating concrete (SCC) is assessed through development and testing of six binary mixes at fixed water-to-binder (w/b) ratio of 0.36. In each of the six SCC mixes, a different percentage of cement is replaced with fly ash. The development of compressive strength for each of the mixes is assessed by testing samples after 3, 7, and 28 days of curing. Durability of each of the six SCC mixes is assessed by measuring the charge passed in Rapid Chloride Permeability (RCP) test. Charge passed was measured in samples cured for 1, 3, 7, 14, 28, and 40 days of curing. All mixes out-performed the control mix in terms of resistance to chloride penetration. Binary mix in which 20% of cement is replaced with fly ash exhibited 28-day strength slightly surpassing the control mix.

1. Introduction

The use of self-consolidated concrete (SCC) in construction is gaining universal popularity due to its ability flow under its own weight and generally high quality of the finished product. The production of cement, the main ingredient in concrete, is accompanied by emission of significant amounts of CO_2 into the atmosphere. Therefore, decreasing the usage of cement through its partial replacement with more sustainable alternatives is a legitimate consideration. Fly ash, silica fume, and ground granulated blast furnace slag (GGBS), also known as supplementary cementitious materials (SCM), are industrial by-products that has been used extensively to improve fresh and hardened properties of concrete. Their reuse as partial cement replacements save precious landfill space, but may also enhance durability of concrete. Concrete structures that are in marine environments or in soils containing high levels of chloride ions are likely to get damaged when these chloride ions migrate through concrete voids and corrode reinforcing steel.

In this study, sustainable SCC mixes in which cement is partially replaced with fly ash were produced and tested to assess their compressive strength development and resistivity to chloride ion migration. Resistivity to chloride ions migration is assessed in this paper using the rapid chloride penetration (RCP) test in accordance with ASTM C1202 [1]. Concrete compressive strength was tested on standard 150 x 150 x 150 mm cubes after 3, 7, and 28 days of curing.

Mohamed [2] studied the durability and strength of SCC mixes containing various percentages of fly ash and chopped basalt fibres to assess compressive strength development and resistance to chloride penetration. Eight SCC mixes were developed in which the cement was partially replaced with 10%, 20%, 30% and 40% fly ash. In some mixes, 1% to 2% chopped basalt fibres were added. The compressive strength was determined after 3, 7 and 28 days of curing by testing standard 150x150x150 mm cubes in accordance with BS EN 12390-3:2009 [3]. Resistance to chloride penetration was determined using the RCP test conducted according to ASTM C1202 [1] on samples that have been cured for 7, 14, 28, 40 and 70 days. The highest 28-day compressive strength of 67.96 MPa was obtained on mixes in which 20% of the cement was replaced with fly ash (FA20). After each of the curing ages, the concrete resistance to chloride penetration improved as the FA dosage increased compared to the control mix.

Mohamed et al. [4] developed ANN models to predict the resistance of sustainable SCC mixes to chloride penetration. Model input parameters included water-to-binder (w/b) ratio, aggregate content, fly ash content, silica fume content, superplasticizer content, and number of curing days. The output data was the level of chloride penetration. The model was developed using one hidden layer with 7 neurons and ANN implemented the back-propagation method. A total number of 70 data sets was used to train the ANN model, and 20 data sets tested by the investigators were used to validate the accuracy of the ANN model. The ANN model with learning rate of 0.3, momentum of 0.5 and epochs of 5000 achieved an accuracy of 95%.

Ahari [5] investigated the compressive strength and chloride penetration resistance of 17 SCC binary, ternary and quaternary mixes containing various percentages of SCMs including GGBS and fly ash. The percentage of cement replacement with fly ash ranged from 18% to 36% while percentage of GGBS ranged from 8% to 18%. The compressive strength was tested after 7, 28 and 90 days of curing. Test results showed that replacing cement with 18% GGBS produced a binary mix with 28-day compressive strength of 54.6 MPa which exceeds the control mix. The highest compressive strength of 56.6 MPa for binary mixes was obtained when 36% of the cement was replaced with fly ash. The chloride penetration resistance was tested after 28 days and after 90 days of curing. The chloride penetration resistance of the 36% fly ash mix was better than the control mix, after 28 days of curing.

Khodair [6] studied the effect of high volume of fly ash and slag as cement replacement of the properties of SCC. 20 SCC mixes were developed with different ranges of fly and slag at a constant w/b ratio of 0.38. Nine samples were tested for compressive strength was tested at 3-, 14-, and days using a 100 X 200 mm cylinder according to ASTM C39 [7]. The permeability of concrete was tested at 90 days using the RCP test that is based on ASTM C1202 standards [1]. The results indicated that using SCMs as a replacement for cement lowered the 28-day compressive strength compared to the control mix. The maximum compressive was obtained by replacing the cement with both 25% fly ash and 25% slag. All mixes containing SCMs had low permeability according to ASTM C1202 [1].

Singh [8] investigated the durability of self-consolidating concrete containing iron slag (IS) as replacement of fine aggregates. The percentage of IS that replaced the fine aggregate ranged from 0% to 40%. The compressive strength was tested after 28, 91 and 365 days of curing. The permeability of SCC mixes was measured using RCP test after 7, 28, 91, and 365 days of curing. The results showed that the use of IS increased the compressive strength of SCC compared to the control mix. The highest 28-day compressive strength was 40 MPa, achieved by replacing fine aggregates with 40% of IS. Increasing the percentage of IS decreased the permeability of concrete and improved resistance to chloride penetration compared to the control mix as indicated by the very low passing charge.

Gesoglu [9] studied the fresh and hardened properties of SCC containing fly ash combined with marble powder and limestone filler. The SCC mixes were produced as binary and ternary mixes at a constant w/b ratio of 0.35. RCP tests were conducted on six 100 x 200 mm standard cylindrical specimens according to AASHTO T277 [10]. The compression test was conducted on standard 150 x 150 x 150 mm cubes according to ASTM C39 [8]. The compressive strength was measured after 28 days and after 90 days of curing, while the chloride permeability test was conducted on samples that has been cured for 90 days. The results showed that high replacement percentage of cement by fillers affected the fresh properties negatively, while replacement of cement with fly ash enhanced concrete fresh properties. Fly ash mixes produced lower 28 days compressive strength compared to the control mix due to the slow hydration process.

Beglarigale and Yazici [11] studied the effect of GGBS and steel microfibers on reducing the deleterious effects of alkali-silica reaction (ASR) on concrete. The investigators noted that adding GGBS and steel fibers to tested samples showed a reduction on expansion associated with ASR compared to control samples. Other studies on 50-year old concrete panels have shown that expansion due to ASR may result in significant damage and loss of compressive strength in the long term [12].

2. Experimental Program

The purpose of this study is to investigate the resistance to chloride penetration of SCC mixes in which cement is partially replaced with various percentages of fly ash. A total of six SCC mixes were produced with various percentages of fly ash at a constant w/b ratio of 0.36. While the fixed w/b is in a way limitation of this study, w/b = 0.36 is a typical average ratio for SCC nowadays in many parts of the world. Total binder content is 480 kg/m^3 and the total natural course gravel content is 800 kg/m^3. Fine aggregates content is a combination of 582.4 kg/m^{3}black sand and 313.6 kg/m^3 dune sand. The superplasticiser dosage was maintained at 7.2 kg/m^3 in each of the six trial mixes. The six binary SCC mixes were created by partial replacement of cement with 10%, 15%, 20%, and 25%, 30%, or 40% fly ash.

The compressive strength was determined by testing standard 15x 150x150 mm cubes in accordance the BS EN 12390-3:2009 [9]. Samples for compression test were cured for 3, 7 and 28 days. The resistance of the SCC mixes to chloride penetration was assessed using the RCP test conducted on cores extracted from standard 150 x 150 x 150 mm cylinders. The RCP test was conducted in accordance with ASTM C1202 [1] on samples cured for 1, 3, 7, 14, 28 and 40 days of curing. The chloride penetration level is determined by the currents the current (I0, I30, etc.) and total passing charge, Q, measured in coulombs using Equation 1.

$$Q = 900\ (I_0 +\ 2I_{30} +\ 2I_{60} + \cdots +\ 2I_{300} + 2I_{330} + 2I_{360}) \tag{1}$$

Where $I_0,\ I_{30},\ I_{60}, \ldots$ are the Current (Ampere) immediately after the voltage is applied, at 30 minutes and at 60 minutes. The passing charge computed from Equation 1 is converted to concrete penetrability rating according to Table 1.

Table 1. Chloride Ion Penetrability Based on Charge Passed

Charge Passed (Coulombs)	Chloride Ion Penetrability
> 4000	High
2000 – 4000	Moderate
1000 – 2000	Low
100 – 1000	Very Low
< 100	Negligible

3. Results and Discussion

The fly ash mixes were tested for the compressive strength after 3, 7, and 28 days of curing. Table 2 shows the compressive strength of fly ash mixes at different curing ages. The mixture name FA10 means a binary mix in which 10% of the cement in the control mix was replacing with fly ash, and so on. Table 2 and Figure 1 show that FA20, the binary mix in which 20% of the cement was replaced with fly ash is the optimum mix in terms of compressive strength as it marginally surpassed the 28-day compressive strength of the control mix. This is remarkable noting the notoriously slow reactivity of fly ash. Table 2 also shows that fly ash replacement below the optimum ratio of 20% (10% and 15%) or above the optimum ratio (30% and 40%) produce lower 28-day compressive strength compared to the control mix.

Figure 1 shows that the compressive strength of binary fly ash mixes coverage to the strength of control mix over time, except for FA20 which slightly exceeded the control mix after 28-days of curing.

Table 2. Compressive Strength of Binary Fly Ash Mixes

Mixture Type	Compressive Strength (MPa)		
	3d	7d	28d
Control Mix	51	61.48	66.08
FA 10	46.3	54.3	61.325
FA 15	42	50.3	62.5
FA 20	46.225	50.025	67.96
FA 25	38.6	43	61.7
FA 30	38.6	46.4	56.5
FA 40	31.43	36.7	55.75

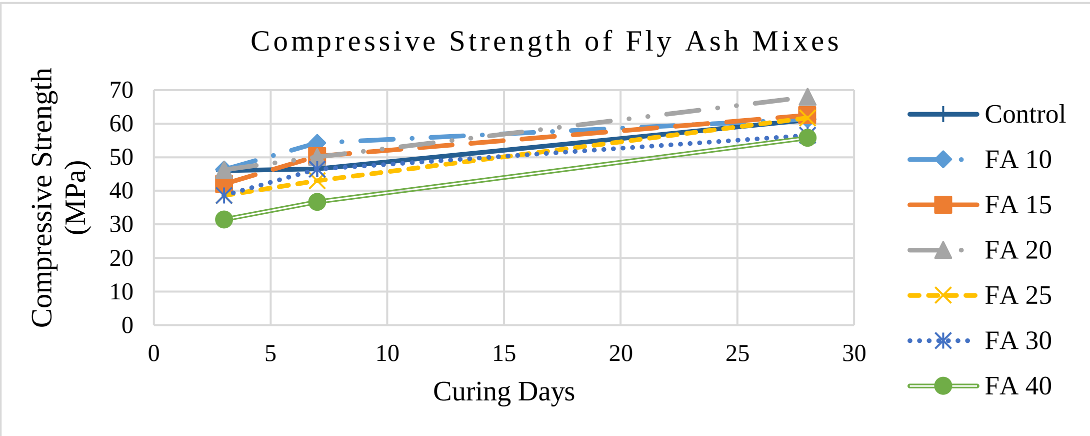

Figure 1. Compressive Strength of Fly Ash Mixes

Figure 2 shows the passing charge versus curing days for binary fly ash mixes. The passing charge was lower than the control mix for all replacement ratios and decreases with increase in cement replacement ratio. The higher the replacement ratio, the lower the passing charge.

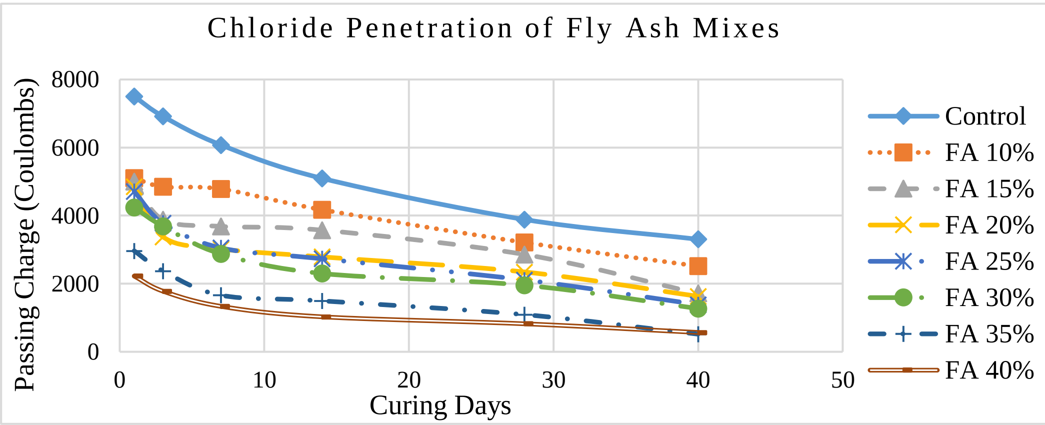

Figure 2. Chloride Penetration of Fly Ash Mixes

The best resistance to chloride penetration in fly ash mixes was exhibited by FA40 after 14 days of curing where the passing charge classifies as very low. FA20, the mix that produced the highest compressive strength of fly ash mixes, exhibited low chloride ion permeability after 40 days of curing.

4. Conclusions

In this paper, compressive strength development and chloride penetration resistance of six binary self-consolidating concrete mixes were assessed through an experimental program. Binary mixes contain cement that is partially replaced with various percentages of fly ash. The compressive strength was tested after 3, 7, and 28 days of curing. The chloride permeability of concrete was tested after 1, 3, 7, 14, 28, and 40 days of curing. The following observations were made:

- Partial replacement of cement with fly ash improves resistance to chloride penetration resistance compared to a control mix. This applied to cement replacement ratios examined in this study and after each of the curing days examined in this study as well.
- Binary mix FA20 in which 20% of the cement was replaced with fly ash produced the maximum 28-day compressive strength, slightly surpassing the control mix and higher than all other fly ash mixes. The chloride ions permeability for this mix was rated as *moderate* after 3 days of curing and rated as *low* after 40 days of curing.

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5. References

[1] ASTM C1202-17, (2017) Standard Test Method for Electrical Indication of Concrete & apos;s Ability to Resist Chloride Ion Penetration, *ASTM International*
[2] Mohamed O, Al-Hawat W, 2016 Influence of fly ash and basalt fibres on strength and chloride penetration resistance of self-consolidating concrete *Materials Science Forum* **866** 3-8
[3] BS EN 12390-3:2009, Testing hardened concrete Part 3. Compressive Strength of Test Specimens. *British Standards Institution*
[4] Mohamed O, Ati M, Al Hawat W, 2015 Using neural networks to predict chloride penetration of sustainable self-consolidating concrete, *Civil-Comp Press.*
[5] Ahari R, Erdem T, Ramyar K, 2015 Permeability properties of self-consolidating concrete containing various supplementary cementitious materials *Const. and Build. Materials* **79** 326-336
[6] Khodair Y, Bommareddy B, 2017 Self-consolidating concrete using recycled concrete aggregate and high volume of fly ash, and slag *Construction and Building Materials* **153** 307-316
[7] ASTM C 39/ C39M-10, 2010 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, *American Society for Testing and Materials*, Pennsylvania, PA
[8] Singh G, Siddique R, 2016 Effect of iron slag as partial replacement of fine aggregates on the durability characteristics of self-compacting concrete *Const. and Building Materials* **128** 88-95
[9] Gesoglu M, Güneyisi E. Kocabag M, Bayram V, Mermerdas K, 2012 Fresh and hardened characteristics of self-compacting concretes made with combined use of marble powder, limestone filler, and fly ash *Construction and Building Materials* **37** 160-170
[10] ASSHTO T277-89, 1990 Rapid determination of the chloride permeability of concrete. *American association of states highway and transportation officials*, Standard Specifications-Part II, Washington, DC.
[11] Beglarigale A Halit Yazici H, 2014 Mitigation of detrimental effect of alkali-silica reaction in cement-based composites by combination of steel microfibers and ground granulated blast-furnace slag *J. of Mat. in Civil Engineering* **16(**12) doi.10.1061/(ASCE)MT.1943-5533.0001005
[12] Mohamed O A, Rens K L, and Stalnaker J J, 2001 Time effect of Alkali-aggregate reaction on performance of concrete, *Journal of Materials in Civil Engineering* **13**(2) 143-151