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Effect of Ordinary Portland Cement (OPC) and Blended Hydraulic Cement (BHC) on the Behaviour of Self-Compacting Concrete

D.S. Deshabandu, K.C. Ariyarathne, M.A.A.D.O. Athapaththu and B. Janarthanan

Abstract: Self-compacting concrete (SCC) is a special type of concrete that flows under its own weight while enhancing the compressive strength and durability compared to conventional concrete. This is an effort to present the possibility of using Blended Hydraulic Cement (BHC) instead of ordinary Portland cement (OPC) in SCC production. In order to achieve the required workability and basic mechanical properties, 10 control mixes of SCC with OPC were prepared using the coarse aggregate size of 5 mm – 14 mm. Each mix was cast using 100% OPC and 100% BHC separately. Fresh properties of the SCC were tested by using slump flow, V-funnel, L-box and J-ring test according to the EFNARC guideline. 9-cubes and 6-cylindrical specimens were cast per mix to determine the compressive strength at the 7th, 28th and 56th days. Test results illustrate that the workability properties of fresh concrete mix are moderately good using both cement types. Most mixes show higher 28th and 56th-day compressive strengths for SCC mix made of BHC than OPC compared with 7th-day compressive strength variation. Fly ash in BHC contributes later strength gaining of SCC in this study. Thus, the experimental investigation indicates the suitable mix designs used in the current construction industry.

Keywords: Compressive strength, Fly ash, Blended hydraulic cement, Self-compacting concrete (SCC), Superplasticizer

1. Introduction

Concrete is the most commonly used artificial composite material in the construction industry. Conventional concrete requires proper compaction given by vibration as an external energy input. Improper compaction leads to honeycombs. To address these shortcomings of conventional concrete, self-compacting concrete (SCC) was introduced to the construction industry. SCC was first developed in Japan in 1988 to achieve noise-free construction sites with improved quality of concrete [1]. The use of SCC offers economic, social and environmental benefits over traditional vibrated concrete construction. Ingredients of SCC are cement, sand, aggregate, water and admixtures, where the first four ingredients are similar to conventional concrete. SCC should be compacted under its own weight without any compaction, eliminating external vibrations and reducing labour cost, construction time, and noise pollution [2]. This makes the pumping process feasible for casting high-rise buildings, long-span bridges, wide slabs, deep foundations etc. [3]. Self-compacting concrete should satisfy the following abilities: passing, filling, flowing abilities, and segregation resistance at the plastic stage and strength at the hardened stage. Several tests such as U-box, L-box, J-ring, V-funnel, and slump flow test should be performed to assay the aforementioned abilities at the plastic stage.

In recent years, apart from ordinary Portland cement (OPC), developers have used different types of blended materials to blend with OPC and developed new varieties of cement. BHC is a good example of that where OPC is blended with fly ash. Since cement contributes a considerable percentage of the total volume in SCC, BHC is now popular in the local market.

Mr. D.S. Deshabandu, Undergraduate Student, Department of Civil Engineering, Faculty of Engineering, University of Jaffna.
Email:2017e025@eng.jfn.ac.lk
Mr. K.C. Ariyarathne, Undergraduate Student, Department of Civil Engineering, Faculty of Engineering, University of Jaffna.
Email:2017e010@eng.jfn.ac.lk
Eng. M.A.A.D.O. Athapaththu, AMIE(SL), B.Sc. Eng. (Hons) (Jaffna), Instructor in Department of Civil Engineering, Faculty of Engineering, University of Jaffna.
Email: athapaththu@eng.jfn.ac.lk
Eng. (Dr.) B. Janarthanan, B.Sc Eng. (Hons) (Moratuwa), Ph.D (Steel Structures) (QUT, Brisbane), Senior Lecturer in Department of Civil Engineering, Faculty of Engineering, University of Jaffna.
Email:jana151188@eng.jfn.ac.lk
http://orcid.org/0000-0003-2476-7102

The main objective of this study is to investigate the possibility of using BHC in SCC. There is no globally accepted method to design appropriate mix proportions of SCC mix. Thus, this experimental investigation followed a trial-and-error method to produce a workable SCC mix with OPC and BHC with good fresh and hardened properties to fulfil the current construction needs.

2. Literature Review

SCC is fresh concrete, which flows under its own weight and does not need external vibration. SCC shows good performance in compressive strength, and now it is used in construction worldwide. Therefore, a profitable and easily usable mix design is necessary for the industry. In SCC, cement contributes a considerable percentage of the total volume, and it has high physical and chemical properties, which helps to improve the SCC performance and strength. OPC and BHC were used for this experimental investigation.

In BHC, a considerable amount of fly ash is blended with OPC as an additive, which causes BHC to behave differently to OPC. Since the effect of BHC on the behaviour of SCC has not been evaluated before, this study considered the previous research studies performed with the addition of mineral admixtures like fly ash, dolomite, metakaolin etc., with SCC. Dinakar et al. [4] tried to find a proportioning method to produce high-quality SCC with fly ash. To obtain the required strength of SCC with fly ash, designers need to follow the 'efficiency concept' already developed for mixing conventional concrete with fly ash. To obtain the high deformability of SCC, adding a superplasticizer is a must. Unlike conventional concrete, there is no global standard available for the design process of SCC. Higher powder content and lower coarse-aggregate content is required to achieve self-compatibility [2]. Increasing the powder content can be done using fly ash instead of additional cement, and it is an economically feasible solution since fly ash is a by-product. Using the mineral admixtures like fly ash also increases the slump of the SCC mix. It was reported that replacing cement with about 30% fly ash helped to reach enhanced rheological properties and high flowing ability of concretes. Several researchers ([5], [6], [7]) have proposed a mixed design method based on studies of paste volume and superplasticizer compatibility by mixing trial mixes. However, final product must be fulfilling the requirements of workability such as passing ability, filling ability and flowability, and segregation resistance.

Bhabuiya [8] has conducted a research study on 'Effects of fly ash and dolomite powder on the properties of self-compacting concrete' and analysed the freshened and hardened properties of SCC. Different proportions of fly ash and dolomite powder were mixed by mass percentages in this study. Slump flow for all the mixes was in SF1 class (550 mm – 650 mm) which is an indication of good deformability according to EFNARC guidelines [9]. V-funnel times were in the VF1 class (less than 8 seconds), which means all were good in terms of their viscosity. L-box ratios of all mixes were good according to EFNARC guidelines [9]. When considering the compressive strengths, mix without dolomite powder containing 100% fly ash showed the highest compressive strength in all 3-day, 7-day and 28-day tests. Thus, the use of dolomite powder as a filling material instead of fly ash caused to decrease the compressive strength [8]. Considering the aspect of quality control of SCC, fly ash is more appropriate than other types of binder materials [10].

High amount of fly ash slows down the early strength gain of concrete and delays the construction speed. This can be eliminated using optimal amount of fly ash, providing a more technological and environmentally friendly concrete mix [11]. The optimal dosage of fly ash is already included in the BHC because it is manufactured under certain standards. Considering the above facts, it is better to check SCC properties made with BHC compared to OPC. No research study investigates the possibility of using BHC for SCC production. Therefore, this study investigated the effect of OPC and BHC on the behaviour of SCC because almost every past investigation about the use of OPC / FA cement has been done for manually mixed fly ash in their laboratories in small scale and no experiments carried out to assess scale in industrially produced BHC.

3. Methodology

3.1 Materials

Cement – Grade 42.5 R BHC with standard consistency 31.5% and grade 42.5 R OPC with standard consistency 30.0% were used in the study.

Fine Aggregate - Natural River sand sieved by 4.75 mm sieve was used to avoid impurities that negatively affect SCC properties.

Coarse Aggregate – Locally sourced crushed stone free from much flaky and elongated particles was used for the concrete. It was sieved using a 14 mm and 5 mm sieve to get a 5-14mm range aggregate.

Water - Potable water was used for both mixing and curing purposes. This water was free from any number of substances and organic materials that can affect the fresh and hardened properties of SCC.

Admixtures – CASHTEC chemical admixture was used as a water reducer in this study.

3.2 Mixing Procedure

Since there are no standard mix design methods available to determine the mixing proportions of materials in SCC, a trial-and-error method was followed to find appropriate mixing proportions to obtain a workable SCC mix that passes the standard workability tests. Therefore, ten workable SCC mixes (control mix designs) were adopted with OPC cement type. BCC replaced the OPC portion of these control mixes, and standard workability tests were performed. Mixing proportions of control mix designs are shown in Table 1.

Slump Flow Test

Each fresh concrete mix has gone through several fresh property tests to ensure the concrete has self-compacting abilities. Thus, slump flow test, L-box test, V-funnel test and J-ring test were performed according to EFNARC guidelines to observe the workability, filling ability, passing ability and segregation resistance. Obtained results were recorded for the analysis purpose.

The slump flow test (Figure 1) is a method to measure the flowability, performed according to the BS EN 12350-8:2010 [12]. In this test, the inverted slump cone is filled in one layer of SCC without compaction and slowly lifted vertically without any disturbance. Then the diameter of the concrete spread was measured in two perpendicular directions. The mean spread value in millimetres was recorded. Required values should lie between 650 mm and 800 mm.

J-Ring Test

The J-Ring test (Figure 2) was used to investigate the passing ability of SCC. The mixture was allowed to flow through tight openings, including spaces between reinforcing bars and other obstructions without segregation or blocking. To measure the passing ability of the SCC, the difference between the slump flow test results with and without J-ring was compared.

Table 1 - Mixing Proportions for SCC (for 1 m^3 of Concrete Mix)

	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (kg)	Admixture (%)
Mix 01	540.0	650.0	900.0	190.5	1.20
Mix 02	540.0	650.0	900.0	176.0	1.60
Mix 03	524.3	874.5	687.2	188.2	1.20
Mix 04	524.3	874.5	687.2	178.0	1.60
Mix 05	454.7	777.7	866.9	177.7	1.20
Mix 06	454.7	777.7	866.9	172.2	1.60
Mix 07	495.3	874.6	715.5	191.7	1.20
Mix 08	495.3	874.6	715.5	183.4	1.60
Mix 09	483.2	725.9	889.5	173.0	1.60
Mix 10	489.7	826.2	777.7	179.1	1.60

In most cases, the value difference is negligible, hence the flowability of the SCC is ensured. Additionally, the height difference between the inside and outside concrete levels of the J-ring reinforcement bars was measured, which should be less than 10 mm.

V-Funnel Test
V funnel test (Figure 3) is V-shaped equipment designed to assess the filling ability of SCC. SCC should be filled into the V shaped funnel, without vibrating or tamping. Then the valve at the bottom of the V-funnel should be opened while starting the stop watch. The time required for the filled concrete to entirely flow through narrow-opening valve shall be measured. The measured time should be between 8-12 seconds, and a discontinuous flow is a sign of blocking and segregation of a mix.

L-Box Test
The L-box test (Figure 4) was used to investigate filling and passing ability of SCC to flow through tight obstructions without segregation or blocking. The vertical section of the L-box is filled with SCC, and the bottom gate is lifted to allow filled concrete in the vertical part to flow into the horizontal part. Conversely, the level of concrete at the end of the horizontal section is measured as the proportion of remaining concrete in the vertical section after concrete become settled. The ratio between the two readings should lie between 0.8 to 1.0 for required workability.

Figure 1 - Slump

Figure 2 - J-Ring test

Figure 3 – V-funnel test

Figure 4 – L-Box

Compressive Strength Test
After examining the fresh properties of SCC, nine cubes and six cylindrical specimens were cast for each mix. They were kept under room temperature for 24 hours until hardened. Then, all cubes and cylinders were placed in a curing tank, and compressive strength tests were carried out on the 7th, 28th and 56th days for both cubes and six cylindrical specimens.

Cube strength is 20% higher than Cylindrical strength. This is obvious as the cylinder sample height is 300 mm, higher than the height of the cube (150 mm). Eurocode 2 still uses the concrete strength in terms of cube and cylinder strengths. Therefore, both strength values were measured during this experimental study. The resistivity of the hardened concrete was also measured before crushing the concrete. After that, the effect of OPC and BHC on the behaviour of SCC was analysed.

4. Results and Discussion

The following results, such as mix-designs, workability tests, compressive strengths and resistivity values, were obtained from the laboratory experiments and analysed to determine the behaviour of SCC with BHC and OPC. The observed experimental data for the fresh properties of mixture and hardened properties were recorded and analysed for the ultimate motive of finding the best mix design parameters for optimum fresh properties and compressive strength.

4.1 Fresh Properties

4.1.1 Slump Flow Variation
Table 2 and Figure 5 interpret the variations of slump flow for all mix designs.

Table 2 - Slump Flow Variation for Both Cement Types

	Slump flow (mm)	
	For OPC	For BHC
Mix 01	735	690
Mix 02	735	730
Mix 03	590	671
Mix 04	720	707
Mix 05	663	693
Mix 06	660	690
Mix 07	675	718
Mix 08	685	715
Mix 09	650	610
Mix 10	675	695

The mean spread diameter values of slump flow of all mix designs are in an acceptable range. When considering OPC and BHC, the mixes with BHC show a slightly high slump flow value than OPC mixes. The increase of cement fines content causes it, and the mixture tends to behave as an entirely homogeneous mixture while showing the increased flowing ability of the mixture.

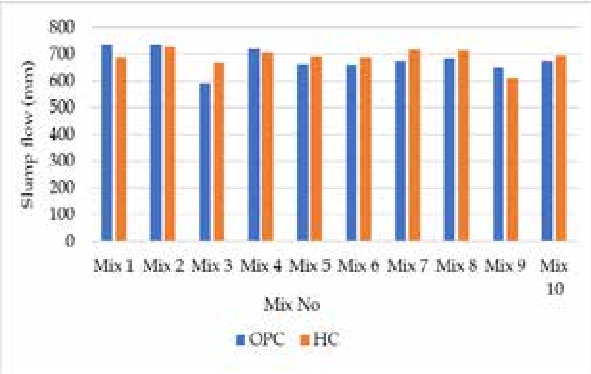

Figure 5 - Variations of Slump Flow

4.1.2 V-Funnel Time Variation

Table 3 and Figure 6 interpret the V-funnel test result variation between mixes with OPC and BHC, and all V-funnel times are in an acceptable range.

Table 3 - V-Funnel Time Variation

	V-Funnel time (s)	
	For OPC	For BHC
Mix 01	8.00	5.60
Mix 02	12.48	11.64
Mix 03	5.86	4.03
Mix 04	7.20	5.55
Mix 05	4.41	5.56
Mix 06	5.43	5.40
Mix 07	3.74	3.78
Mix 08	4.28	6.22
Mix 09	4.29	6.29
Mix 10	3.58	7.88

When considering the behaviour of SCC made of OPC and BHC, the SCC mixes with BHC show a slightly high V-funnel time value than OPC mixes because the increase of fines content in BHC causes to increase the cohesiveness of the mixture.

4.1.4 L-Box Variation

Table 5 and Figure 8 show the L-box test results for both SCC mixes with OPC and BHC.

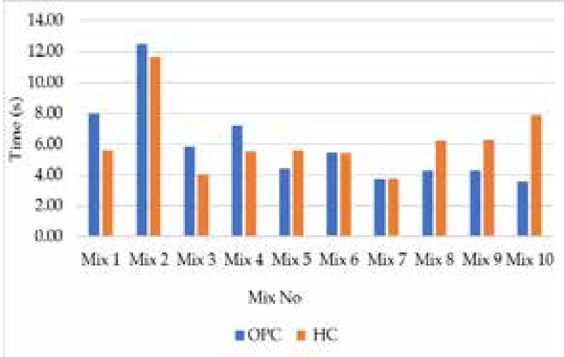

Figure 6 - Variations of V-Funnel Time

4.1.3 J-Ring

The variations of the height difference of J-ring for mixes are shown in Table 4 and Figure 7. According to that, most of the observed values for SCC mixes made of OPC and BHC are in the required range (0-10 mm) as mentioned in the EFNARC guideline. Moreover, mixes with BHC show less height difference compared with OPC mixes. That could be due to fly ash in BHC acting as a viscosity reducing agent and increasing the passing ability.

Table 4 - J-Ring Height Difference Variation for Both Types of Cement

	Height difference (mm)	
	For OPC	For BHC
Mix 01	18	14
Mix 02	16	16
Mix 03	17	7
Mix 04	7	4
Mix 05	8	10
Mix 06	10	9
Mix 07	8	4
Mix 08	5	3
Mix 09	10	13
Mix 10	6	9

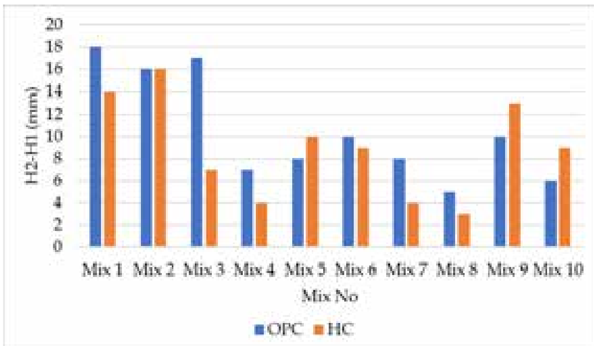

Figure 7 - Variations of the Height Difference of J-Ring

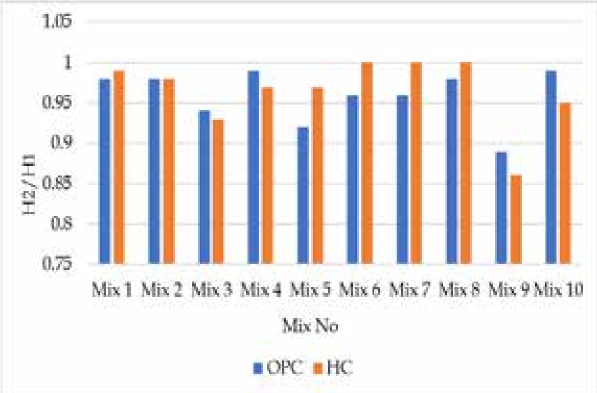

Figure 8 - Variations of Blocking Ratio of L-Box

Due to fly ash in BHC, SCC mixes present higher L-Box blocking ratios than OPC mixes because fly ash acts as a viscosity reducing agent and increases the passing ability of the concrete mixture through tight openings.

Table 5 - L-Box Blocking Ratio variation for Both Types of Cement

	Blocking ratio	
	For OPC	For BHC
Mix 01	0.98	0.99
Mix 02	0.98	0.98
Mix 03	0.94	0.93
Mix 04	0.99	0.97
Mix 05	0.92	0.97
Mix 06	0.96	1.00
Mix 07	0.96	1.00
Mix 08	0.98	1.00
Mix 09	0.89	0.86
Mix 10	0.99	0.95

4.2 Hardened Properties

4.2.1 7-Day Compressive Strength

Tables 6 and 7 indicate the 7th-day compressive strength values of the cubical and cylindrical specimens, respectively. Figure 9 and Figure 10 interpret the 7th-day compressive strength variation between SCC mixes with OPC versus BHC, respectively.

Table 6 - Variation of 7-day Compressive Strength of Cube for Both Types of Cement

	7-day compressive strength (MPa)	
	For OPC	For BHC
Mix 01	59.26	45.00
Mix 02	58.97	46.45
Mix 03	31.10	40.89
Mix 04	46.06	48.67
Mix 05	32.05	32.47
Mix 06	34.95	35.71
Mix 07	34.38	36.78
Mix 08	43.84	36.36
Mix 09	42.47	39.55
Mix 10	36.50	36.77

Here, mix 01 and 02 have the highest proportion of coarse aggregate than other mix designs, and they show higher 7th-day compressive strength than other mixes. Furthermore, most mixes that contain OPC have higher compressive strength than BHC mixes. The fly ash slows down the early strength development of concrete, leading to reduced 7th-day strength of SCC with BHC.

Table 7 - Variation of 7-Day Compressive Strength of Cylinder for Both Types of cement

	7-day compressive strength (MPa)	
	For OPC	For BHC)
Mix 01	50.04	38.36
Mix 02	43.40	31.60
Mix 03	28.26	29.44
Mix 04	36.38	35.79
Mix 05	32.63	29.74
Mix 06	28.38	20.08
Mix 07	30.99	30.75
Mix 08	37.79	29.06
Mix 09	37.10	36.36
Mix 10	27.81	26.85

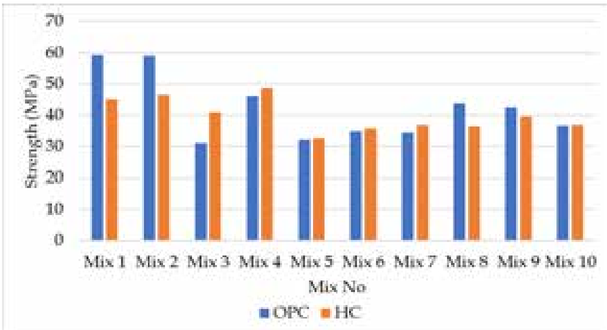

Figure 9 - Variations of 7-Day Compressive Strength of Cubes

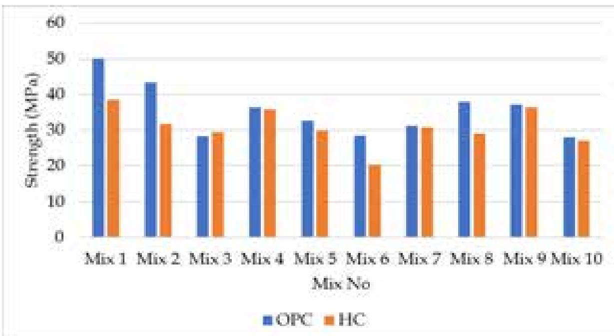

Figure 10 - Variations of 7-Day Compressive Strength of Cylinders

4.2.2 28-Day Compressive Strength

Tables 8 and 9 indicate the 28th-day compressive strength values of cubical and cylindrical specimens. Figures 11 and 12 interpret the 28th-day compressive strength variation between SCC mixes with OPC and BHC, respectively.

Most mix designs (except mix 01 and 02) present comparatively high compressive strength for SCC made of BHC in 28th day compressive strength compared to OPC. According to the results, the variation of the 28th day compressive strength of cylindrical and cubical cubes was almost similar.

Table 8 - Variation of 28-Day Compressive Strength of Cube for Both Types of Cement

	28-day compressive strength (MPa)	
	For OPC	For BHC
Mix 01	66.97	57.93
Mix 02	74.97	57.13
Mix 03	39.00	45.13
Mix 04	52.23	60.06
Mix 05	38.75	44.92
Mix 06	38.21	49.43
Mix 07	38.73	49.79
Mix 08	51.61	50.20
Mix 09	45.40	46.51
Mix 10	41.15	50.26

Table 9 - Variation of 28-day Compressive Strength of Cylinder for Both Types of Cement

	28-day compressive strength (MPa)	
	For OPC	For BHC
Mix 01	56.16	40.81
Mix 02	61.25	45.46
Mix 03	34.29	40.78
Mix 04	44.90	49.65
Mix 05	35.43	39.59
Mix 06	30.54	32.34
Mix 07	35.23	45.24
Mix 08	41.13	42.92
Mix 09	38.35	39.40
Mix 10	33.23	41.50

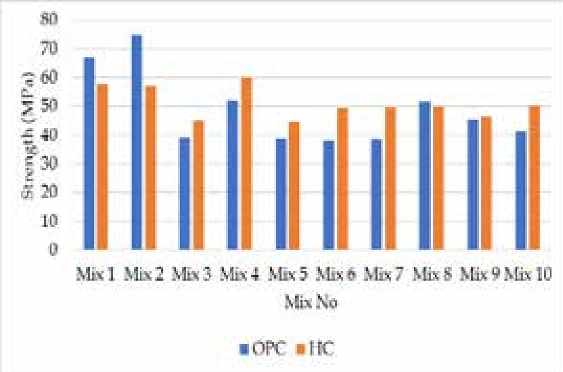

Figure 11 - Variations of 28-day Compressive Strength of Cubes

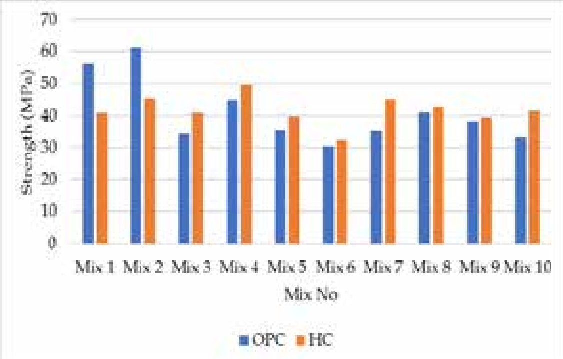

Figure 12 - Variations of 28-day Compressive Strength of Cylinders

4.2.3 56-Day Compressive Strength

Table 10 and Figure 13 show the compressive strength results for each SCC mix made with OPC and BHC. In 56th day compressive strength, most of the mix also indicates higher compressive strength for SCC with BHC than SCC mix made of OPC (except mix 01 and mix 02). But in contradiction, SCC mix 01 and mix 02 produce the greater compressive strengths for OPC among all mixes on the 7th, 28th and 56th than SCC with BHC. This may be due to higher coarse aggregate percentage.

Table 10 - Variation of 56-day Compressive Strength of Cube for Both Types of Cement

	56-day compressive strength (MPa)	
	For OPC	For BHC
Mix 01	67.96	62.57
Mix 02	76.92	61.32
Mix 03	39.10	49.17
Mix 04	53.29	66.25
Mix 05	45.84	48.84
Mix 06	43.59	50.96
Mix 07	48.39	52.69
Mix 08	53.69	54.46
Mix 09	47.11	49.30
Mix 10	46.18	53.93

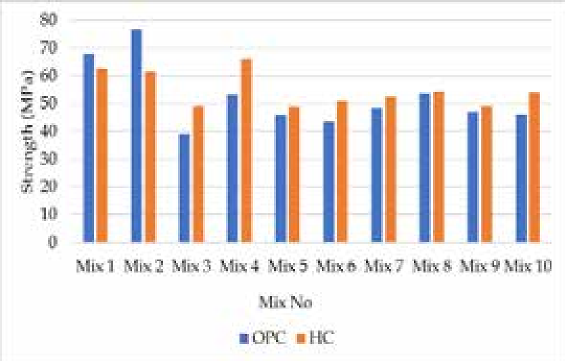

Figure 13 - Variations of 56-day Compressive Strength of Cubes

As mentioned in the above paragraphs, mixes 3 to 10 show higher later compressive strength development (28th day and 56th day) for BHC than OPC. However, less early strength was observed for mixes made of BHC compared to OPC (7th day). Since BHC contains fly ash, it leads to gain compressive strength later. Thus, a higher compressive strength could be obtained in most mixes with BHC. According to the mix, the compressive strength of cylinders was almost similar to the variations of 28-day compressive strength of cube vs mix designs.

4.2.4 Surface Resistivity

The variations of the 7th-day surface resistivity for all mix designs is shown in Table 11 and Figure 14. According to that, SCC with OPC presents higher surface resistivity than SCC with BHC.

Table 11 - Variation of 7-day Surface Resistivity

	7-day Surface resistivity (KΩ.cm)	
	For OPC	For BHC
Mix 01	6.3	3.8
Mix 02	7.2	4.3
Mix 03	6.4	3.3
Mix 04	6.7	3.6
Mix 05	6.6	5.7
Mix 06	8.4	6.7
Mix 07	6.2	6.0
Mix 08	5.6	5.8
Mix 09	5.7	4.5
Mix 10	4.5	3.9

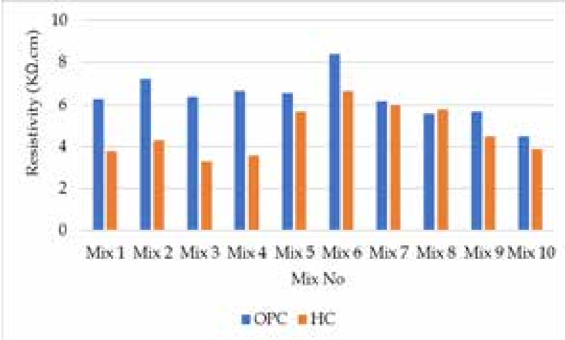

Figure 14 - Variations of 07-day Surface Resistivity

Tables 12 and 13 indicate the 28th day and 56th-day surface resistivity values for all mix designs and the variations of the 28th day and 56th-day surface resistivity for all mix designs are elaborated in Figures 15 and 16, respectively. The SCC made of BHC, entirely showed higher surface resistivity on both days than SCC with OPC.

When increasing the fines content of the cement by adding fly ash on BHC, the mixture behaved as an entirely homogeneous mixture and showed high surface resistivity than OPC.

Table 12 - Variation of 28-day Surface Resistivity

	28-day Surface resistivity (KΩ.cm)	
	For OPC	For BHC
Mix 01	10.1	9.7
Mix 02	12.1	22.4
Mix 03	10.9	15.9
Mix 04	10.2	14.9
Mix 05	9.5	25.5
Mix 06	11.1	24.8
Mix 07	8.8	30.4
Mix 08	8.0	23.5
Mix 09	8.7	17.9
Mix 10	8.4	22.8

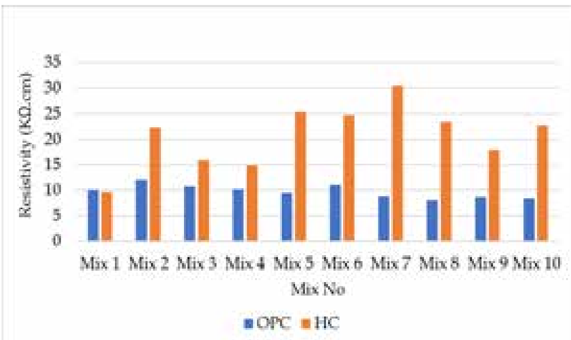

Figure 15 - Variations of 28-day Surface Resistivity

Table 13 - Variation of 56-day Surface Resistivity

	56-day Surface resistivity (KΩ.cm)	
	For OPC	For BHC
Mix 01	15.8	15.5
Mix 02	34.1	36.8
Mix 03	12.4	28.4
Mix 04	18.2	37.1
Mix 05	13.1	46.7
Mix 06	25.6	59.8
Mix 07	16.8	56.7
Mix 08	10	51.6
Mix 09	9.8	38.3
Mix 10	14.3	44.6

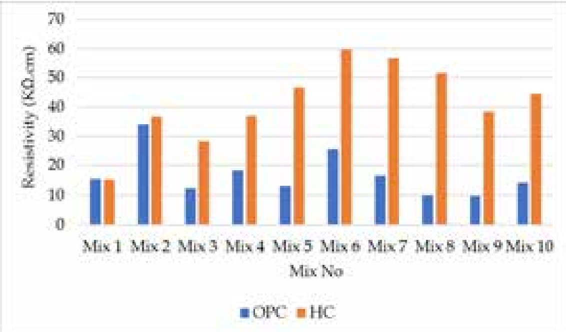

Figure 16 - Variations of 56-day Surface resistivity

4.2.5 Cost Analysis

Cost analysis was performed to check the financial feasibility of the SCC with both OPC and BHC cements. The cost per unit strength per unit volume (LKR/MPa.m^3) was calculated for all ten SCC mixes made of both OPC and BHC by using the unit prices of all ingredients except water. Figure 17 shows the cost per strength per 1 m^3 for considering the 28th day strength. Figure 18 shows that the cost per strength per 1 m^3 for considering the 56th day strength. When considering the 56th day compressive strength in Figure 18, the all-mix designs except mixes 01 and 02 show average 12% less cost per strength per 1 m^3 for SCC mixes made of BHC than OPC. When considering the 28th day compressive strength, this same behaviour can be observed. Hence, less cost per strength can be observed when using BHC in a same mix design.

Therefore, the use of BHC can be expected to be economically advantageous.

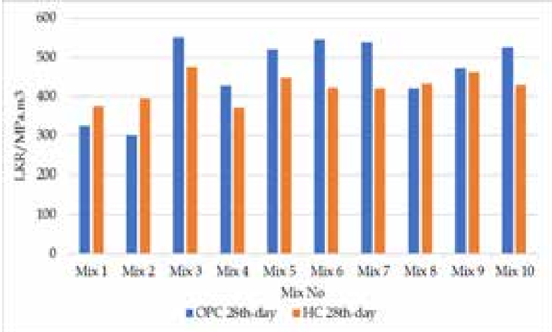

Figure 17 - Variations of Cost Per Unit Strength for Both Types of Cement (28th day)

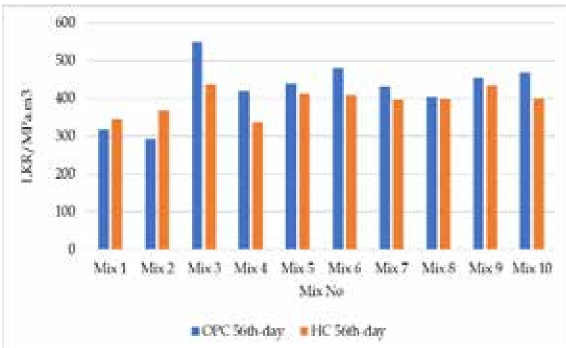

Figure 18 - Variations of Cost Per Unit Strength for Both Types of Cement (56th day)

5. Conclusions

The feasibility of using BHC, instead of OPC in SCC, has been investigated in this study. According to the results, the workability properties of fresh concrete are moderately good using both cement types. The BHC almost showed a high slump flow value (650 mm – 730 mm), less v-funnel time (4 s – 6 s), less height difference for J-Ring (4 mm- 10 mm) and a high blocking ratio for L-Box (0.95 - 1.00) when compared with OPC. Hence BHC causes to produce proper fresh properties such as flowing ability, filling ability and passing ability than OPC in SCC.

Although there is a reduction in 07-day compressive strength for SCC mix with the replacement of BHC, a higher compressive strength can be observed on the 28th day and 56th day. It is caused by the fly ash in BHC, and it increases the later strength development. Moreover, higher compressive strength could be obtained by decreasing the water/cement ratio. It can be further justified that, the strength of the concrete with BHC in mixes 01 and 02 which contain higher coarse aggregate has reduced about 23 % in 7th day, and 18% in 28th day compared with compressive strength in mixes with OPC. Moreover, mixes 03 and 04 which contain higher amount of fine aggregate, presented the higher compressive strength at

28th day with BHC compared with OPC mix and it is about 15%. In addition, 56th day compressive strength with BHC is higher by 25% than OPC mix. 7th day compressive strength of both OPC and BHC mixes in mixes 05, 06 and 10 is same. Moreover, it can be observed that all three days strength of mix design 09 with BHC have same strength value as its OPC mix strength value.

When increasing the fines content of the cement by adding fly ash to BHC, the mixture behaved as an entirely homogeneous mixture and showed high surface resistivity than OPC. But there is a delay in the early days to get the hardened properties such as compressive strength and surface resistivity due to the fly ash. Also, the compressive strength of SCC mixes on the 7th day for BHC is about 70% relatively to 56th-day strength, and the 7th-day compressive strength for OPC is about 80%. On the 28th day, compressive strength for SCC mix with BHC is about 90% relative to the 56th-day strength, whereas it is about 95% with OPC concrete mixes.

When considering cost analysis, less cost per strength can be observed for SCC mixes with BHC in the same mix design. Therefore, the use of BHC can be expected to be economically advantageous.

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