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Utilization of Filler Materials in Self-Compacting Concrete as a Partial Cement Replacement

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Abstract: Disposal of industrial waste materials such as cement Kiln dust, granulated ground blast furnace slag, and brick powder causes a nuisance in our environment. This research aimed to use these materials as partial cement replacement in production of self-compacting concrete having cement contents of 450 and 500 kg/m^3 at ratios of 5%, 10%, 15%, and 20% of cement weight. Fresh and hardened properties were estimated in this study. Results showed that increasing filler materials content led to a significant improvement in fresh properties. On the other hand, hardened properties generally decreased with the addition of these minerals. Results indicated that relative splitting tensile/compressive strengths mostly did not exceed 0.09. Relative flexural/compressive strengths mostly exceeded 0.15 at cement content equalling 450 kg/m^3. Relative splitting tensile/flexural strengths were less than 0.6 for most mixes.

Keywords: brick powder; cement kiln dust; granulated ground blast furnace slag; industrial waste materials; self-compacting concrete

1 INTRODUCTION

Sustainability is generally defined as achieving our needs without consuming future generations to meet our own needs. The three pillars of sustainability are environment, economy, and society. The green emissions of cement can be decreased by using supplementary cementitious materials such as fly ash, slag cement, silica fume, etc. Concrete applications can provide green benefits. Sustainable concrete is utilized in pavements, sidewalks, and parking areas that drain directly to the subsurface, eliminating the need for drainage structures, underground piping, retention basins, and direct discharge into rivers and lakes [1]. Production of cement increases, releasing green gases [2]. The need for cement is increased year after year. Cement is a major factor in carbon dioxide emissions [3]. Sustainability in cement production can be achieved by utilizing Portland cement replacement [4, 5].

Self-compacting concrete (SCC) is a special type of concrete that occupies any spaces in formwork without vibrations and has enough cohesion to be handled without segregation or bleeding [6]. It is a composition of cement, aggregates, water, mineral admixtures, and chemical admixtures.

Cement kiln dust (CKD) is a by-product formed while burning the raw materials in a rotary kiln to produce clinker. It can be used as cement replacement and supplementary cementitious materials in concrete and mortar [7]. Most CKD is disposed off in landfills. Many researches discussed the environmental, engineering, and economic benefits. Al-Jabri et al. [8] found that increasing CKD content up to 15% did not affect strength. Taha et al. [9] reported that CKD had a positive effect on concrete with low strength. Maslehiddin et al. [10] found that 10% CKD did not affect Portland cement requirements and improved compressive strength. Abdel-Gawwad [3] stated that concrete which included up to 5% CKD had similar properties to plain concrete. On the other hand, Najim et al. [11] found that increased CKD content led to a systematic decrease in mortar strength. Shoaib et al. [12] reported that increasing CKD dosage decreased hardened properties. Maslehiddin et al. [13] state that the maximum use for CKD was 5% due to an increase in chloride effect that causes corrosion in reinforcement.

Granulated ground blast furnace slag (GGBFS) is a by-product of iron manufacturing in the blast furnace. It consists of silicates and aluminosilicates of calcium [14]. The addition of GGBFS to SCC had many benefits related to consistency, compatibility, and retaining for a long time [15].

Brick powder (BP) originates from the demolition of existing buildings or manufacturing. It contains a significant percentage of silica and Alumina. Pozzolanicity of bricks and clays was investigated by Baronio and Binda [16]. Boukhelkhal et al. [17] found that the optimum percentage was 10% brick powder (BP), which decreased compressive strength. Seleem et al. [18] studied the effect of GGBFS and BP on the fresh and hardened properties of SCC. They concluded that SCC mixes incorporating higher contents of GBFS showed greater improvement than those containing high contents of BP that showed worsening in the fresh properties compared to the control mix. It also showed that the use of GBFS and BP as partial replacement of cement in SCC mixes produced a slight decrease in the compressive strength and tensile strength.

Most of the previous researches on the effect of CKD, GGBFS and BP studied their effect on SCC properties individually, and there is no research that compared the effect of the three types of minerals on SCC properties. Therefore, the present work is aimed to make a comparative study on the effect of CKD, GGBFS and BP by the ratios 5%, 10%, 15%, and 20% from cement weight on the fresh and hardened properties of SCC having cement contents of 450 and 500 kg/m^3. Relative strengths were found to get the relations between them.

2 EXPERIMENTAL PROCEDURES

2.1 Materials

Ordinary Portland cement Type I grade 52.5N was used according to ASTM C494. The coarse aggregate was dolomite with a maximum size of 10 mm and a specific gravity of 2.67. The sand was natural local siliceous sand with a specific gravity of 2.57 and a fineness modulus of 2.6. The sieve analysis for coarse and fine aggregates is shown in Fig. 1. CKD was obtained from the cement manufacturing process. GGBFS was provided from steel industries. BP was provided from the manufacturing of bricks. As recommended in EFNARC [19], these filler materials must be passed through a sieve of 150 μm, as shown in Fig. 2.

Table 1 Chemical and physical properties for Portland cement and mineral additives

Elements	Cement	CKD	GGBFS	BP
SiO_2 / %	18.83	17.1	35.4	64.17
CaO / %	61.54	49.3	36.87	3.65
MgO / %	1.27	1.14	6.83	0.50
Al_2O_3 / %	4.20	4.24	17.4	12.07
Fe_2O_3 / %	5.31	2.89	1.40	12.33
SO_3 / %	1.96	2.10	0.55	< 0.01
K_2O / %	0.49	0.36	0.46	1.87
TiO_2 / %	0.20	0.34	0.11	1.82
Na_2O_3 (%)	0.21	3.84	0.48	1.15
P_2O_5 / %	0.29	0.12	0.04	0.14
L.O.I / %	5.70	15.8	-	1.83
Color	Grey	Grey	Grey	Red
Specific density	3.15	2.60	2.80	2.54
Blaine fineness / cm^2/gm	3300	3500	4088	2925

Chemical compositions of Portland cement and filler materials are listed in Tab. 1. Superplasticizer Viscocrete-3425 based on polycarboxylate type F was used in this research.

2.2 Mix Design

A total of 26 mixes were performed in this study. Two CCs 450 and 500 kg/m^3 were used. Each cement content was divided into three filler materials: CKD, GGBFS, and BP. Each filler material was used as partial cement replacement at ratios 5%, 10%, 15%, and 20% from cement weight and two control concrete without filler materials. The identifications of these mixes were as follows: (XM-CC) where X: refers to filler materials ratio (5%, 10%, 15%, and 20%), M: filler materials type (CKD, GGBFS, and BP), and CC: cement content (450 and 500 kg/m^3). All mixes were prepared using a water/cement ratio of 0.35, Sand: dolomite ratio of 1:1 and superplasticizer content of 2% from cement weight to reach an acceptable rheological property in SCC. The concrete mix proportions are summarized in Tab. 2.

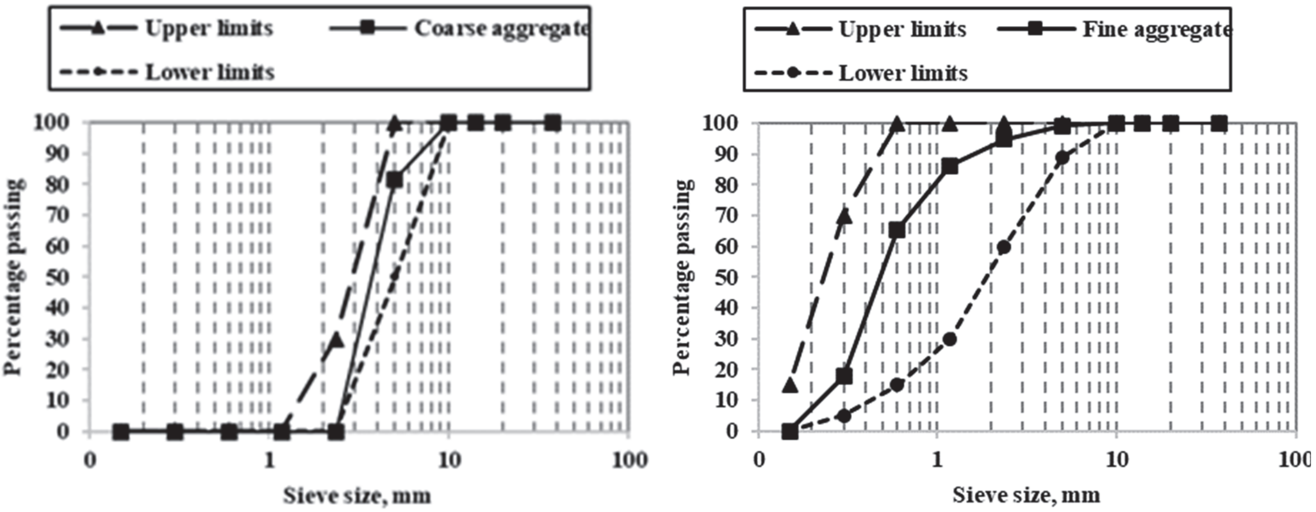
2.3 Mixing Procedures

Mixing time was constant for the same homogeneity and uniformity to all mixes. Initially started with mixing aggregates, cement, and filler materials using a standard mixer of 40 L for 1 min, then added 80% of water and mixed for another 1 min, after that superplasticizer was added to the rest of water and mixed with materials for another 3 min.

2.4. Test Methods

2.4.1 Fresh Concrete Tests

The fresh tests were performed just after mixing according to EFNARC [19]. These tests included slump flow test to measure slump flow diameter (SFD), T50, V-funnel test to measure the efflux time, and L-box test to measure the blocking ratio (H2/H1).



a) b)

Figure 1 Aggregates gradations: a) Coarse aggregate; b) Fine aggregate

(a) (b) (c)

Figure 2 Filler materials: a) CKD; b) GGBFS and c) BP

Table 2 Mix proportions for SCCs

Mix No.	Mix description	Cement	Water	Additives	additives	Coarse aggregate	Sand	Viscocrete
		kg/m^3	kg/m^3	%	kg/m^3	kg/m^3	kg/m^3	kg/m^3
Mix 1	Control-450	450	157.5	-	-	910	910	9.0
Mix 2	5CKD-450	427.5	157.5	5	22.5	910	910	9.0
Mix 3	10CKD-450	405	157.5	10	45	910	910	9.0
Mix 4	15CKD-450	382.5	157.5	15	67.5	910	910	9.0
Mix 5	20CKD-450	360	157.5	20	90	910	910	9.0
Mix 6	5GGBFS-450	427.5	157.5	5	22.5	910	910	9.0
Mix 7	10GGBFS-450	405	157.5	10	45	910	910	9.0
Mix 8	15GGBFS-450	382.5	157.5	15	67.5	910	910	9.0
Mix 9	20GGBFS-450	360	157.5	20	90	910	910	9.0
Mix 10	5BP-450	427.5	157.5	5	22.5	910	910	9.0
Mix 11	10BP-450	405	157.5	10	45	910	910	9.0
Mix 12	15BP-450	382.5	157.5	15	67.5	910	910	9.0
Mix 13	20BP-450	360	157.5	20	90	910	910	9.0
Mix 14	Control-500	500	175	-	-	865	865	10.0
Mix 15	5CKD-500	475	175	5	25	865	865	10.0
Mix 16	10CKD-500	450	175	10	50	865	865	10.0
Mix 17	15CKD-500	425	175	15	75	865	865	10.0
Mix 18	20CKD-500	400	175	20	100	865	865	10.0
Mix 19	5GGBFS-500	475	175	5	25	865	865	10.0
Mix 20	10GGBFS-500	450	175	10	50	865	865	10.0
Mix 21	15GGBFS-500	425	175	15	75	865	865	10.0
Mix 22	20GGBFS-500	400	175	20	100	865	865	10.0
Mix 23	5BP-500	475	175	5	25	865	865	10.0
Mix 24	10BP-500	450	175	10	50	865	865	10.0
Mix 25	15BP-500	425	175	15	75	865	865	10.0
Mix 26	20BP-500	400	175	20	100	865	865	10.0

2.4.2 Hardened Concrete Tests

Hardened concrete tests, including compression, indirect tension, and flexural, were conducted on all mixes. Dimensions of specimens were designed according to BS EN 12390-1 [20]. The compressive strength test was conducted on cube-shaped specimens having sides of 150 mm according to BS EN 12390-3 [21]. The indirect tensile strength test was conducted on cylinder-shaped specimens having 150 diameters and 300 mm height according to BS EN 12390-6 [22]. A flexural strength test was carried out on prism shape specimens having a square cross-section of 100 mm side length and a total span of 500 mm. The prisms were loaded under four points bending on a loaded span equal to 300 mm according to BS EN 12390-5 [23]. All specimens were tested at age 28 days using a 2000 kN capacity testing machine (Technotest). Five specimens were cast from each mix, de-molded 24 hours after casting and cured in water for 28 days.

3 RESULTS AND DISCUSSION

3.1 Fresh Properties

Fresh properties of SCC mixes are listed in Tab. 3. SFD represents the filling ability of SCC. All values of SFD for all mixes are within the limits of EFNARC [19], i.e., from 650-800 mm. Increasing CKD, GGBFS, and BP contents lead to an increase in the SFD values. For CC equalling 450 kg/m^3, the maximum enhancement was recorded in BP mixes, and the minimum enhancement was in GGBFS mixes. The opposite was observed at CC equalling 500 kg/m^3, where the maximum enhancement was found in GGBFS mixes, and the minimum was in BP mixes. T50 represents the flowability of SCC. All mixes were within the range of EFNARC limits [19], i.e., 2-5 sec, except mix 5GGBFS-450. Increasing CKD, GGBFS, and BP contents led to a decrease in the values of T50 except for mixes 5CKD-450 and 5GGBFS-450. For mixes of CC equal to 450 kg/m^3, the maximum decrease was in BP mixes, and the minimum decrease was in CKD mixes. While for mixes of CC equal to 500 kg/m^3, the maximum decrease was in CKD mixes, and the minimum decrease was in BP mixes. Ofuyatan et al. [24] found that increasing GGBFS contents improved SFD and reduced T50. Percentage of 10% GGBFS recorded the highest SFD and the shortest T50. Mohamed et al. [25] found that replacing cement with GGBFS improved the flowability but decreased the viscosity. On the other hand, increasing GGBFS contents beyond 35% increased segregation and bleeding. Regarding the V-funnel's efflux, all mixes within recorded values lie within the limits of EFNARC [19], i.e., 6-12 sec. Increasing CKD, GGBFS, and BP contents led to a decrease in the efflux time except for mixes 5CKD-450 and 5BP-500. For mixes having CC equal to 450 kg/m^3, the maximum decrease was for BP mixes, the minimum decrease was for CKD mixes. For mixes of CC equal to 500 kg/m^3, the maximum decrease in the efflux time was for CKD mixes, while the minimum was for BP mixes. Ofuyatan et al.[24] stated that replacing cement by 10% GGBFS had the shortest efflux time. The L-box test results showed that the ratios of H2/H1 for all mixes were within the recommended range of EFNARC [19], i.e. 0.8-1. Increasing CKD, GGBFS, and BP contents mostly led to an increase in H2/H1 ratio for mixes having CC equal to 450 kg/m^3, but scarcely improve H2/H1 ratio in mixes having CC equal to 500 kg/m^3. For mixes of CC equal to 450 kg/m^3, the maximum increase was found in GGBFS mixes, and the minimum was found in BP mixes. Ofuyatan et al. [24] stated that 30% GGBFS had the highest blocking ratio and passing ability. Leelavathi et al. [26] observed that increasing GGBFS contents (10%-50%) improved the fresh properties of SCC. Mansor et al. [27] found that increasing BP contents led to improving fresh properties. Mixes with CC equal to 500 kg/m^3 showed a higher filling ability, and passing- ability than mixes with CC equal to 450 kg/m^3. It can be stated that using filler materials as partial cement replacement by weight enhanced the fresh properties of SCC.

Table 3 Fresh properties for SCCs

Mix description	Slump flow test		V-funnel test	L-box test
	SFD / mm	T50 / s	Efflux time / sec	H2/H1
Recommended in EFNARC	650-800	2-5	6-12	0.8-1
Control-450	650	4.77	11.3	0.82
5CKD-450	650	4.80	11.98	0.80
10CKD-450	660	4.51	10.58	0.83
15CKD-450	700	3.36	8.93	0.83
20CKD-450	735	2.96	8.31	0.87
5GGBFS-450	680	5.50	11.31	0.88
10GGBFS-450	650	4.20	10.38	0.88
15GGBFS-450	695	3.73	8.32	0.93
20GGBFS-450	725	2.31	8.64	0.94
5BP-450	650	4.53	11.20	0.80
10BP-450	680	3.45	7.97	0.84
15BP-450	710	3.35	7.96	0.80
20BP-450	710	2.71	6.70	0.93
Control-500	660	4.75	9.78	0.94
5CKD-500	690	2.58	8.25	0.88
10CKD-500	740	2.54	7.27	0.93
15CKD-500	765	2.01	6.48	0.98
20CKD-500	775	2.38	6.08	0.98
5GGBFS-500	735	3.20	8.22	0.81
10GGBFS-500	775	3.00	8.40	0.88
15GGBFS-500	730	3.00	7.30	0.98
20GGBFS-500	785	2.50	6.50	1.00
5BP-500	695	4.98	10.49	0.83
10BP-500	715	2.84	6.49	0.85
15BP-500	745	2.53	6.41	0.88
20BP-500	770	2.50	6.70	0.93

3.2 Hardened Properties

3.2.1 Compressive Strength

Compressive strength, f_{cu}, for SCCs mixes are listed in Tab. 4. Increasing CKD, GGBFS, and BP ratios led to a decrease in compressive strength values. For mixes of CC equalling 450 kg/m^3, the reduction in f_{cu} ranged from 2.6% for 5% CKD to 10.9% for 20% CKD and ranged from 6.5% for 5% GGBFS to 10.7% for 20% GGBFS. The reduction in strength ranged from 9.3% for 5% BP to 28% for 20% BP. Replacing cement by 5% CKD, 10% GGBFS, and 5% BP recorded the minimum decrease in f_{cu} compared with the control mix. For mixes of CC equal to 500 kg/m^3, the reduction in f_{cu} ranged from 6.2% for 5% CKD to 14.9% for 20% CKD. The reduction in f_{cu} ranged from 6.3% for 5% GGBFS to 26.6% for 20% GGBFS. On the other hand, the reduction in f_{cu} ranged from 6.9% for 5% BP to 26.7% for 20% BP. Replacing cement by 5% CKD, 5% GGBFS, and 5% BP recorded the minimum decrease in f_{cu} compared with the control mix. Al-Rezaiqi et al.[28] found that 10% CKD and 20% CKD had similar strength to control concrete (within ±5%) at curing time of 28 days, 20% CKD had a lower value. They found that CKD major elements were portlandite (45–50%), calcite (15–20%), and Ca-based minerals. Mohsen et al. [29] found a decrease in f_{cu} with CKD due to the fewer amounts of C_2S and C_3S, and SiO2. Alkhatib et al. [30] revealed that compressive strength decreased by 5.5%, 6.8%, and 8.5% for 10% CKD, 15% CKD, and 20% CKD, replacement ratios respectively. Increasing CKD dosage leads to increasing free-lime content combined with water and forms $Ca(OH)_2$ [31]. Increasing CKD leads to increasing the quantity of sulfates which decreases the strength due to the formation of calcium sulfoaluminate hydrate [32]. Ofuyatan et al. [24] found that increasing GGBFS content led to a decrease in f_{cu} by 1.1% and 3.6% for 10% GGBFS and 30% GGBFS replacement ratio except the mix having 20% GGBFS replacement ratio which had strength similar to control mix. The decrease in compressive strength is due to a weak interfacial transition and porosity of mortar during adhesion to the fine and coarse aggregates [33]. Mohamed et al. [25] revealed that increasing GGBFS doses up to 60% increased the strength of control concrete. Leelavathi et al. [26] observed that increasing GGBFS contents improved f_{cu} (1%-7.8%). Mansor et al. [27] found that increasing BP contents up to 50% decreases f_{cu} (6.5%-51.3%). Mixes with CC equal to 500 kg/m^3 showed a higher reduction in f_{cu} than mixes of CC equal to 450 kg/m^3. The coefficient of variation's values was less than or equal to 0.10 for 20 mixes and was less than 0.15 for six mixes.

3.2.2 Splitting Tensile Strength

The splitting tensile strength, f_t, for SCC mixes is listed in Tab. 4. Increasing CKD, GGBFS, and BP contents led to a decrease in f_t except for mixes 5GGBFS-450 and 5CKD-500, which were enhanced by 3.7% and 3.9%. For mixes where CC equals 450 kg/m^3, the reduction in f_t ranged from 4.7% for 5% CKD to 16.5% for 20% CKD. The reduction in f_t ranged from 19.5% for 5% GGBFS to 22.5% for 20% GGBFS. The reduction in f_t ranged from 12% for 5% BP to 22.6% for 20% BP. For mixes of CC equal to 500 kg/m^3. The reduction in f_t ranged from 2.6% for 10% CKD to 34% for 20% CKD. The reduction in f_t ranged from 12.4% for 5% GGBFS to 25.2% for 20% GGBFS. The reduction in f_t ranged from 24.6% for 5% BP to 41.7% for 20% BP. It is observed that mixes with CC of 500 kg/m^3 showed a higher reduction in f_t than mixes having a CC of 450 kg/m^3. The coefficient of variation`s values is less than or equal to 0.10 for nineteen mixes and is less than 0.20 for seven mixes.

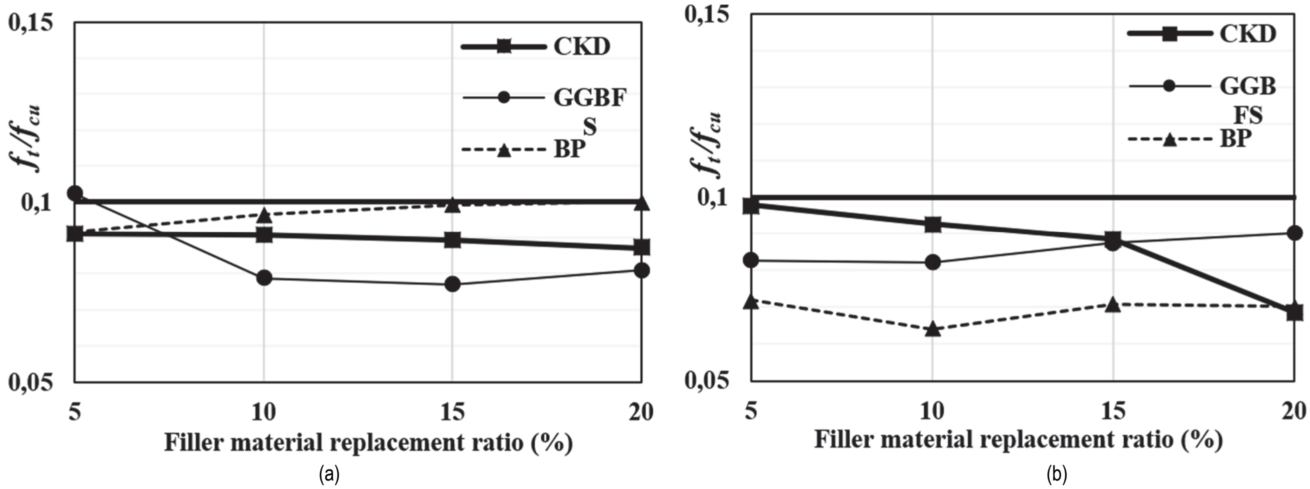
Table 4 Hardened properties for SCCs

Mix description	f_c			f_t			f_f		
	Mean / MPa	SD / MPa	C.O.V	Mean / MPa	SD / MPa	C.O.V	Mean / MPa	SD / MPa	C.O.V
Control-450	39.03	3.31	0.09	3.63	0.23	0.06	6.00	0.68	0.11
5CKD-450	38.03	2.18	0.06	3.46	0.30	0.09	5.94	0.69	0.12
10CKD-450	37.48	4.32	0.12	3.40	0.20	0.06	5.64	0.77	0.14
15CKD-450	36.54	3.54	0.10	3.26	0.34	0.10	5.40	0.60	0.11
20CKD-450	34.77	2.58	0.07	3.03	0.58	0.24	4.68	0.49	0.10
5GGBFS-450	36.47	2.46	0.07	3.73	0.21	0.06	6.66	0.69	0.10
10GGBFS-450	37.05	3.04	0.08	2.92	0.10	0.03	6.48	0.41	0.06
15GGBFS-450	36.48	2.95	0.08	2.81	0.23	0.08	6.45	0.48	0.07
20GGBFS-450	34.82	2.75	0.08	2.82	0.25	0.09	5.64	0.58	0.10
5BP-450	35.40	3.31	0.09	3.24	0.18	0.06	5.94	0.61	0.10
10BP-450	33.04	3.38	0.11	3.19	0.26	0.08	6.06	0.64	0.11
15BP-450	30.23	3.05	0.10	3.00	0.30	0.10	5.82	0.90	0.15
20BP-450	28.08	2.50	0.09	2.81	0.27	0.10	4.80	0.50	0.10
Control-500	43.87	4.68	0.11	3.88	0.71	0.18	6.30	0.60	0.10
5CKD-500	41.15	2.95	0.07	4.03	0.26	0.06	6.00	0.60	0.10
10CKD-500	40.76	3.37	0.08	3.78	0.23	0.06	5.64	0.64	0.11
15CKD-500	40.18	4.24	0.11	3.55	0.39	0.12	5.33	0.35	0.07
20CKD-500	37.32	2.05	0.05	2.56	0.12	0.05	5.20	0.50	0.10
5GGBFS-500	41.08	1.78	0.04	3.40	0.25	0.07	6.23	0.52	0.08
10GGBFS-500	39.20	4.02	0.11	3.22	0.40	0.12	5.55	0.55	0.10
15GGBFS-500	35.78	2.73	0.08	3.13	0.42	0.14	5.18	0.55	0.11
20GGBFS-500	32.20	1.99	0.06	2.90	0.45	0.16	4.98	0.59	0.12
5BP-500	40.86	3.89	0.10	2.94	0.20	0.07	5.64	0.74	0.13
10BP-500	40.28	2.47	0.06	2.58	0.19	0.07	4.88	0.35	0.07
15BP-500	36.01	4.12	0.12	2.55	0.39	0.15	4.28	0.35	0.08
20BP-500	32.17	2.33	0.07	2.26	0.19	0.08	3.84	0.48	0.13

SD: Standard deviation, and C.O.V: Coefficient of variation

3.2.3 Flexural Strength

Values of flexural strength, f_f, for SCC mixes are listed in Tab. 4. Increasing filler materials contents led to a decrease in f_f except for mixes 5GGBFS-450, 10GGBFS-450, 15GGBFS-450, and 5BP-450 where they improved by 11%, 8%, 7.5%, and 6%, respectively. For mixes having CC equal to 450 kg/m^3, the reduction in f_f ranged from 1% for 5% CKD to 22% for 20% CKD. The reduction in f_f for 20% GGBFS was 6%. The reduction in f_f ranged from 1% for 10% BP to 20% for 20% BP. For CC 500 kg/m^3. The reduction in strength ranged from 4.8% for 5% CKD to 17.5% for 20% CKD. The reduction in strength ranged from 1% for 5% GGBFS to 20.9% for 20% GGBFS. The reduction in strength ranged from 10.7% for 5% BP to 39% for 20% BP. Ofuyatan et al. [24] found that increase of GGBFS contents led to decrease of strength by 6%, 3%, and 21.2% for 10% GGBFS, 20% GGBFS, and 30% GGBFS, respectively. The negative effect in flexural strength due to poor structure and partial cement replacement leads to stress concentrations in a weak zone of interfacial transition between mortar and aggregates [34]. Alkhatib et al. [30] revealed that 10% CKD, 15% CKD, and 20% CKD decreased the f_f by 5.8%, 10.26%, and 18.2%, respectively. The reduction due to weak interfacial zone is formed from chloride, alkalis, and calcium hydroxide by CKD. Mansor et al. [27] found that increasing BP contents up to 50% decreased strength from 2.9% to 44.7%. Mixes with CC equalling 500 kg/m^3 showed a higher decrease in f_f than mixes having CC equal to 450 kg/m^3. The coefficient of variation`s values is less than or equal to 0.10 for fifteen mixes and is less than 0.15 for eleven mixes.



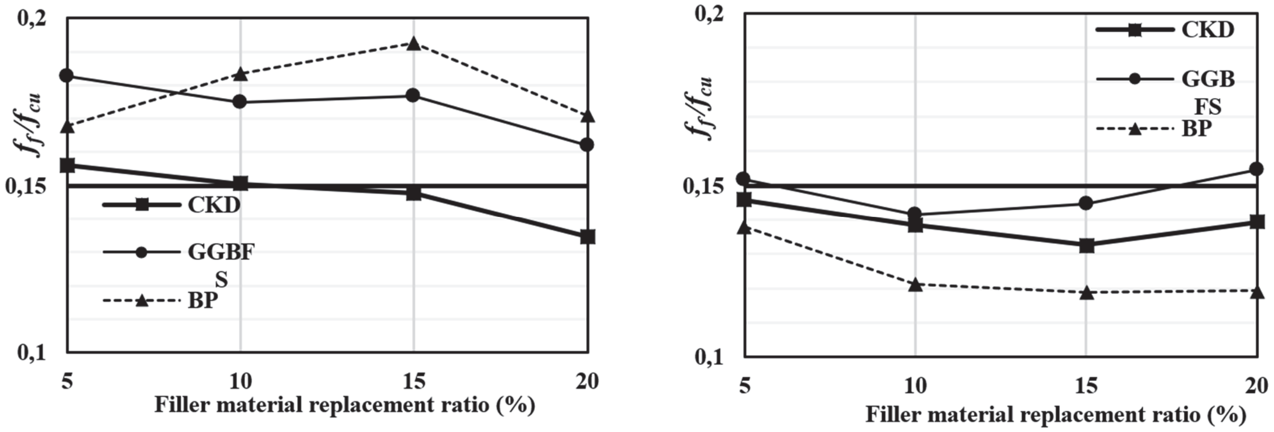
(a) (b)

Figure 3 Relative splitting tensile/compressive strength: a) cement content 450 kg/m^3 and b) cement content 500 kg/m^3

3.2.4 Relative Strengths

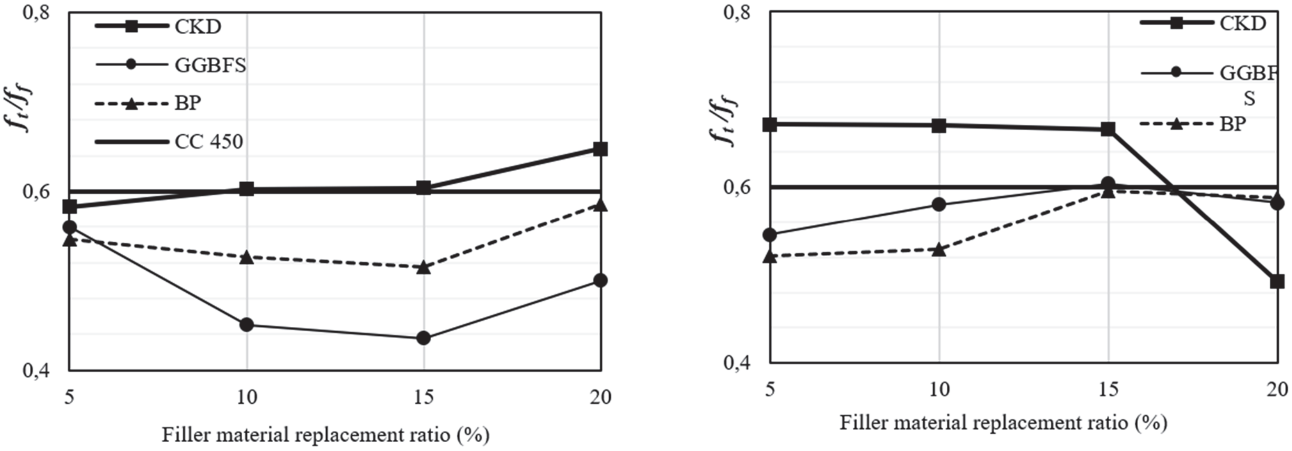
The strengths ratios were estimated for the different SCC mixes. Fig. 3 shows relative f_t/f_{cu} for SCC mixes. All ratios of f_t/f_{cu} for all SCC mixes containing mineral admixtures did not exceed that of the control mix, which equals 0.09 for mixes having CC of 450 kg/m^3 and 0.08 for mixes having CC equal to 500 kg/m^3 except mix 5GGBFS-450. Fig. 4 shows the f_f/f_{cu} ratios for SCC mixes and the control mix. Most ratios of f_f/f_{cu} exceed the ratio of f_f/f_{cu} for the control mix, which equals 0.15 for CC of 450 kg/m^3 but it did not exceed the ratio of the control mix having CC of 500 kg/m^3, which equals 0.14 except mixes 5GGBFS-500 and 20GGBFS-500. Fig. 5 shows the ratios of f_t/f_f for SCC mixes. All ratios did not exceed that of the control mix, which equals 0.6 except mixes 15CKD-450 and 20CKD-450 for CC which equals 450 kg/m^3, 5CKD-500, 10CKD-500, and 15CKD-500 for CC which equals 500 kg/m^3.

Fresh and hardened properties of SCC incorporating the other four different mineral additives including ceramic, granite, porcelain and marble powders will be investigated to be compared with the results of the present work.



(a) (b)

Figure 4 Relative flexural/compressive strength: a) cement content 450 kg/m^3 and b) cement content 500 kg/m^3



(b) (b)

Figure 5 Relative splitting tensile/flexural strength: a) cement content 450 kg/m^3 and b) cement content 500 kg/m^3

4 CONCLUSIONS

This paper studied fresh, hardened properties and relative strengths of SCCs containing CKD, GGBFS, and BP as mineral admixtures. The following conclusions can be drawn:

- Increasing CKD, GBBFS, and BP contents improved the flowability, filling ability, and passing ability for SCC compared with control concrete.
- Mixes with CC 500 kg/m^3 showed a higher enhancement in fresh properties than mixes with CC 450 kg/m^3.
- Increasing CKD, GBBFS, and BP contents decreased compressive strength for CCs 450 and 500 kg/m^3.
- Increasing CKD, GBBFS and BP contents led to decrease splitting tensile strength except 5% CKD for CC 450 kg/m^3 and 5% GGBFS for CC 500 kg/m^3.
- Increasing CKD, GBBFS and BP content decreased flexural strength except 5% GGBFS, 10% GGBFS, 15% GGBFS, and 5% BP for CC 450 kg/m^3.
- Mixes with CC 500 kg/m^3 showed a higher reduction in hardened properties than mixes with CC 450 kg/m^3.
- relative splitting tensile/compressive strength for mixes with CKD, GGBFS, and BP contents did not exceed ratio 0.09. relative flexural/compressive strength for most SCCs exceeded ratio 0.15 at cement content 450 kg/m^{3}and did not exceed ratio 0.14 at cement content 500 kg/m^3 for SCCs. relative splitting tensile/flexural strength for SCCs was mostly less than ratio 0.6.

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