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FILLER MATERIALS USING AS A PARTIAL CEMENT REPLACEMENT IN SELF-COMPACTING CONCRETE

Ahmed Mohamed EL-nopy[1]*, Mohamed Taha Noaman[2], Mohamed Hassan Seleem[3]

[1] Ass. Dr Civil Engineering Department, Higher Technological Institute,10th of Ramadan city, Egypt.
[2] Ass. Prof Civil Engineering Department, Al-Azhar University, Egypt.
[3] Prof Materials Engineering Department, Zagazig University, Egypt.
*Corresponding author: ahmed.el-nopy@hti.edu.eg

ملخص عربى:

التأثيرات البيئية الناتجة عن استهلاك الموارد الطبيعية على نطاق واسع في صناعة البناء، والتي تعتبر أساسية مثل الأسمنت. هذه العملية لا تخدم المقترحات ووجهات النظر المستدامة. التخلص من المخلفات الصناعية ضار بالنظام البيئي ويحتاج إلى تكلفة عالية. بعد هذه الحقائق، هدفت هذه الدراسة إلى استخدام أربع إضافات مالئة وهى بودرة الرخام وبودرة الجرانيت وبودرة السيراميك وبودرة البورسيلين كبديل جزئي للأسمنت في إنتاج خرسانة ذاتية الدمك تملك محتويات أسمنت 450 و 500 كجم / م 3. الإضافات المالئة تم إستخدامها بنسبة 5%، 10%، 15%، و 20% من وزن الأسمنت. أجريت الخصائص الطازجة في هذه الدراسة من خلال اختبارات انسياب الهبوط، زمن 50، فوهة -V، و صندوق -L. تم تقدير خصائص الصلابة في اختبارات الضغط والشد الإنحناء في وقت المعالجة 28 يوم. أشارت النتائج إلى أن زيادة محتوى المواد المالئة أدى إلى تحسين الخصائص الطازجة بشكل كبير. من ناحية أخرى ، لوحظ أقصى تحسن في مقاومة الانضغاط فقط في الخلطات المحتوية على 15% بودرة سيراميك، 20% بودرة بورسيلين، 5% بودرة رخام، و15% بودرة جرلنيت فقط مع محتوى أسمنت 450 كجم / م 3. نسبة الشد/الضغط لكل الخلطات لم تتجاوز 0.09 للخرسانة العادية. نسبة الإنحناء/الضغط لكل الخلطات تتجاوز 0.15 للخرسانة العادية. نسبة الشد/الإنحناء لكل الخلطات لم تتجاوز 0.06 للخرسانة العادية.

ABSTRACT:

Environmental impacts due to consuming large-scale of natural resources in construction industry, which like cement is fundamental. This process does not serve sustainable propositions and perspectives. Disposal of industrial waste materials is harmful to environmental system and needs to a high cost. After these facts this study aimed to use four filler additives (marble powder (MP), granite powder (GP), ceramic powder (CP), and porcelain powder (PP)) as a partial cement replacement in the production of self- compacting concrete having cement contents of 450 and 500 kg/m^3. Filler additives were used at ratios of 5%, 10%, 15%, and 20% from cement weight. Fresh properties were conducted in this study through slump flow, T50, V-funnel, L-box tests. Hardened properties were estimated in compression, splitting-tensile, and flexural tests at curing time of 28 days. Results mentioned that increasing filler materials content significantly improved fresh properties. On the other hand, the maximum improvement in compressive strength was observed only in mixes containing 15% CP, 20% PP, 5% MP, and 15% GP at cement content 450 kg/m^3. Results indicated that relative splitting tensile/compressive strengths for mixes containing filler materials mostly did not exceed control concrete ratio of 0.09. Relative flexural/compressive strengths for these mixes exceeded control concrete ratio of 0.15, and did not exceed control concrete ratio 0.6 for relative splitting tensile/flexural strengths.

Keywords: Granite powder; Marble powder; Ceramic powder; porcelain powder; self-compacting concrete, fresh and hardened properties.

1 INTRODUCTION

The productive sector drives economic and social development in civil construction using concrete worldwide which make it the second consumed material on the planet after water [1]. It is one of effected industries in the production of wastes in the environment [2]. Increasing demand of concrete causes exhaustion of the natural resources [3]. Now-days the global consumption for cement is 4600 Mt per year and will be 6000 Mt at the end of year 2050 [4]. It is about 0.94 ton emissions of CO_2 are generated for each ton of cement production, 0.55 ton of which is chemically released by the decomposition of $CaCO_3$, and the rest from processing (mainly burning and grinding) [5]. Leads to 7% of anthropogenic carbon dioxide emissions [6]. Use of industrial waste materials (IWMs) as a partial cement replacement can be the way to reduce carbon footprint and greenhouse effect.

Disposal of IWMs in landfills leads to environmental impacts and high cost. Nandi et al. [7] estimated transportation of IWMs and found it costs US$ 120 per ton of residue. The utilization of IWMs in production of concrete leads to decrease of CO_2 emissions [8].

Self-compacting concrete (SCC) is a concrete that can fill formwork under it is self-weight without needing for vibration and maintains its homogeneity in dense reinforcement. SCC has numerous advantages in itself and the application process: excellent performance in fresh state; economic benefits through increase rate of works and reduction of equipment and workmanship costs; decrease noise due to absence of vibrators; and production of complicated structures and highly congested reinforcement section [9]. SCC needs to high fines content throughout high cement consumption to achieve fresh state stability [10]. IWMs as a partial cement replacement improved properties of SCC, while reducing costs and environmental impact [8].

Ceramic powder (CP) is hard, durable, and highly resistant to chemical, biological, and physical degradation forces. The amount of waste for CP ranges from 3%-7% of the total production [11]. Many researchers studied utilization of CP as a partial aggregate replacement [12,13]. Lavat et al. [14] studied CP as cement replacement and found a decline in strength at early age. Torgal and Jalali [13] revealed that 20% CP had a slight decrease in compressive strength and a high enhancement for water permeability and chloride ion diffusion.

Vejmelková et al. [15] stated that utilization of CP led to appositive findings in mechanical, durability and thermal properties.

Porcelain powder (PP) is obtained during production process. Polishing step roughly removes 1 mm from the tile surface and 100 gm of PP is produced from 1 m^2 of porcelain tile [16]. Water-cooled machine using carbide, magnesium-based, and / or diamond abrasive tools perform the polishing, so PP is consisted of fine particles of porcelain tile and small amount of particles form abrasive tool. Previous researchers found that utilization of PP enhanced the compressive strength for mortar at 84 days [17]. Microstructure of concretes showed reduction in porosity and water absorption [18]. Ramos et al. [19] observed that use of PP significantly reduce emissions of CO_2 for mortar.

Marble and granite are types of stones that used in constructions and decorative purposes. Marble powder (MP) generating from cutting, processing, and polishing is in huge quantity. Singh et al. [20] found that mechanical properties and water porosity was improved with concrete containing MP up to 15% . Singh et al. [21] found that a positive impact in environment as reduction in cement consumption and river sand extraction is done with incorporating of MP in concrete. Rana et al. [22] observed that the best results in mechanical and durability properties were in mix containing 10% MP. Khyaliya et al. [23] found that mixes with MP up to 25% improved durability against aggressive environmental condition. Tunc [24] reported that utilization of MP up to 15% had economic profit and they developed nonlinear equations between compressive and splitting tensile strength. Topcu et al [25] found that MP contents up to 36% maintained workability of SCC but decreased the mechanical performance. Usyal and Sumer [26] stated than utilization of MP up to 10% improved fresh and mechanical properties. Usyal and Tanyildizi [26] found that utilization MP up to 30% led to a higher workability and a higher compressive strength.

Granite powder (GP) has physical and chemical attributes, and the most importantly is a fine material. Karmegam et al. [27] reported that GP has a better resistance to moisture, stains, cracks, cold, heat, and scratches. Vijayalakshmi et al. [28] found that the reduction in strength was slight for mixes containing GP up to 15%. Elyamany et al. [29] found an increase in super-plasticizer with the increase in GP content. They found also that increasing GP content led to increasing the compressive strength. Karmegam et al. [27] found that replacement of cement with GP at ratio 5%, 10%, 15%, and 20% led to enhancement fresh properties and improved compressive strength with GP content up to 10%. Sadek et al. [30] stated that incorporation 30%, 40%, and 50% GP in SCC improved compressive strength by 7.8%, 23.1%, and 39.3%m respectively

Most of the previous researches individually studied the effect of CP, PP, MP, and GP in SCC properties, and there is no research compared between the effects of the four types of additives on SCC properties. Therefore, the present work is aimed to give a comparative study on the effect of CP, PP, MP, and GP by the ratios of 5%, 10%, 15%, and 20% from Cement weigh on the fresh and hardened properties of SCC having cement contents (CC) of 450 and 500 kg/m^3. Relative strengths were found to get the relations between them.

2. EXPERIMENTAL PROGRAM

2.1 Materials

Powder materials in this study were ordinary Portland cement Type I grade 52.5N according to ASTM C494; CP and PP provided from manufacture in Sokhna; MP and GP supplied from manufacture in 10th of Ramadan city. Filler materials passed through sieve opening of 150 μm as recommendation in EFNARC [31], as shows in Fig. 1· Viscocrete-3425 superplasticizer based on type F was used with a specific gravity of 1090 kg/m^3 and solid content of 39.0% . Table 1 shows the chemical compositions and physical properties of the used Portland cement and additives. The fine aggregate was natural siliceous has specific gravity of 2.57 and a fineness modulus of 2.6. The coarse aggregate was dolomite of maximum size equals 10 mm and a specific gravity equals 2.67. Particle size distribution for the used aggregates is shown in Fig. 2.

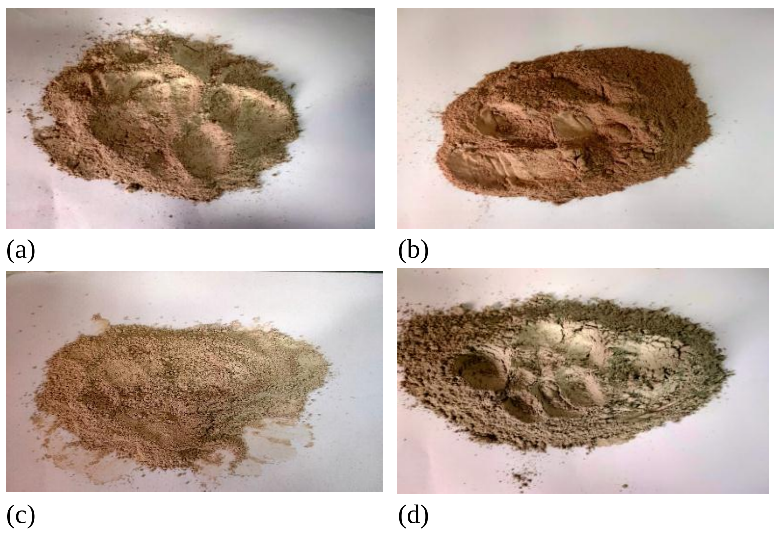


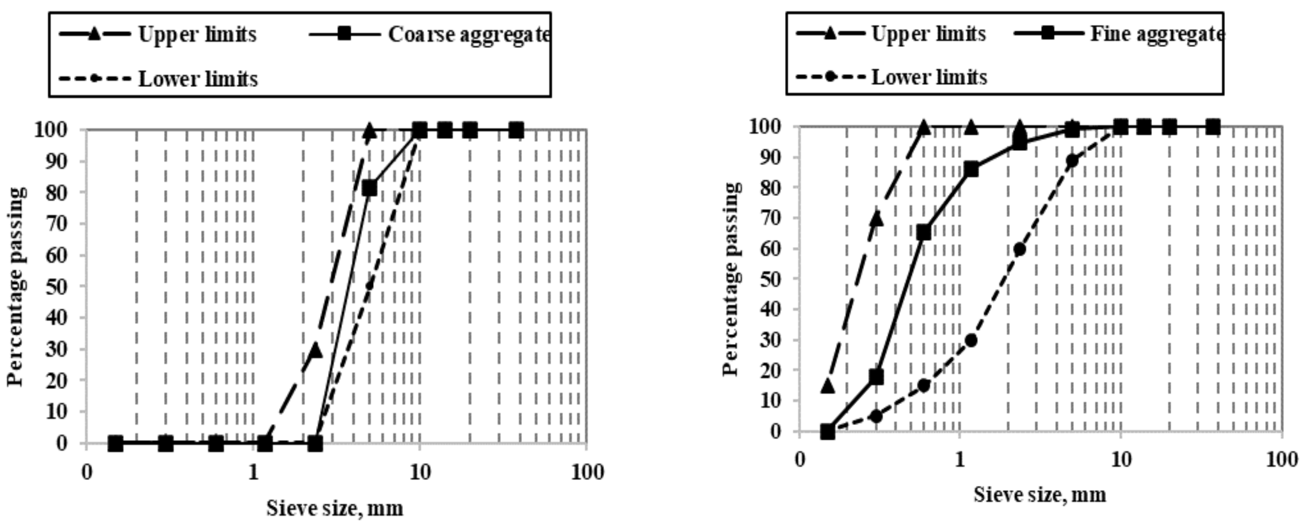
Fig. 1 Filler additives; (a) CP (b) PP (b) MP (b) GP

2.2 Mix Design

Thirty-four mixes of SCCs were investigated in this study. Control concretes were reference mixtures had Two CC of 450 and 500 kg/m^3. Water/cement ratio was maintained at 0.35 for all mixes. The cement was replaced with CP, PP, MP, and GP at ratios of 5%, 10%, 15%, and 20% from cement weight. Sand: dolomite ratio was 1:1 for all mixes. Superplasticizer content was 2% from cement weight to reach acceptable fresh properties. Mix proportions are presented at Table 2. Mixes were coded as follow: (XM-CC) where: X: refers to ratio of filler materials (5%, 10%, 15%, and 20%); M: type filler materials (CP, PP, MP, and GP); CC: cement content (450 and 500 kg/m^3).

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

Elements	Cement	CP	PP	MP	GP
SiO_2 (%)	18.83	60.10	65.24	5.42	70.54
CaO (%)	61.54	3.11	2.42	56.42	1.10
MgO (%)	1.27	1.43	0.15	< 0.01	< 0.01
Al_2O_3 (%)	4.20	23.11	19.59	0.39	13.47
Fe_2O_3 (%)	5.31	2.40	3.07	1.19	3.58
SO_3 (%)	1.96	0.02	< 0.01	< 0.01	< 0.01
K_2O (%)	0.49	1.74	1.63	0.39	4.06
TiO_2 (%)	0.20	0.85	0.75	0.16	0.47
Na_2O_3 (%)	0.21	0.56	0.91	< 0.01	3.82
P_2O_5 (%)	0.29	0.31	0.26	< 0.01	0.06
L.O.I (%)	5.70	6.06	5.60	35.59	2.52
Color	Grey	White	Red	White	Grey
Specific density	3.15	2.48	2.47	2.81	2.57
Blaine fineness (cm^2/gm)	3300	4100	4088	3900	3600



(a) (b)

Fig. 2 Grading curve; (a) Coarse aggregate (b) Fine aggregate

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	5CP-450	427.5	157.5	5	22.5	910	910	9.0
Mix 3	10CP-450	405	157.5	10	45	910	910	9.0
Mix 4	15CP-450	382.5	157.5	15	67.5	910	910	9.0
Mix 5	20CP-450	360	157.5	20	90	910	910	9.0
Mix 6	5PP-450	427.5	157.5	5	22.5	910	910	9.0
Mix 7	10PP-450	405	157.5	10	45	910	910	9.0
Mix 8	15PP-450	382.5	157.5	15	67.5	910	910	9.0
Mix 9	20PP-450	360	157.5	20	90	910	910	9.0
Mix 10	5MP-450	427.5	157.5	5	22.5	910	910	9.0
Mix 11	10MP-450	405	157.5	10	45	910	910	9.0
Mix 12	15MP-450	382.5	157.5	15	67.5	910	910	9.0
Mix 13	20MP-450	360	157.5	20	90	910	910	9.0
Mix 14	5GP-450	427.5	157.5	5	22.5	910	910	9.0
Mix 15	10GP-450	405	157.5	10	45	910	910	9.0
Mix 16	15GP-450	382.5	157.5	15	67.5	910	910	9.0
Mix 17	20GP-450	360	157.5	20	90	910	910	9.0
Mix 18	Control-500	500	175	-	-	865	865	10.0
Mix 19	5CP-500	475	175	5	25	865	865	10.0
Mix 20	10CP-500	450	175	10	50	865	865	10.0
Mix 21	15CP-500	425	175	15	75	865	865	10.0
Mix 22	20CP-500	400	175	20	100	865	865	10.0
Mix 23	5PP-500	475	175	5	25	865	865	10.0
Mix 24	10PP-500	450	175	10	50	865	865	10.0
Mix 25	15PP-500	425	175	15	75	865	865	10.0
Mix 26	20PP-500	400	175	20	100	865	865	10.0
Mix 27	5MP-500	475	175	5	25	865	865	10.0
Mix 28	10MP-500	450	175	10	50	865	865	10.0
Mix 29	15MP-500	425	175	15	75	865	865	10.0
Mix 30	20MP-500	400	175	20	100	865	865	10.0
Mix 31	5GP-500	475	175	5	25	865	865	10.0
Mix 32	10GP-500	450	175	10	50	865	865	10.0
Mix 33	15GP-500	425	175	15	75	865	865	10.0
Mix 34	20GP-500	400	175	20	100	865	865	10.0

2.3 Mixing Procedures

SCCs were prepared in 40 L a standard mixer 60 rpm with the following steps: 1) Mixing dry materials for 1 min; 2) 80% of water was gradually added for 1 min; 3) superplasticizer was added to rest of water and mixed for 1 min. Mixing time was not less than 5 min for all mixes.

2.4 Fresh Concrete Tests

According to EFNARC [31] fresh concrete tests were performed just after mixing. These tests were slump flow test to measure slump flow diameter (SFD); T50, V-funnel test to measure the efflux time; and L-box test to estimate the blocking ratio (H2/H1).

2.5 Hardened Concrete Tests

Hardened concrete tests were performed on specimen with dimensions designed according to BS EN 12390-1 [32]. They were compression, indirect tension, and flexural tests on all mixes. The compressive strength was determined on 150 mm side length cube- specimens according to BS EN 12390-3 [33]. The indirect tensile strength was determined on cylindrical specimens of 150 mm diameter and 300 mm height according to BS EN 12390-6 [34]. A flexural strength test was carried out on 100x100x400 mm prism specimens according to BS EN 12390-5 [35] and were loaded under four points bending on a loaded span equal to 300 mm. All specimens were tested at age 28 days using a 2000 kN capacity testing machine (Technotest). Five specimens were casted for each concrete type, de-moulded 24 hours after casting and cured in water for 28 days.

3. RESULTS AND DISCUSSION

3.1 Fresh Properties

Table. 3 represents fresh properties of SCCs. SFD refers to the filling ability of SCC. Values of SFD for all mixes are within EFNARC limits [31], i.e., from 650-800 mm except GP mixes with CC 450 kg/m^3. For CC 450 kg/m^3, increasing CP, PP, and MP contents increased SFD values. Increasing GP contents decreased SFD values. The maximum improvement is observed for CP mixes. The minimum improvement is observed for PP mixes. On the other hand, for CC 500 kg/m^3, increasing CP, PP, MP, and GP contents increased SFD values. The maximum improvement was observed for GP mixes. The minimum improvement is observed for CP mixes. T50 represents the flowability of SCC. All mixes were within EFNARC limits [31], i.e., 2-5 sec, except mixes 5GP-500 and 10GP-500. For CC 450 kg/m^3, Increasing CP, PP, MP, and GP contents decreased T50 values except mix 5PP-450. MP mixes had the maximum decrease in T50. The minimum decrease is observed in PP mixes. For CC 500 kg/m^3, increasing CP, PP, MP, and GP contents led to decreasing T50 values. The maximum decrease is in CP mixes. The minimum decrease is in PP mixes. Regarding the V-funnel's efflux time, all mixes within the limits of EFNARC [31], i.e., 6-12 sec. For CC 450 kg/m^3, Increasing CP, PP, MP, and GP contents decreased the efflux time except mixes 5GP-450 and

10GP-450. The maximum decrease in efflux time is revealed in CP mixed. The minimum decrease is for GP mixes. For CC 500 kg/m^3, Increasing CP, PP, MP, and GP contents decreased the efflux time. The maximum decrease was for MP mixes. The minimum decrease was for GP mixes. The L-box test results show the blocking ratios in terms of H2/H1. H2/H1 ratios represent the passing ability for SCC. Results are within the recommended range of EFNARC [31] , i.e. 0.8-1. For CC 450 kg/m^3, increasing CP, PP, MP, and GP contents enhanced H2/H1 ratio except mix 5PP-450. The maximum H2/H1 ratios are for MP mixes. The minimum H2/H1 ratios are for PP mixes. At CC equals 500 kg/m^3, increasing GP content decreased H2/H1 ratios. The maximum enhancement is in MP mixes. The minimum enhancement is for CP mixes. Consequently, it can be stated that utilization of filler materials as a partial cement replacement by weight enhanced the fresh properties of SCCs. Mixes with CC equals 500 kg/m^3 showed a higher fresh properties than those of CC equals 450 kg/m^3. Matos et al. [36] found that mix with 10% PP reduced efflux time. 20% PP had the same efflux time for control concrete, but 30% PP increased efflux time. They also found that T50 decreased in mix with 10% PP, and then gradually increased in mixes with 20% PP and 30% PP. They found that passing ability was improved up to 20% PP. Medeiros et al. [37] found that increase PP content led a decrease the consistency of SCCs, and mix with 30% PP had the minimum consistency. The reduction can be attributed to the high surface area of PP that needed high water demand. Heidari and Tavakoli [38] observed that increasing CP contents decreased slump values, but it is closer to that of the control concrete. Choudhary et al. [39] found that increasing MP content improved SFD. Although increasing MP content decreased T50 time, efflux time, and improved passing ability, it is a direct indication of lower viscosity and a higher workability. Jain et al. [40] found that T50 and V-funnel time were decreased with increasing GP content up to 40%. It means high flow ability due to adequate lubrication between particles of smaller size for GP. They found that passing ability improved with increasing GP content, but mixes with 60% GP and 80% GP had a slight blocking.

3.2 Hardened Properties

3.2.1 Compressive strength

Table 4 shows Compressive strength, f_{cu}, for SCCs. For CC 450 kg/m^3, 5% CP and 20% CP decreased f_{cu} by 7.9% and 6.6%. 10% CP and 15% CP improved f_{cu} by 2.2% and 19%. 5% PP, 10% PP, and 15% PP decrease f_{cu} by 13.7%, 11.9%, and 3.6%, respectively. Twenty percentage of PP improved f_{cu} by 11.8%. 5% MP, 15% MP, and 20% MP improved f_{cu} by 8.2%, 1.6%, and 3.1%m respectively. Ten percentage of MP decreased f_{cu} by -20%. 5% GP and 10% GP decreased f_{cu} by 22.8% and 9.1%. 15% GP and 20% GP improved f_{cu} by 26.4% and 5.7%. The maximum improvement in f_{cu} is observed in mixes with 15% CP, 20% PP, 5% MP, and 15% GP. For CC equal to 500 kg/m^3. 5% CP, 10% CP, 15% CP, and 20% CP decreased f_{cu} by 25.7%, 27.1%, 24%, and 22.7%, respectively. 5% PP, 10% PP, 15% PP, and 20% PP decreased f_{cu} by 19.8%, 26.2%, 30.4%, and 40.7%, respectively. 5% MP, 10% MP, 15% MP, and 20% MP decreased f_c by 22%, 36.7%, 29.2%, and 25.3%, respectively. 5% GP, 15% GP, and 20% GP decreased f_{cu} by 22.2%, 33.5%, and 56.8%, respectively. Mix with 10% GP had similar f_{cu} to control concrete. The minimum reduction in f_{cu} is observed for 20% CP, 5% PP, 5% MP, and 10% GP. Mixes with CC equals 500 kg/m^3 showed a higher reduction in f_{cu} than mixes of CC equals 450 kg/m^3. Matos et al. [41] stated that increase PP contents reduced f_{cu} by 10.4%, 20.9%, and 26.9% for 10% PP, 20% PP, 30% PP, respectively. They saw that PP promoted to more efficient cement hydration. Medeiros et al. [37] observed that 5% PP had the same f_{cu} for control concrete, then from 10% PP-30% PP f_{cu} was reduced within 8.6%-20.2%. Pozzolanic activity of PP contributes at a later age. Particles shape of PP is irregular, so it increases friction between particles and reduce filling effect. PP particles tends to agglomerate which fixed the pozzolanic reaction with $Ca(OH)_2$ in hydration process, so it need more superplasticizer to avoid agglomerate. Heidari and Tavakoli [38] reported that the f_{cu} decreased as the portion of CP increased due to inactive pozzolanic reaction and prevention growth of C–S–H gel. This reduction was 0.48%, 1.45%, 2.4%, 6.79%, 9.46%, and 19.9% for 10% CP, 15% CP, 20% CP, 25% CP, 30% CP, and 40% CP, respectively. Choudhary et al. [39] found that utilization MP up to 10% improved. f_{cu} by 5.2%. MP enhanced packing density by filling pores between sand and cement particles. It inert and non-pozzolanic materials, but in form of calcite and dolomite mineral can be responsible in reduction the nucleation barrier for the formation of calcium hydroxide. Jain et al. [40] found that GP content up to 40% improved f_{cu} . However, the surface roughness for GP exhibits to a better interfacial transition zone between aggregates and past which improves f_{cu}. They found increase the content beyond 40% decreased f_{cu} because of increase of a substantial number of voids in the concrete, and shortage cement past due to high surface area of GP.

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
Control-450	650	4.77	11.3	0.82
5CP-450	675	3.17	10.93	0.84
10CP-450	710	2.80	7.35	0.93
15CP-450	715	2.69	6.60	0.93
20CP-450	760	2.11	5.91	0.93
5PP-450	655	4.85	11.22	0.81
10PP-450	665	4.26	10.33	0.88
15PP-450	670	3.57	8.20	0.92
20PP-450	695	2.91	5.91	0.91
5MP-450	650	2.82	8.79	0.92
10MP-450	680	2.28	8.07	0.93
15MP-450	680	2.18	6.87	0.93
20MP-450	690	2.18	6.28	0.95
5GP-450	660	4.45	11.73	0.90
10GP-450	625	4.11	11.56	0.93
15GP-450	610	2.94	8.76	0.93
20GP-450	610	2.73	6.26	0.97
Control-500	660	4.75	9.78	0.94
5CP-500	700	2.97	7.84	0.93
10CP-500	720	2.61	6.95	0.93
15CP-500	750	2.60	6.31	0.93
20CP-500	775	2.57	5.96	0.94
5PP-500	735	4.72	7.96	0.93
10PP-500	740	4.66	6.92	0.93
15PP-500	745	3.20	6.89	1.00
20PP-500	750	2.73	6.41	1.00
5MP-500	730	5.00	8.18	0.95
10MP-500	745	3.20	6.68	0.97
15MP-500	760	2.50	6.05	0.97
20MP-500	770	2.26	6.20	1.00
5GP-500	745	5.87	6.80	0.94
10GP-500	750	5.35	6.81	0.88
15GP-500	780	4.86	7.16	0.88
20GP-500	795	3.94	6.38	0.81

3.2.2 Splitting tensile strength

Table 4 splitting tensile strength, f_t, for SCCs . Increasing CP, PP, MP, and GP contents led to a decrease in f_t except mixes 10PP-450 and 10CP-500. For CC equal to 450 kg/m^3, 5% CP, 10% CP, 15% CP, and 20% CP decreased f_t by 16.2%, 10.3%, 3.1%, and 12.3%, respectively. 5% PP, 15% PP, and 20% PP decreased f_t by 5.6%, 27.6%, and 11.3%, respectively. Ten percentage of PP improved f_t by 3.1%. 5% MP, 10% MP, 15% MP, and 20% MP decreased f_t by 13.4%, 31.6%, 24.9%, and 23.7%, respectively. 5% GP, 10% GP, 15% GP, and 20% GP decreased f_t by 48.1%, 9.6%, 31.6%, and 17.3%, respectively. The minimum reduction in f_t is observed in mixes with 15% CP, 5% MP, and 10% GP. The maximum improvement in f_t was observed in mixes with 10% PP. For CC 50 kg/m^3, 5% CP, 15% CP, and 20% CP decreased f_t by 35.6%, 32.9%, and 15.5%, respectively. Ten percentage CP had similar f_t to control concrete. 5% PP, 10% PP, 15% PP, and 20% PP decreased f_t by 32%, 18.8%, 15%, and 39.7%, respectively. 5% MP, 10% MP, 15% MP, and 20% MP decreased f_t by 18.5%, 14.6%, 31.7%, and 35.5%, respectively. 5% GP, 10% GP, 15% GP, and 20% GP decreased f_t by 43.8%, 13.8%, 43.1%, and 50.2%, respectively. The minimum reduction in f_t was observed in mixes with 10% CP, 10% PP, 10% MP, and 10% GP. 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.

3.2.3 Flexural strength

Table 4 presents values of flexural strength, f_f, for SCCs . For CC 450 kg/m^3, 5% CP, 10% CP, 15% CP, and 20% CP enhanced f_f by 37.5%, 36.9%, 55.3%, and 55%, respectively. Ten percentage PP, 15% PP, and 20% PP decreased f_f by 3.6%, 16.1%, and 6.9%, respectively. Only 5% PP enhanced f_f by 1.8%. 5% MP and 10% MP enhanced f_f by 20.1% and 1.3%. 15% MP and 20% MP decreased f_f by 3%, 1.4%. 5% GP, 10% GP, 15% GP, and 20% GP enhanced f_f by 22.8%, 39.9%, 41.3%, and 12.8%, respectively. The maximum improvement in f_f was observed for mixes with 15% CP, 5% PP, 5% MP, 15% GP. For CC 500 kg/m^3, 5% CP, 10% CP, 15% CP, and 20% CP decreased f_f by 20.3%, 12.6%, 19.4%, and 8.4%, respectively. 5% PP and 10% PP enhanced f_f by 13.5% and 12.4%. 15% PP and 20% PP decreased f_f by 5.5% and 2.1%. 10% PP, 15% PP, and 20% PP decreased f_f by 3.8%, 25%, and 11.5%, respectively. Only 5% MP improved f_f by 11%. 5% GP and 10% GP improved f_f by 4.6% and 23%. 15% GP and 20% GP decreased f_f by 10.4% and 24.3%. The maximum improvement in f_f is observed for mixes with 5% PP, 5% MP, and 10% GP. The minimum reduction in f_f is observed for mixes with 20% CP. Mixes with CC equals 500 kg/m^3 showed a higher decrease in f_f than mixes having CC equals 450 kg/m^3.

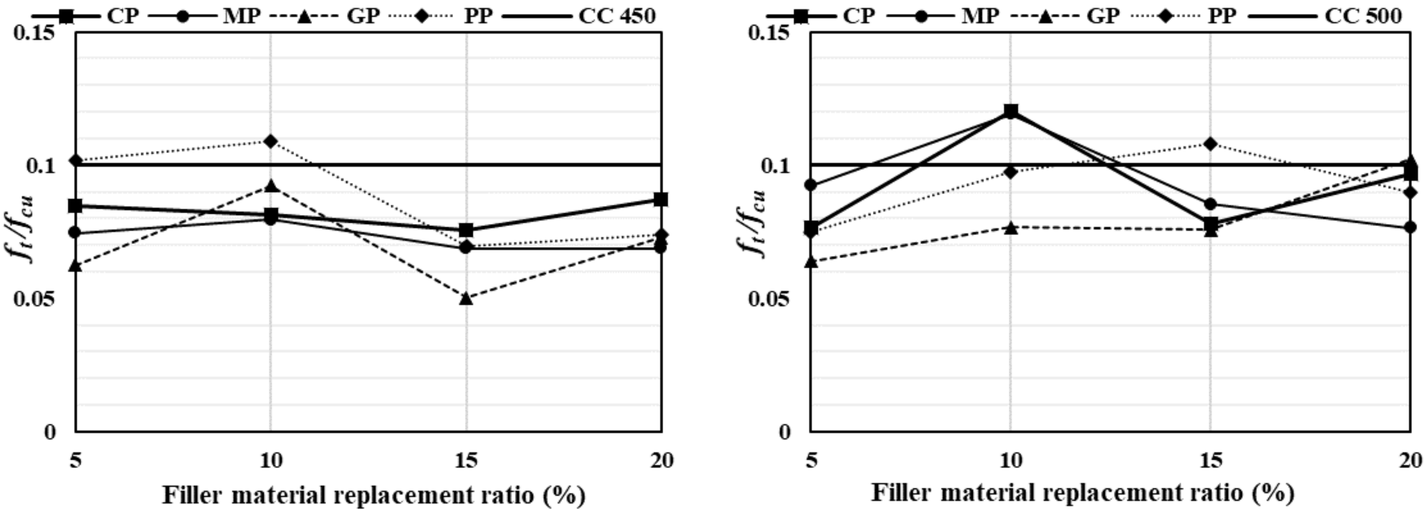
3.2.4 Relative strengths

The relative strengths were estimated for all 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 filler materials did not exceed ratio of the control mix, which equals 0.09 for mixes having CC of 450 kg/m^3 and 0.08 for mixes having CC equals 500 kg/m^3 except mixes 10PP-450, 10CP-500, 10MP-500, and 15PP-500,. Fig. 4 shows the f_f/f_{cu} ratios for SCC mixes and the control mix. All ratios of f_f/f_{cu} for all

SCC mixes containing filler materials exceeded ratio of the control mix, which equals 0.15 for mixes having CC of 450 kg/m3 and 0.14 for mixes having CC equals 500 kg/m3 except mixes 15PP-450, 15MP-450, 20PP-450, and 20PP450. 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 for mixes having CCs of 450 and 500 kg/m^{3}except mixes 10PP-450 and 10CP-500 .

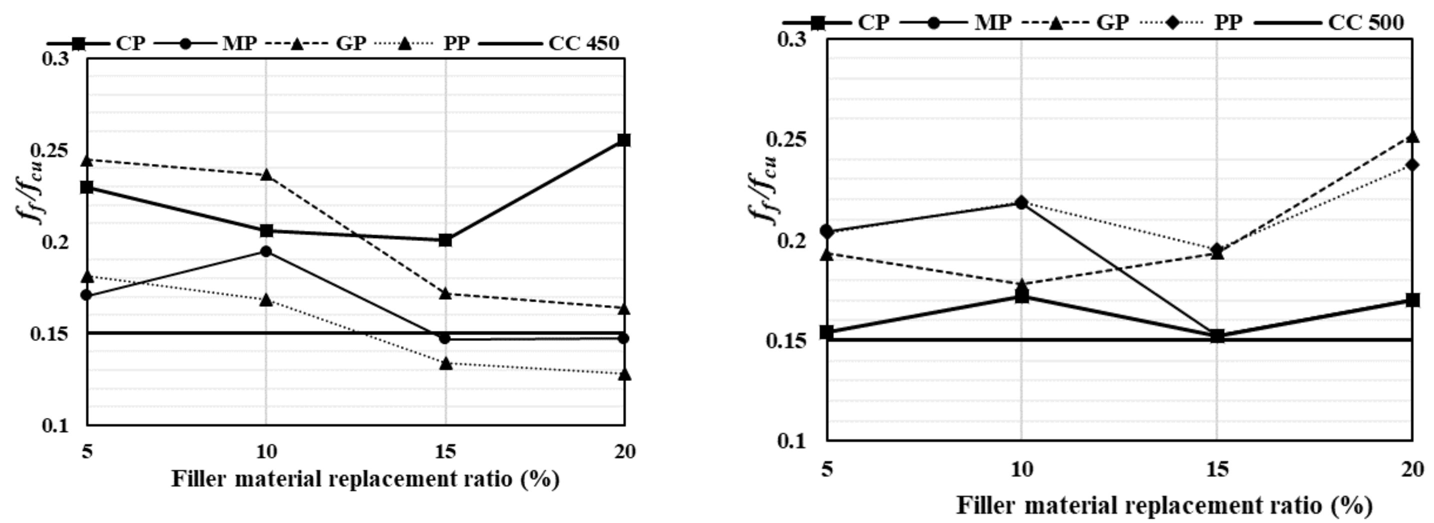
Table 4 Hardened properties for SCCs

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
5CP-450	35.93			3.04			8.25		
10CP-450	39.91			3.26			8.21		
15CP-450	46.46			3.52			9.32		
20CP-450	36.46			3.18			9.30		
5PP-450	33.70			3.43			6.108		
10PP-450	34.37			3.74			5.784		
15PP-450	37.62			2.63			5.0325		
20PP-450	43.66			3.22			5.586		
5MP-450	42.22			3.14			7.21		
10MP-450	31.23			2.48			6.08		
15MP-450	39.64			2.73			5.82		
20MP-450	40.25			2.77			5.92		
5GP-450	30.12			1.88			7.37		
10GP-450	35.49			3.28			8.39		
15GP-450	49.33			2.48			8.48		
20GP-450	41.28			3.00			6.77		
Control-500	43.87	4.68	0.11	3.88	0.71	0.18	6.30	0.60	0.10
5CP-500	32.60			2.50			5.02		
10CP-500	31.96			3.85			5.51		
15CP-500	33.35			2.60			5.08		
20CP-500	33.91			3.28			5.77		
5PP-500	35.17			2.64			7.152		
10PP-500	32.39			3.15			7.08		
15PP-500	30.52			3.30			5.952		
20PP-500	26.01			2.34			6.168		
5MP-500	34.24			3.16			6.99		
10MP-500	27.79			3.31			6.06		
15MP-500	31.05			2.65			4.73		
20MP-500	32.77			2.50			5.57		
5GP-500	34.12			2.18			6.59		
10GP-500	43.58			3.34			7.75		
15GP-500	29.18			2.21			5.65		
20GP-500	18.93			1.93			4.77		



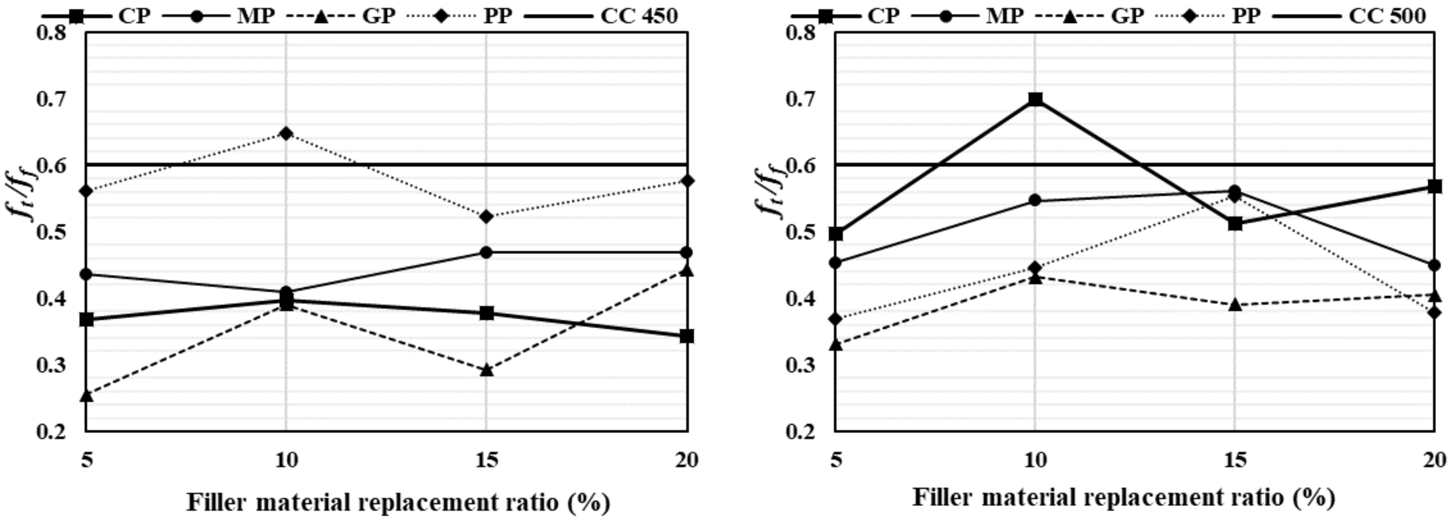
(a) **(b)**

Fig. 3 Relative f_t/f_{cu}; (a) CC 450 kg/m^3 and (b) CC 500 kg/m^3



(a) **(b)**

Fig. 4 Relative f_f/f_{cu} ; (a) CC 450 kg/m^3 and (b) CC 500 kg/m^3



(a) (b)

Fig. 5 Relative f_t/f_f ; (a) CC 450 kg/m^3 and (b) CC 500 kg/m^3

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:

1. Increasing CP, PP, MP, and GP contents enhanced the flowability, filling ability, and passing ability for SCC compared with control concrete.
2. Mixes with CC 500 kg/m^3 showed a higher improvement in fresh properties than mixes with CC 450 kg/m^3.
3. The maximum improvement in f_{cu} was recorded in mixes with 15% CP, 20% PP, 5% MP, and 15% GP at CC 450 kg/m^3. The minimum reduction in f_{cu} was observed for mixes containing 20% CP, 5% PP, 5% MP, and 10% GP at CC 500 kg/m^3.
4. Increase CP, PP, MP, and GP contents decreased f_t . the minimum reduction was for mixes containing 15% CP, 5% MP, and 10% GP at CC 450 kg/m^3. The minimum reduction was for mixes with 10% CP, 10% PP, 10% MP, and 10% GP at CC 450 kg/m^3. Only improvement is observed mixes containing 10% PP at CC 450 kg/m^3.
5. The maximum improvement in f_f was observed for mixes containing 15% CP, 5% PP, 5% MP, and 15% GP at 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/m3. The maximum improvement in f_f was observed for mixes containing 5% PP, 5% MP, and 10% GP, the minimum reduction in f_f was observed for mixes with 20% CP at CC 500 kg/m^3.
6. Mixes with CC 500 kg/m^3 showed a higher reduction in hardened properties than mixes with CC 450 kg/m^3.

7. Relative f_t/f_{cu} for mixes with CP, PP, MP, and GP contents did not exceed control concrete ratio of 0.09 for mixes having CC 450 kg/m^3, and control concrete ratio of 0.08 for mixes having CC of 450 kg/m^3. Relative f_f/f_{cu} for most SCCs exceeded control concrete ratio 0.15 for CC 450 kg/m^3 and ratio 0.14 for CC of 500 kg/m^3 for SCCs. Relative f_t/f_f for SCCs was mostly less than ratio 0.6.

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