MECHANICAL AND PHYSICAL PROPERTIES OF CEMENTITIOUS COMPOSITES CONTAINING FLY ASH OR SLAG CLASSIFIED WITH HELP OF PARTICLE SIZE DISTRIBUTION

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Fly ash (FA) and granulated blast furnace slag (GBFS) produced as waste materials from coal power plants and iron/steel sector are commonly used in the concrete industry for partial substitution of cement. As the production of cement releases a substantial amount of carbon dioxide, its replacement with FA or GBFS reduces carbon dioxide emissions. This study explores the effects of FA and GBFS fineness determined by particle size distribution (PSD) on the hydration rate and compactness of cementitious materials. Firstly, FA and GBFS were classified to have three different fineness ranges with the help of PSDs without any grinding process: FA and GBFS without PSD, FA and GBFS with 0-25 µm PSD and FA and GBFS with 0-63 µm PSD. Then, flexural strength, compressive strength, and water absorption properties of cementitious composites containing FA and GBFS with four different replacement levels up to 20% wt. of cement and with three different fineness were investigated at curing ages of 7, 28, and 90 days. Results revealed that cementitious composites that contain FA and GBFS with lower PSD yield better mechanical and physical properties.

Keywords: *Cementitious composites; particle size distribution; fineness; fly ash; granulated blast furnace slag.*

1. Introduction

Pozzolans are siliceous and aluminous materials that possess little or no binding properties, but they are frequently used with cementitious materials so that they gain better binding properties [1-5]. Many research efforts have been made on the use of pozzolanic materials in concrete in place of ordinary Portland cement to enable reductions in carbon dioxide emissions as well as to improve durability and some of the mechanical properties of concrete [6-9]. Two commonly used pozzolans as cement replacement materials are fly ash and granulated blast furnace slag. Fly ash (FA) is a byproduct kept by filters in coal-fired power stations. Fly ash has been incorporated into cementitious composites as cement replacer and the mechanical properties and durability of the developed composites have been extensively studied [10-18]. Granulated blast furnace slag (GBFS) is a waste material obtained from iron production in the steel power plant. GBFS has also been considered as a supplementary cementitious material in Portland cement-based composites [19-24]. These materials reduce the calcium hydroxide gels resulting from the hydration of the cement and produce calcium-silicate-hydrate (C-S-H) gels providing binding properties.

The effect of material fineness on the mechanical properties of concrete can be significant. For example, as the fineness of powder materials increases, the rate of hydration of the cement also increases, which, in return, enhances the mechanical properties [25]. The fineness of fly ash and blast furnace slag can also have an important influence on the properties of concrete. Mechanical, permeability and physical properties of various cementitious composites incorporating fly ash and blast furnace slag with different fineness have been studied in previous researches [26-34].

The fineness of powder materials of FA and GBFS was mostly obtained by grinding [26-31]. Studies on the fineness of FA and GBFS obtained with the help of a vacuum sieve or air separator have been limited. Chindaprasirt et al. [32] showed that the compressive strength of mortar is affected by the fineness of fly ash. In another study, Chindaprasirt et al. [33] found that the resistance to chloride penetration of concrete improves with increasing fineness of fly ash. Bentz et al. [34] investigated that the effect of fly ash and cement with different fineness on the mechanical properties of cementitious composites and found that a 35% reduction in cement use can be achieved by replacing fly ash with cement.

Despite the above-mentioned studies, there is still a need for further researches to reveal the effect of fineness of supplementary cementitious materials determined by particle size distribution (PSD) on the hydration rate and compactness of cementitious materials. To this end, the fineness of FA and GBFS was first formed into two PSD ranges of 0-25 to 0-63 µm using vacuum sieve in this study. Mortar composite specimens with fly ash or slag that are used either as received from the supplier or with two specific fineness degrees were fabricated. Four different replacement levels (5%, 10%, 15%, and 20 wt.% of cement) were

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considered. The mechanical and physical properties of cementitious composites containing fly ash and granulated blast furnace slag with different PSDs were obtained at 7, 28, and 90 days and results were analyzed comparatively.

2.Materials and methods

2.1.Materials

A commercially available CEM I 42.5 R ordinary Portland cement (OPC) that conforms with EN 197-1 [35] was used in this study. The Class C fly ash was used in all mixtures. The Class F fly ash has high pozzolanic activity and increases the strength of specimens in increasing curing ages due to the pozzolanic effect. Therefore, to better evaluate the effect of fineness, Class C fly ash that minimizes pozzolanic activity was used in this study. The granulated blast furnace slag used in this study was obtained from Bolu Cement. The fly ash and granulated blast furnace slag were used without grinding. The sand used here was in accordance with EN 196-1 standard [36]. The chemical and physical properties of the cement fly ash and granulated blast furnace slag are provided in Table 1.

2.2. Methods

2.2.1.Fineness analyses of FA and GBFS

The particle size distribution of cement, fly ash and granulated blast furnace slag were given in Fig. 1. As can be seen in Fig. 1, while 79.2% and 49.05% of FA particles passed through 63 µm and 25 µm sieves, respectively whereas 96% and 66% of GBFS particles passed through 63 µm and 25 µm sieves, respectively. The particle size distribution of FA and GBFS were determined using an air jet (Fig. 2) complying with EN 933-10 [37]. By sieving process, the fineness of fly ash and granulated blast furnace slag was formed into two different fineness that are PSD ranges of 0-25 µm (3050 and 4050 cm^2/g fineness) to 0-63 µm (2880 and 3975 cm^2/g fineness). 61.93% and 68.75% particles of FA and GBFS passed through 25 µm sieve for 0-63 µm PSD, respectively. Because of high carbon content, particles above 63 µm were not used in order not to affect the compactness. The chemical and physical properties of FA and GBFS with different fineness are listed in Table 2.

Table 1

The chemical and physical properties of cement fly ash and granulated blast furnace slag

Chemical properties (%)	**OPC**	**FA**	**GBFS**
SiO_2	21.01	46.59	35.2
Al_2O_3	5.39	12.42	17.51
Fe_2O_3	3.23	9.74	0.68
CaO	62.11	14.50	37.7
MgO	1.97	7.23	5.51
SO_3	3.10	5.52	0.69
Na_2O	0.39	1.01	0.42
K_2O	3.82	2.28	1.71
Physical properties			
Specific Blaine fineness (cm²/g)	3351	2830	3940
Specific gravity (unitless)	3.17	2.47	2.89

2.2.2. Mixture proportions

To evaluate the effects of fly ash and slag with different fineness degrees on physical and mechanical properties of cementitious composites, first mortar composites with 100% OPC, named as base mixture, was separately prepared before casting composites incorporating fly ash and slag. The water to binder ratio and sand to cement ratio was kept at 0.50 and 3, respectively. The cement

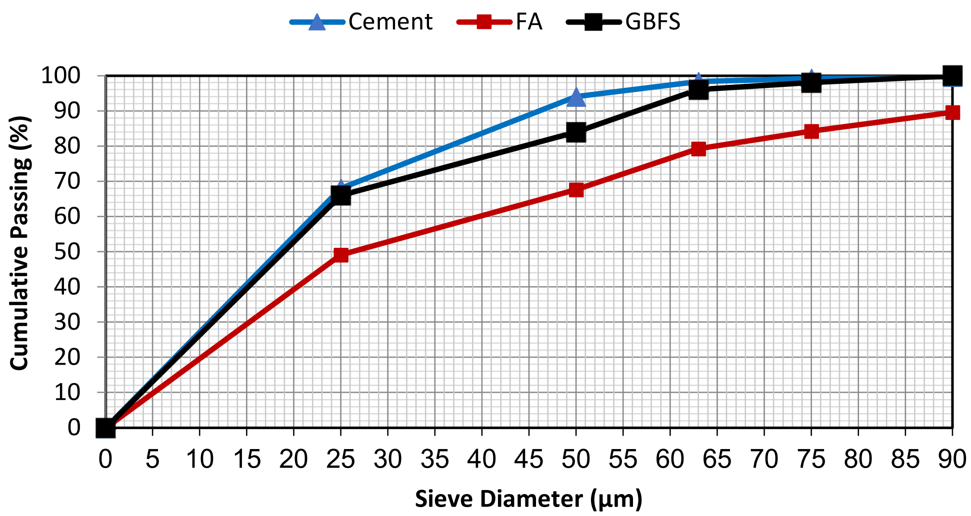


Fig. 1 - The particle size distribution of cement, fly ash and granulated blast furnace slag.

Fig. 2 - Vacuum sieve (air jet sieve).

Table 2

The chemical and physical properties of FA and GBFS with different range of PSDs.

Chemical properties (%)	FA (0-25)	FA (0-63)	GBFS (0-25)	GBFS (0-63)
SiO_2	43.85	46.72	32.90	35.78
Al_2O_3	11.84	12.63	16.40	17.25
Fe_2O_3	9.84	9.86	0.72	0.71
CaO	15.21	14.98	38.29	38.01
MgO	7.85	7.46	5.71	5.55
SO_3	7.44	5.11	0.76	0.54
Na_2O	0.86	0.99	0.34	0.41
K_2O	2.45	2.21	1.75	1.65
Specific Blaine fineness (cm^2/g)	3050	2880	4050	3975

Table 3

Mixture proportions of different cement mortars.

Ingredient (g)	Base	5%	10%	15%	20%
Water	225	225	225	225	225
Portland cement	450.0	427.5	405.0	382.5	360.0
FA or GBFS	0.0	22.5	45.0	67.5	90.0
Standard sand	1350	1350	1350	1350	1350

in these base specimens were replaced with fly ash or slag at replacement ratios of 5, 10, 15, and 20% wt. of cement. Both as-received fly ash and slag (reference specimens) and fly ash and slag with PSD ranges of 0-25 and 0-63 μm were used at all replacement ratios. In Table 3, mixture proportions of different mortars were presented.

2.2.3. Testing for flexural strength

Flexural strength testing on cementitious composites containing FA and GBFS with different fineness was conducted at 7-, 28-, and 90 days complying with EN 196-1 [36]. For flexural strength testing, three prismatic specimens with dimensions of 40×40×160 mm were produced and cured in tap water for 7-, 28-, and 90-days. Three-point bending specimens were loaded at a loading rate of 50 ± 10 N/s to compute flexural strength, and the results of three specimens were averaged to obtain final values.

2.2.4.Testing for compressive strength

Compressive strength testing on cementitious composites containing FA and GBFS with different fineness were conducted at 7-, 28-, and 90-days comply with EN 196-1 [36]. For compressive strength testing, six prismatic specimens after flexural tests were loaded at a loading rate of 2.4 kN/s and the results of six specimens were averaged to obtain final values.

2.2.5. Testing for water absorption

Water absorption tests on cementitious composites, containing FA and GBFS with different fineness were explored at 7-, 28-, and 90-days complying with ASTM C642 [38]. For water absorption tests, six prismatic specimens having dimensions of 50×50×50 mm were produced and cured in tap water for 7-, 28-, and 90-days. In the experiment, cementitious composites were cured in tap water for the determined periods, dried with the help of a towel, and then weighed (B). After stored in an oven at 100 ± 5°C for 24 hours, the cementitious composites were weighed again (A) at room temperature. The percentage of volume of permeable voids were calculated using Equation 1. The results of six specimens were averaged and reported in the following section.

Volume of permeable voids (%): $\left[\frac{\mathrm{B-A}}{\mathrm{A}}\right] \times 100(1)$

2.2.6. Testing for consistency

The consistency tests on cementitious composites, containing FA and GBFS with different fineness were carried out complying with EN 1015-3 [39] by turning the shaking device. In this part, to monitor the fresh properties of mortar samples having FA and GBFS with different fineness, workability measurements in terms of mini-slump test were made. In this test, cementitious composite mortars prepared in compliance with EN 196-1 [36] were filled in 2 layers in a steel container with the truncated conical mold on the flow table and tamped 25 times for each time. The truncated cone mold was then removed by slowly lifting it upwards. Then the flow table was stroked 25 times in 15 s in accordance with TS EN 1015-3 [39] by turning the shaking device. The diameter of the cementitious composite mortar flow after shaking was measured in both perpendicular directions and averaged.

3. Results and discussion

3.1. Effect of fineness on mechanical properties

The compressive strength of cementitious composites incorporating as-received fly ash or slag (reference) and fly ash or slag with PSD ranging from 0-25 μm and 0-63 μm are shown in Table 4 for 7, 28, and 90 days. Results are shown for the specimens with fly ash or slag at replacement ratios of 5%, 10%, 15%, and 20% wt. of cement. The compressive strength results are also provided for the specimens fabricated with 100% OPC (base).

Table 4 illustrates that the compressive strength reduced by increasing the additive level of fly ash and granulated blast furnace slag. At 7-, 28-, and 90-days, the highest compressive strengths were observed for the base specimen with 100% OPC. The decrease in the compressive strength ranged from 7.5% for 5% replacement ratio to 16.5% for 20% replacement ratio at different curing ages for fly ash replacement. When slag is replaced with OPC at different levels, the compressive strength decreased by 7.4% for 5% replacement ratio and 19.8% for 20% replacement ratio at different curing ages.

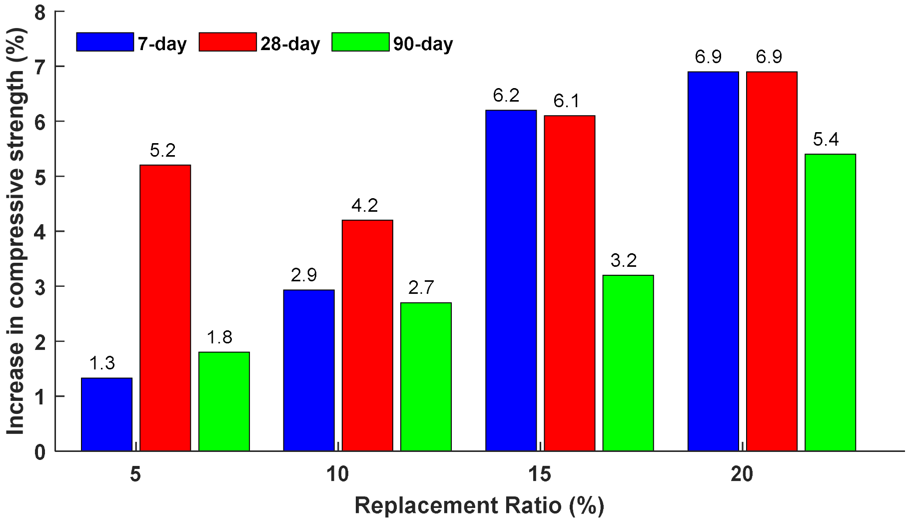
However, the specimens prepared by fly ash or slag formed with specific PSD ranges attained relatively higher compressive strengths compared to the specimens prepared by as-received fly ash or slag. Fig. 3 illustrates the change in the compressive strength of the specimens containing fly ash with two different fineness degrees compared to that of specimens containing reference fly ash. The compressive strengths of the specimens containing fly ash with 0-25 μm PSD range increased by 6.9, 6.9 and 5.4% for curing ages of 7, 28, and 90 days, respectively as compared to the specimens with reference fly ash at 20% replacement ratio. Similarly, the corresponding increase in the compressive strength was 3.2, 2.6, and 3.0% for curing ages of 7-, 28-, and 90- days, respectively for the specimens containing fly ash with 0-63 μm PSD range at 20% replacement ratio. For the specimens containing fly ash with 0-25 μm PSD range, there was a higher increase in the compressive strength for higher fly ash replacement ratios. The same trend was also observed for the results obtained for the specimens containing fly ash with 0-63 μm PSD range at 90 days. However, the degree of increase in the compressive strength varied more randomly at other curing ages for these specimens.

Fig. 4 illustrates the change in compressive strength of the specimens containing slag with two different fineness degrees as compared to that of the specimens with reference slag. Improvement in the compressive strength for the specimens containing slag with 0-25 μm PSD range varies between 5.0% and 11.3% for 7-day curing age; between 5.2% and 7.1% for 28-day curing age; and between 2.5% to 5.1% for 90-day curing age for different replacement ratios. These increase values were higher than those observed for the specimens containing slag with 0-63 μm PSD

Table 4

The compressive strength of cementitious composites containing FA and GBFS having the different range of PSDs at 7, 28, and 90 days.

PSDs	Replacement ratio (%)	Compressive Strength (MPa)					
		Fly ash			Blast furnace slag		
		7-day	28-day	90-day	7-day	28-day	90-day
Reference	Base	36.02	48.81	60.07	41.05	52.03	60.62
	5	34.56	45.17	56.85	39.03	48.17	58. 23
	10	33.47	44.29	55.27	37.24	46.26	56.84
	15	31.74	42.27	53.39	35.57	45.01	54.63
	20	30.07	41.07	51.37	32.93	43.89	53.91
0-63 μm	5	35.12	46.89	57.38	39.42	49.52	59.52
	10	34.15	45.56	56.54	38.79	48.52	57.02
	15	33.21	43.84	54.56	36.51	47.65	56.86
	20	31.04	42.15	52.92	34.57	45.42	55.42
0-25 μm	5	35.02	47.52	57.89	40.97	51.07	59.71
	10	34.45	46.15	56.75	39.51	49.19	58.15
	15	33.69	44.85	55.12	38.41	48.22	57.41
	20	32.15	43.91	54.12	36.64	46.18	56.35



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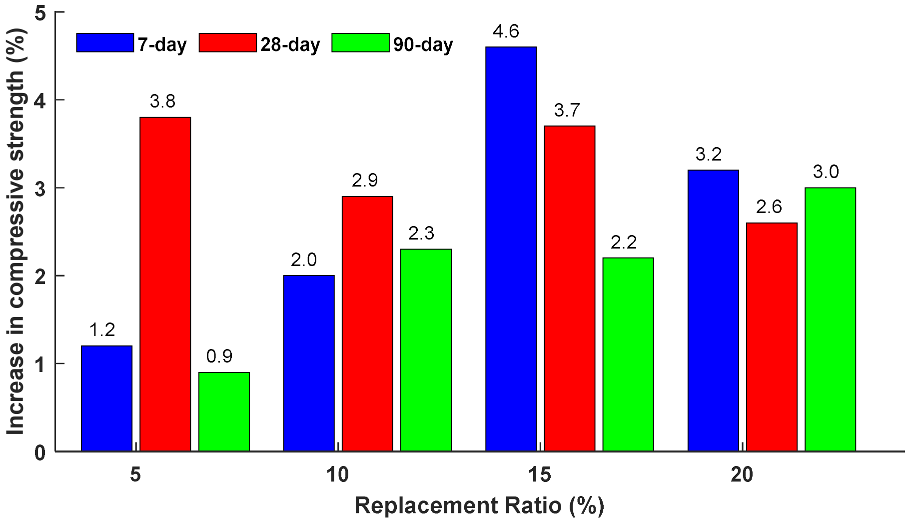

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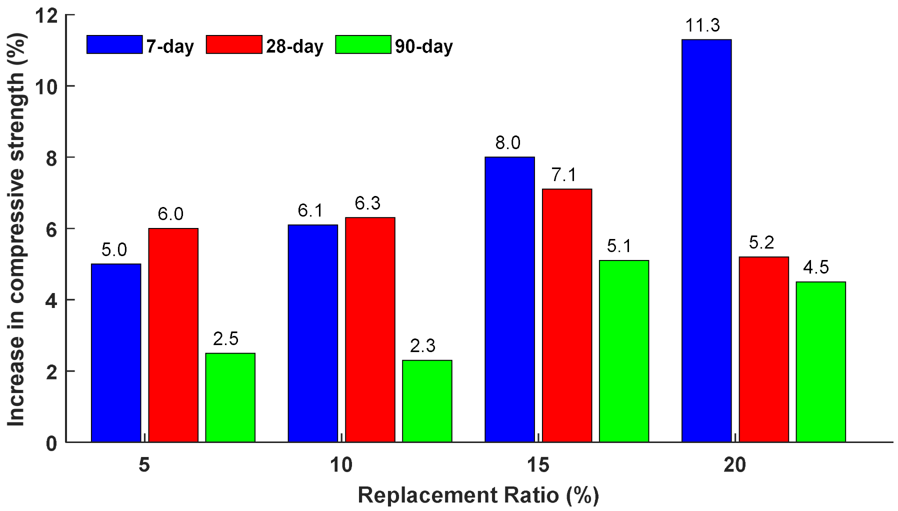
Fig. 3 - Change in compressive strength of cementitious composites containing fly ash with (a) 0-25 µm PSD and (b) 0-63 µm PSD compared to those with reference fly ash at 7-, 28-, and 90-days.



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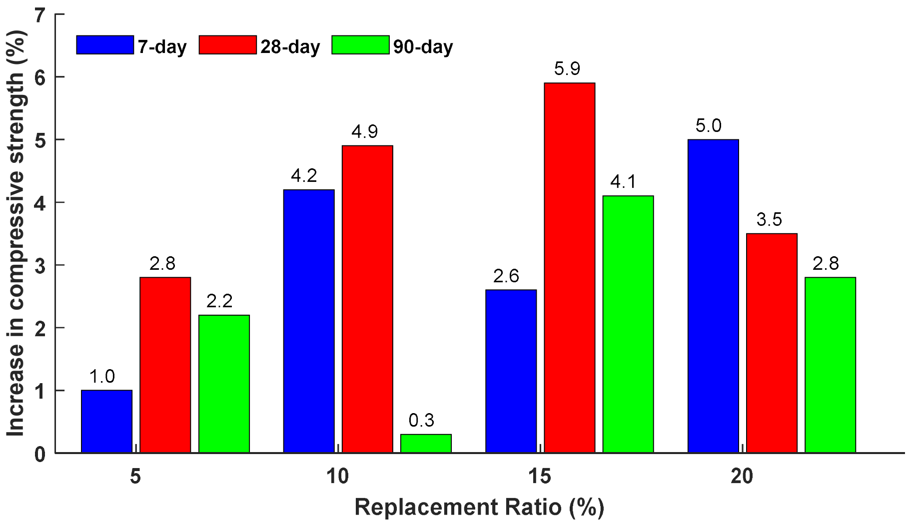


(b)

Fig. 4 - Change in compressive strength of cementitious composites containing GBFS with (a) 0-25 μm PSD and (b) 0-63 μm PSD compared to those with reference GBFS at 7-, 28-, and 90-days.

range. Therefore, it can be concluded that fly ash and slag with finer particle size lead to somewhat higher compressive strength in mortar composites.

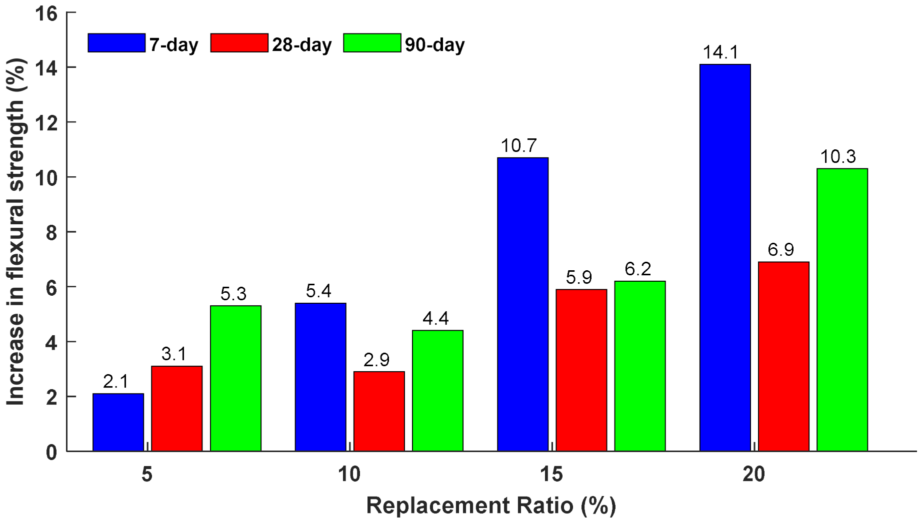
The flexural strength of mortar composites incorporating as-received fly ash or slag, and those containing fly ash or slag with PSD range from 0-25 μm and 0-63 μm are shown in Table 5 for 7, 28, and 90 days for different replacement ratios. The results are also provided for base mortar composite without any fly ash or slag. The 20% replacement of cement with reference fly ash and slag decreased the flexural strength by 11.8% and 8.0%, respectively at 90 days compared to the base mortar composite. However, when the fly ash and slag with 0-25 μm PSD range were used, the same decreases were only 2.7% and 1.5%.

To further explore the effect of fineness of fly ash or slag on the flexural strength of mortar composites, Figs. 5 and 6 show the change in the flexural strength of the specimens containing fly ash or slag with 0-25 μm and 0-63 μm PSD ranges as compared to that of specimens containing reference fly ash or slag. For the specimens incorporating with fly ash, there were increases in between 2.1% and 14.1% at 7 days, 2.9% and 6.9% for 28 days, and 4.4% and 10.3% at 90 days for different replacement ratios when the fly ash with 0-25 μm PSD range was used instead of reference fly ash. Similarly, the increases in flexural strength for the specimens containing fly ash with 0-63 μm PSD range were in between 1.1% and 7.4% at 7 days, 2.3% and 5.8% at 28

Table 5

The flexural strength of cementitious composites with fly ash and GBFS having different range of PSDs at 7-, 28-, and 90-days.

PSDs	Additive ratio (%)	Flexural Strength (MPa)					
		Fly ash			Blast furnace slag		
		7-day	28-day	90-day	7-day	28-day	90-day
Reference	Base	6.89	8.12	10.85	7.76	8.49	11.06
	5	6.67	7.78	10.27	7.58	8.19	10.82
	10	6.43	7.71	10.25	7.47	8.01	10.65
	15	5.98	7.41	10.06	7.39	7.65	10.56
	20	5.54	7.23	9.57	6.84	7.42	10.18
0-63 μm	5	6.78	7.98	10.78	7.64	8.23	11.01
	10	6.65	7.89	10.71	7.56	8.14	10.89
	15	6.42	7.81	10.62	7.42	8.08	10.78
	20	6.12	7.65	10.53	7.04	7.98	10.69
0-25 μm	5	6.81	8.02	10.81	7.72	8.29	11.05
	10	6.78	7.92	10.70	7.65	8.21	11.04
	15	6.62	7.85	10.68	7.45	8.15	10.98
	20	6.32	7.73	10.56	7.15	8.06	10.89



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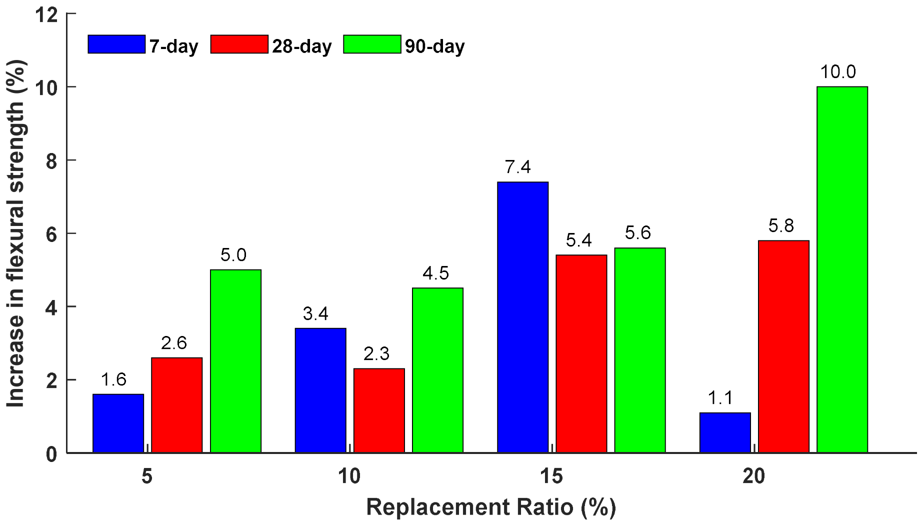
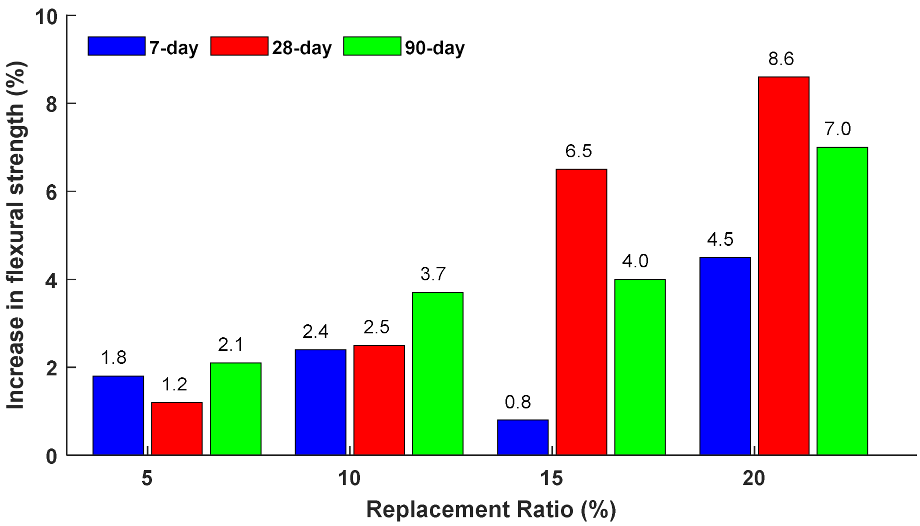


(b)

Fig. 5 - Change in flexural strength of cementitious composites containing fly ash with (a) 0-25 μm PSD range and (b) 0-63 μm PSD range compared to those with reference fly ash at 7-, 28-, and 90-days.



(a)

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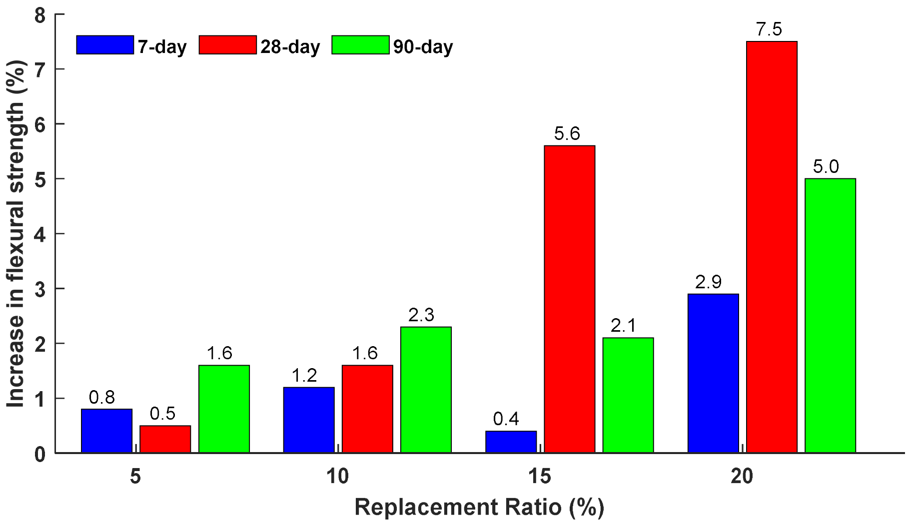

(b)

Fig. 6 - Change in flexural strength of cementitious composites containing GBFS with (a) 0-25 μm PSD range and (b) 0-63 μm PSD range as compared to those with reference GBFS at 7-, 28-, and 90-days.

days, and 4.5% and 10.0% at 90 days as compared to the specimens with reference fly ash.

For the specimens containing slag, the use of finer material also resulted in an increase in flexural strength as shown in Fig. 6 at all curing ages and replacement ratios. However, these increases were more apparent at 15% and 20% replacement ratios and 28-day and 90-day curing ages. Overall, the flexural strength of cementitious composites increased by increasing the fineness of fly ash and granulated blast furnace slag. As the fineness of powder materials increases, the rate of hydration of the cement thus increases, and this may enable good mechanical properties [25]. When the results presented in Figs. 5 and 6 are compared, the effect of material fineness on the flexural strength is more prominent for the fly ash than the slag.

These findings were also reported in several studies in the literature. According to Chindaprasirt et al. [32] demonstrated that compressive strength containing fine fly ash was better than that of samples with reference fly ash at all ages. Hsu et al. [29] showed that the mortar specimens with the best fineness have the highest compressive strength and lowest water absorption and smallest porosity. Likewise, Wang et al. [27] demonstrated that for the development of compressive strength of blast furnace slag cement fraction 0-20 micron is crucial.

3.2. Effect of fineness on water absorption

Water absorption of hardened concrete, i.e., its permeability, significantly affects the durability and mechanical properties of the concrete during its service life [40,41]. The progression of water and other fluids into the concrete is through voids, and the substances that cause deterioration are transported into the concrete in this way [42,43]. Here, the water absorption tests were conducted to get information about the void ratios of cementitious composites containing fly ash and blast furnace slag with different fineness degrees. The test results were evaluated according to the formula given in Equation 1 and the results are presented in Table 6 for the cementitious composites containing FA and GBFS slag at different replacement ratios and with different fineness degrees at 7-, 28-, and 90-days.

The replacement of cement with reference fly ash or slag at 20% results in 6.9% and 13.9% increases, respectively in the volume of permeable voids at curing age of 90 days. However, these increases remain at 3.7% and 11% when the fly ash or slag with 0-63 μm PSD range was used and at only 2.8% and 3.9% when the fly ash or slag with 0-25 μm PSD range was used. Therefore, the mortar specimens with finer fly ash or slag reveal a lower volume of permeable voids as compared to the specimens with reference fly ash or slag. This can be attributed to higher compactness level achieved through fly ash or slag with specific PSD ranges [44-46].

3.3. Effect of fineness on consistency

In this test, cementitious composite mortars prepared in compliance with EN 196-1 [36] were filled in 2 layers in a steel container with the truncated conical mold on the flow table and tamped 25 times for each time. The truncated cone mold was then removed by slowly lifting it upwards. Then the flow table was stroked 25 times in 15 s in accordance with TS EN 1015-3 [39] by turning the shaking device. The diameter of the cementitious composite mortar flow after shaking was measured in both perpendicular directions and averaged. The results obtained were given in Table 7.

Table 6

The water absorption test results of cementitious composites containing FA and GBFS with different ranges of PSDs after 7-, 28-, and 90-days.

PSDs	Replacement ratio (%)	Volume of Permeable Voids (%)					
		Fly ash			Blast furnace slag		
		7-day	28-day	90-day	7-day	28-day	90-day
Reference	Base	8.98	8.59	7.87	8.71	8.45	8.15
	5	9.41	8.78	8.03	9.13	8.85	8.87
	10	9.53	8.97	8.17	9.32	9.09	8.92
	15	9.61	9.19	8.39	9.59	9.18	9.13
	20	9.66	9.23	8.41	9.68	9.23	9.28
0-63 µm	5	9.23	8.66	7.93	9.05	8.63	8.31
	10	9.36	8.92	7.98	9.21	8.98	8.76
	15	9.45	8.98	8.05	9.34	9.06	8.81
	20	9.56	9.08	8.16	9.42	9.16	9.05
0-25 µm	5	9.12	8.56	7.89	8.95	8.45	8.13
	10	9.26	8.85	7.93	9.06	8.75	8.62
	15	9.32	8.86	7.98	9.13	9.03	8.65
	20	9.43	8.89	8.09	9.19	8.98	8.47

Table 7

Consistencies of cement mortars containing FA and GBFS with different range of PSDs

PSDs	Replacement ratio (%)	Flow diameter (mm)	
		Fly ash	Blast furnace slag
Reference	Base	145	145
	5	160	155
	20	180	175
0-63 µm	5	155	150
	20	175	170
0-25 µm	5	150	145
	20	170	165

As illustrated in Table 7, the average flow diameters increased with increasing FA and GBFS replacement ratio that was expected their spherical morphological characteristics of FA and GBFS particles. When the flow diameters of samples having FA and GBFS with 0-25 µm and 0-63 µm PSDs are compared, it can be seen that the flow diameters of specimens with samples having with 0-25 µm PSD were lower than those with samples having with 0-63 µm PSD. This might be due to that as the fineness of FA and GBFS increases, the air gaps among the particles will decrease and thus, workability will decrease. Despite the slight reductions in flow diameter measurements, specimens having FA and GBFS with 0-25 µm PSD were still in a very flowable state.

4. Conclusions

Fly ash and granulated blast furnace slag are currently used as cement replacers in cementitious composites to leverage their environmental, economic and performance benefits. In this study, the influence of FA and GBFS particle size on the mechanical and physical properties of the cementitious composites was investigated. The fineness of FA and GBFS was first formed into two PSD ranges of 0-25 to 0-63 µm using a vacuum sieve. Mortar composite specimens with fly ash or slag that are used either as received from the supplier or with two specific fineness degrees were fabricated. Four different replacement levels (5%, 10%, 15%, and 20 wt.% of cement) were considered. The flexural, compressive and water absorption properties of cementitious composites containing FA and GBFS with different PSDs were determined at 7, 28 and 90 days and results were comparatively analyzed. Findings of this study can be summarized as follows:

- The cementitious composites containing FA and GBFS with 0-25 µm PSD (3050 and 4050 cm^2/g fineness) yielded better mechanical and physical properties as compared to the cementitious composites containing FA and GBFS with 0-63 µm PSD (2880 and 3975 cm^2/g fineness) and reference FA and GBFS (2830 and 3940 cm^2/g fineness).
- The use of FA and GBFS classified with PSD can enable higher cement replacement ratios. For example, mortar composites containing 10% FA with 0-25 µm PSD achieved the same compressive strength at 90-day curing age with mortars that contain only 5% reference FA. Similarly, mortars containing 20% GBFS with 0-25 µm PSD achieved the same compressive strength at 90-day curing age with mortars that contain only 10% reference FA. For mortars with 20% 0-25 µm PSD FA or GBFS, the flexural strength attained the same level of mortars with only 5% reference FA or GBFS.
- The cementitious composites with finer FA and GBFS also provided a lower volume of permeable voids as compared to the cementitious composites with reference FA and GBFS. The lowest water absorption percentage was observed for specimens with 0-25 µm PSD FA and GBFS for the mortars with supplementary cementitious composites.
- Since the grinding process was not used, the powder material particles were not damaged during classification of FA and GBFS. Therefore, with even slight improvement in fineness of FA or GBFS, improvements up to 14% in mechanical and physical properties of mortar composites were achieved.
- The effect of FA or GBFS fineness on compressive strength, flexural strength and water absorption was usually more prominent at higher replacement levels. This suggests that performance improvement of finer FA and GBFS can be even greater for cementitious composites with high FA or GBFS content.

These findings suggest that through suitable particle size distribution, higher levels of fly ash and granulated blast furnace slag replacement with OPC can be used. This will further enhance the use of FA and GBFS, increase waste material utilization, reduce carbon footprint and overall costs of concrete mixtures.

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