Effect of Finely Ground Coal Bottom Ash as Replacement for Portland Cement on the Properties of Ordinary Concrete

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OUTLINE

1. Introduction
2. Materials and Methods
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Introduction

Introduction

1. **Coal use reduction in construction is crucial due to environmental concerns.**
2. **FGCBA is a promising alternative.**
3. **This study investigates the effects of replacing Portland cement with FGCBA and Fly Ash (FA) on various concrete properties, including:**
   - Fresh properties (workability, weight, air content, setting time)
   - Hardened properties (compressive strength, shrinkage)
   - Durability (chloride ion penetration, porosity)

Materials
&
Methods

2.1. Raw Materials

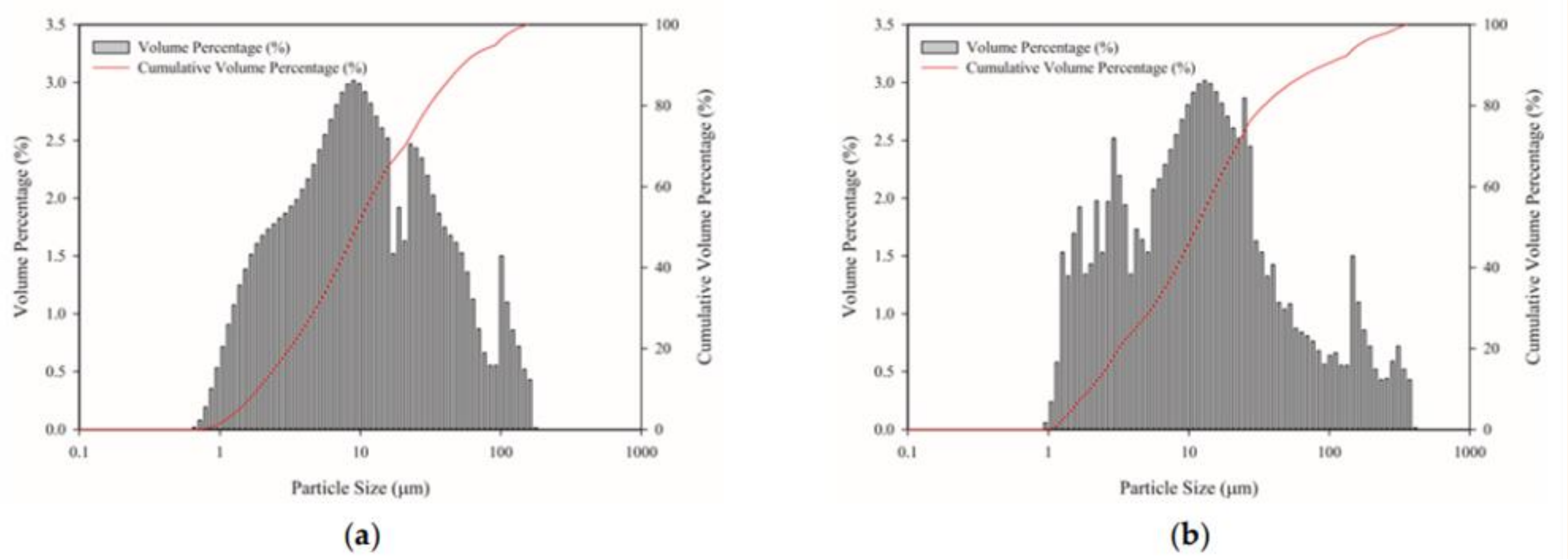

Figure 1. Particle size distribution of powders, determined using a laser diffraction particle size analyzer: (a) fly ash; (b) FGCBA.

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2.1. Raw Materials

Properties	Fine Aggregate	Coarse Aggregate (3/8”)	Coarse Aggregate (6/8”)
Specific gravity	2.6	2.61	2.64
Water absorption (%)	2.06	1.08	0.78
Fineness modulus	2.35	6.34	7.99

Table 1. The properties of aggregate in this study.

2.1. Raw Materials

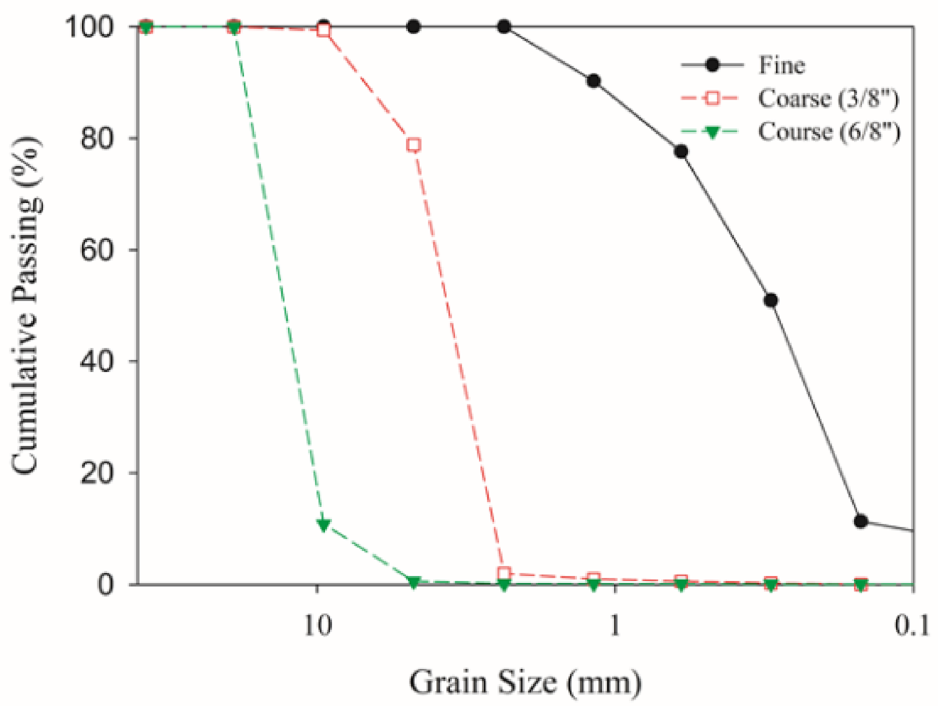

Figure 2. Sieve analysis of fine and coarse aggregates

Time (hours)	Blaine Specific Surface (cm^2/g)
12	2510
24	3100
36	3910
48	4140

Table 2. The Fineness of bottom ash with finely ground time.

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2.1. Raw Materials

										Unit: %
Material	**SiO_2**	**Fe_2O_3**	**Al_2O_3**	**CaO**	**MgO**	**TiO_2**	**K_2O**	**SrO**	**SO_3**	**LOI**
FA	35.53	30.5	4.89	15.95	-	4.97	3.43	1.72	1.07	4.89
FGCBA	31.85	26.9	4.57	13.96	-	3.92	2.75	1.02	0.85	12.07

Table 3. Chemical properties of the FA produced and FGCBA in this study

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2.2. Sample Preparation, Mixing, and Curing

The researchers varied the amount of FGCBA used (0%, 20%, 40%, and 60%) and the water-to-cement ratio (0.4, 0.45, and 0.5) to see how it affects the concrete's properties. They compared the FGCBA concrete to concrete with fly ash (FA) as a control.

The mixing and curing process followed a standard method (ASTM C31). This involved adding ingredients in a specific order, including water, aggregates, cement, and any admixtures. After mixing, the concrete specimens were cured in a specific solution until testing. The researchers tested the concrete's compressive strength at various ages (7, 14, 28, 56, 91, and 180 days).

2.3. Pozzolanic Strength Activity Index

- **The Test Method:**
  - A 20% blend of pozzolanic material (FA or FGCBA) and ordinary Portland cement is created.
  - Mortar specimens are made with this blend following specific proportions and water-to-cement ratio.
  - The specimens are cured in a controlled environment for a set period (usually 28 days).
  - Their compressive strength is measured.
- **Evaluation:**
  - The compressive strength is compared to a control mortar made only with Portland cement.
  - A pozzolanic activity index is calculated based on this comparison. This index indicates how much the pozzolanic material improves concrete strength.
  - This standardized method ensures consistent and reliable evaluation of pozzolanic materials for concrete applications.

Additionally, the passage mentions:

- The test also measures compressive strength at various ages (7, 28, 56, 91, and 180 days).
- Specimen dimensions are 5 cm x 5 cm x 5 cm.
- This method allows researchers to compare the reactivity of different pozzolanic materials (FA vs. FGCBA) under controlled conditions.

2.4. Workability

Unit: kg/m³

Mix Designation	Water	Cement	FA	FGCBA	Fine Aggregate	Coarse Aggregate (3/8″)	Coarse Aggregate (6/8″)	SP
OPC4	210.4	526	0	0	853	652	115	0
OPC45	236.7	526	0	0	853	652	115	0
OPC5	263	526	0	0	853	652	115	0
OPC4-20F	210.4	420.8	105.2	0	853	652	115	0
OPC45-20F	236.7	420.8	105.2	0	853	652	115	0
OPC5-20F	263	420.8	105.2	0	853	652	115	0
OPC4-20B	210.4	420.8	0	105.2	853	652	115	5.26
OPC45-20B	236.7	420.8	0	105.2	853	652	115	3.682
OPC5-20B	263	420.8	0	105.2	853	652	115	2.104
OPC4-40F	210.4	315.6	210.4	0	853	652	115	0
OPC45-40F	236.7	315.6	210.4	0	853	652	115	0
OPC5-40F	263	315.6	210.4	0	853	652	115	0
OPC4-40B	210.4	315.6	0	210.4	853	652	115	7.364
OPC45-40B	236.7	315.6	0	210.4	853	652	115	5.786
OPC5-40B	263	315.6	0	210.4	853	652	115	4.208
OPC4-60F	210.4	210.4	315.6	0	853	652	115	0
OPC45-60F	236.7	210.4	315.6	0	853	652	115	0
OPC5-60F	263	210.4	315.6	0	853	652	115	0
OPC4-60B	210.4	210.4	0	315.6	853	652	115	9.468
OPC45-60B	236.7	210.4	0	315.6	853	652	115	7.890
OPC5-60B	263	210.4	0	315.6	853	652	115	6.312

Table 4. The concrete proportions in this study

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2.5. Unit Weight and Air Content Test

This paragraph describes the procedure for filling a mold for a concrete test specimen according to ASTM C138 standards. Here's a breakdown of the steps:

1. **Filling the Mold:**
    - Concrete is scooped into the mold to ensure even distribution and prevent separation of materials.
2. **Compacting the Concrete:**
    - The concrete is divided into three equal layers.
    - A rod is used to compact each layer to remove air bubbles and voids.
3. **Tapping and Leveling:**
    - The mold sides are tapped 15 times after each layer is compacted.
    - Care is taken to avoid overfilling the mold.
    - A strike-off plate is used with a sawing motion to level and smooth the concrete surface.
4. **Weighing and Measuring:**
    - The final concrete mold is weighed and measured according to specific requirements.

2.6. Setting Time Test

This passage describes a test following ASTM C403 to determine the setting time of mortar (a mixture of cement, sand, and water) separated from fresh concrete.

1. **Sample Preparation:**
   - A representative portion of fresh concrete is sieved to separate the mortar.
2. **Testing:**
   - The separated mortar is kept at a specific temperature.
   - Standardized needles are used to periodically measure the mortar's resistance to penetration at set time intervals.
3. **Evaluation:**
   - A graph is created to show penetration resistance versus time.
   - The initial and final setting times are determined from the graph based on specific resistance values:
     - Initial setting: 3.5 MPa resistance
     - Final setting: 27.6 MPa resistance

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2.7. Compressive Strength Test

This paragraph describes how the compressive strength of concrete specimens was measured following ASTM C39 standards. Here's a breakdown:

- **Specimen Preparation:**
  - Concrete was mixed following specific protocols (Section 2.2) and molded into cylinders (15 cm diameter, 30 cm height).
  - These cylinders were then cured under standard conditions.
- **Compressive Strength Testing:**
  - At designated ages (3, 7, 14, 28, 56, 91, and 180 days), the cylinders were tested for compressive strength according to ASTM C39.
  - This involved placing the cylinders in a compression testing machine.
  - The compressive strength was measured and recorded.
- **Data Analysis:**
  - Three samples were tested for each age group.
  - The results were based on the average value of the three tested samples.

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2.8. Drying Shrinkage Test

This passage discusses the measurement of long-term drying shrinkage in concrete specimens. Here's a breakdown:

- **Background:**
  - Fly ash (FA) is expected to have better volume stability (less shrinkage) than cement.
  - The impact of finely ground coal bottom ash (FGCBA) on shrinkage compared to no ash is unclear and needs investigation.
- **Test Setup:**
  - A steel mold (75 mm x 75 mm x 285 mm) was used to create concrete specimens for drying shrinkage measurement.
  - Measurements were taken at specific ages: 3, 7, 14, 28, 56, and 91 days.
- **Testing Standards:**
  - Instruments were calibrated before measurements.
  - The standard ASTM C157 was followed for testing conditions, except for humidity.
    - Standard temperature: 23°C (maintained)
    - Standard humidity: 50% (could not be achieved due to test location in Taiwan)
    - Actual test humidity: 70% (due to location limitations)

2.9. Test of Chloride Penetration Resistance

This passage describes the preparation of a concrete specimen for a test according to ASTM C1202 to measure chloride ion permeability. Here's a breakdown of the steps:

Specimen Preparation:

1. **Sample Selection:** A 91-day old concrete specimen is chosen for testing.
2. **Surface Drying:** Excess moisture is removed from the specimen after taking it out of water.
3. **Humidity Chamber:** The specimen is placed in a sealed container to maintain at least 95% humidity.

Mounting the Specimen:

1. **Sealant Preparation:** A two-part sealant is mixed (20-40g)
2. **Filter Paper Placement:** Filter paper is placed on a voltage cell screen.
3. **Sealant Application:** Sealant is applied around the voltage cell body next to the filter paper.
4. **Specimen Mounting:** Filter paper is removed, and the specimen is pressed onto the screen. Excess sealant around the edges is smoothed.
5. **Protecting the Specimen:** The exposed surface is covered with an impermeable layer (rubber/plastic sheet).
6. **Sealing the Cell:** A rubber stopper is inserted to minimize moisture exchange. The sealant is cured following manufacturer instructions. (Both sides of the cell are sealed following this process)

2.9. Test of Chloride Penetration Resistance

Solution Filling and Electrical Connection:

1. **Solution Chambers:** One chamber is filled with a 3% NaCl solution, and the other with a 0.3 N NaOH solution.
2. **Electrical Connection:** Lead wires are attached to the cell and connected to a testing system.

Test Completion:

- The entire preparation process is completed within 6 hours for efficiency.

2.10. Density, Absorption, and Voids in Hardened Concrete Test

$$\text{Absorption after immersion, \%} = [(B - A]/A] \times 100, \quad (1)$$

$$\text{Absorption after immersion and boiling, \%} = [(C - A)/A] \times 100, \quad (2)$$

$$\text{Bulk density, dry} = [A/(C - D)]\cdot\rho = g1 \quad (3)$$

$$\text{Bulk density after immersion} = [B/(C - D)]\cdot\rho \quad (4)$$

$$\text{Bulk density after immersion and boiling} = [C/(C - D)]\cdot\rho \quad (5)$$

$$\text{Apparent density} = [A/(A - D)]\cdot\rho = g2 \quad (6)$$

$$\text{Volume of permeable pore space (voids), \%} = (g2 - g1)/g2 \times 100, \quad (7)$$

where
A = mass of oven-dried sample in air, g;
B = mass of surface-dry sample in air after immersion, g;
C = mass of surface-dry sample in air after immersion and boiling, g;
D = apparent mass of sample in water after immersion and boiling, g;
g1 = bulk density, dry, Mg/m3 ;
g2 = apparent density, Mg/m3 ;
ρ = density of water = 1 Mg/m3 = 1 g/cm3 .

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Results & Discussion

3.1. Pozzolanic Strength Activity Index

					Unit: %
Type	**7 days**	**28 days**	**56 days**	**91 days**	**180 days**
FA	91.23	100.7	126.19	130.55	166.88
FGCBA	67.34	86.43	93.47	97.48	109.08

Table 5. Pozzolanic strength activity index determined for each material

3.2. Slump

						Unit: cm
W/B	0.4		0.45		0.5	
Replace (%)	FA	FGCBA	FA	FGCBA	FA	FGCBA
0	9		17		23	
20	12	13	18	18	24	12
40	16	17	20	15	25	13
60	18	13	21	13	27	12.5

Table 6. Effect of replacing cement with FA and FGCBA on the slump of fresh concrete

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3.3. Air Content and Unit Weight of Freshly Mixed Concrete

Unit: kg/cm^3, (%)

W/B	0.4		0.45		0.5	
Replace (%)	FA	FGCBA	FA	FGCBA	FA	FGCBA
0	2301.81, (1)		2267.73, (1.2)		2235.36, (1.5)	
20	2263.93, (1.2)	2246, (1.4)	2231.35, (1.4)	2215.96, (1.5)	2200.38, (1.7)	2187.31, (1.6)
40	2227.27, (1.5)	2196.54, (1.6)	2196.12, (1.6)	2168.31, (1.7)	2166.48, (1.9)	2141.36. (1.8)
60	2191.78, (1.8)	2149.29, (1.4)	2161.98, (1.8)	2122.75, (1.6)	2133.61, (1.8)	2097.38, (1.7)

Table 7. Effect of replacing cement with FA and FGCBA on air content and unit weight of fresh concrete.

3.4. Setting Time

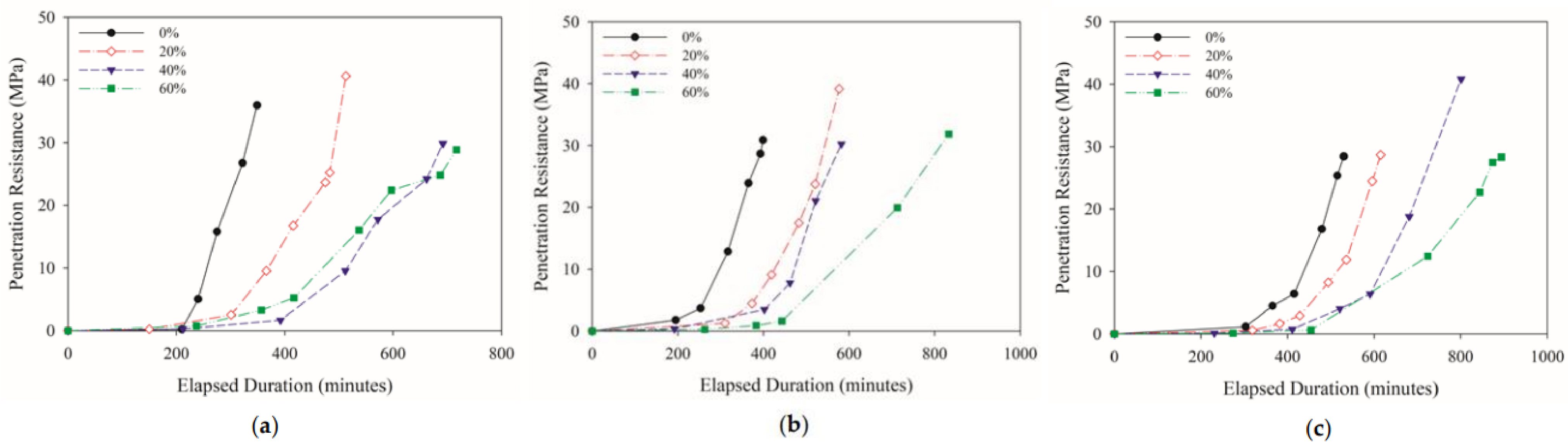

Figure 3. Influence of various FA replacement ratios on elapsed time and impedance resistance profiles at W/B ratios of (a) 0.4, (b) 0.45, and (c) 0.5.

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3.4. Setting Time

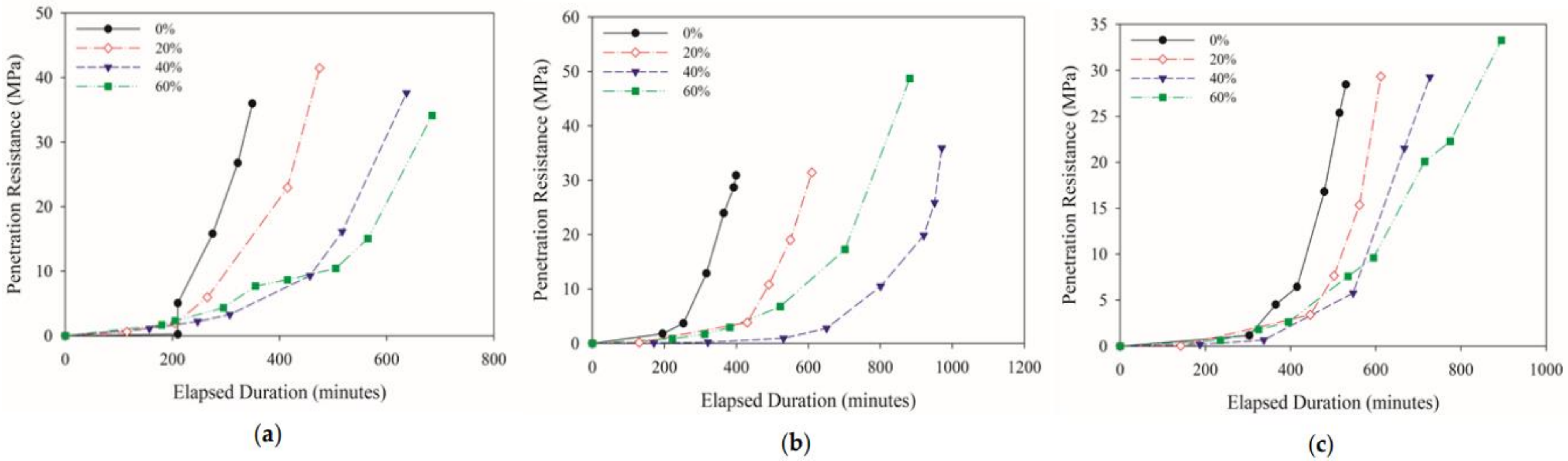
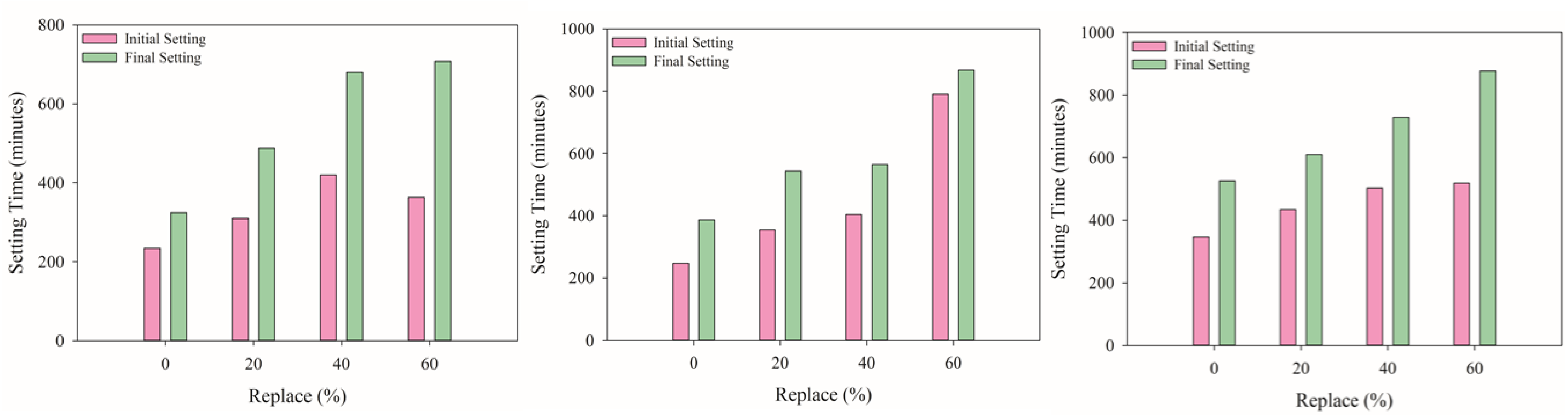


Figure 4. Influence of various FGCBA replacement ratios on elapsed time and impedance resistance profiles at W/B ratios of (a) 0.4, (b) 0.45, and (c) 0.5.

3.4. Setting Time



(a) (b) (c)

Figure 5. Effect of different FA replacement ratios on setting time at W/B ratios of (a) 0.4; (b) 0.45; (c) 0.5.

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3.4. Setting Time

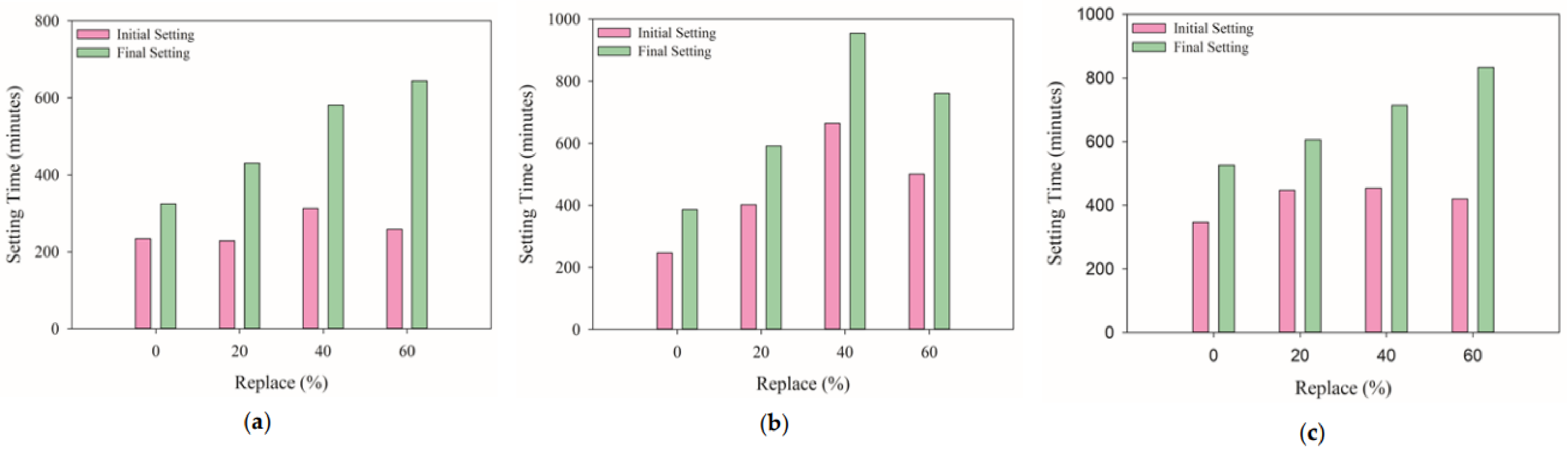

Figure 6. Effect of different FGCBA replacement ratios on setting time at W/B ratios of (a) 0.4; (b) 0.45; (c) 0.5.

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3.5. Compressive strength development

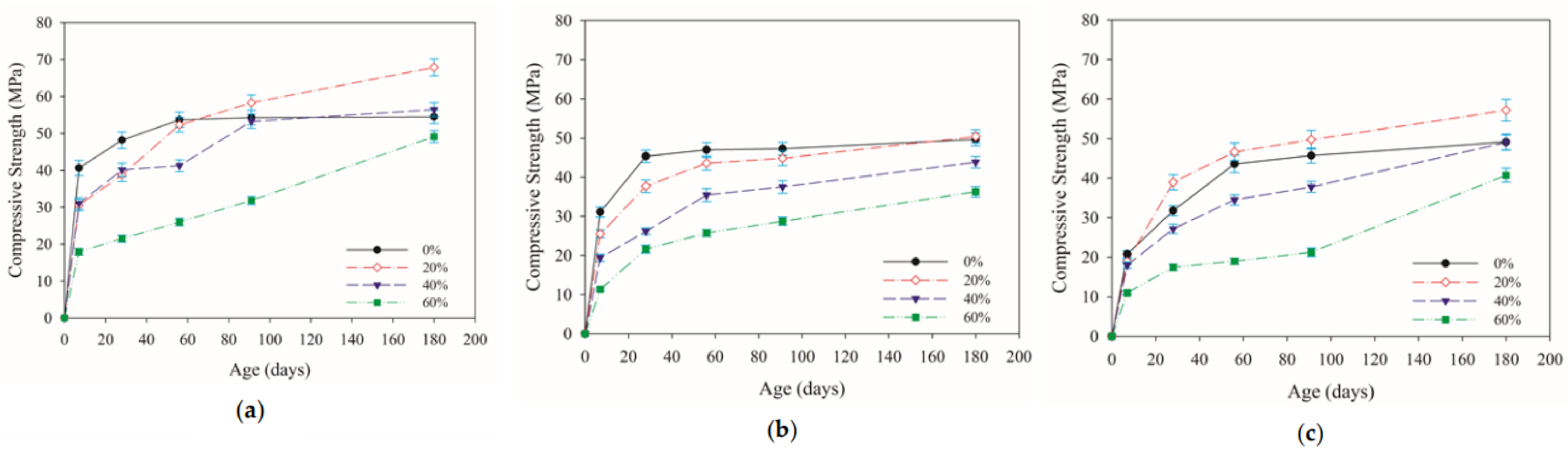

Figure 7. Compressive strength trends with FA as a cement substitute at W/B ratios of (a) 0.4; (b) 0.45; (c)

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3.5. Compressive strength development

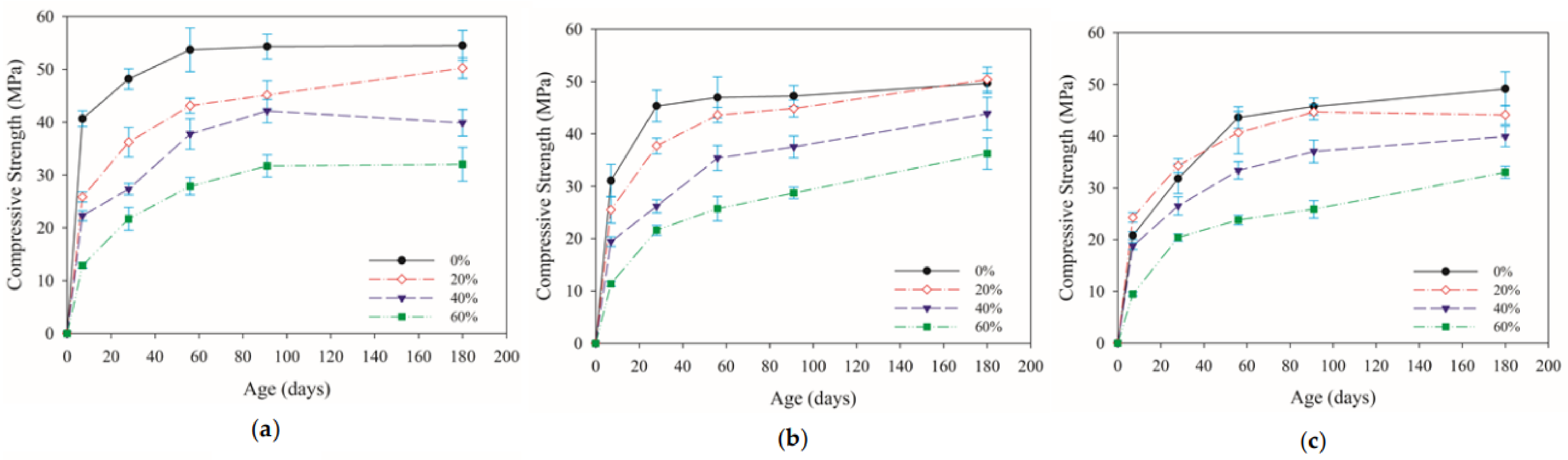

Figure 8. Compressive strength trends with FGCBA as a cement substitute at W/B ratios of (a) 0.4; (b) 0.45; (c) 0.5.

3.6. Drying Shrinkage

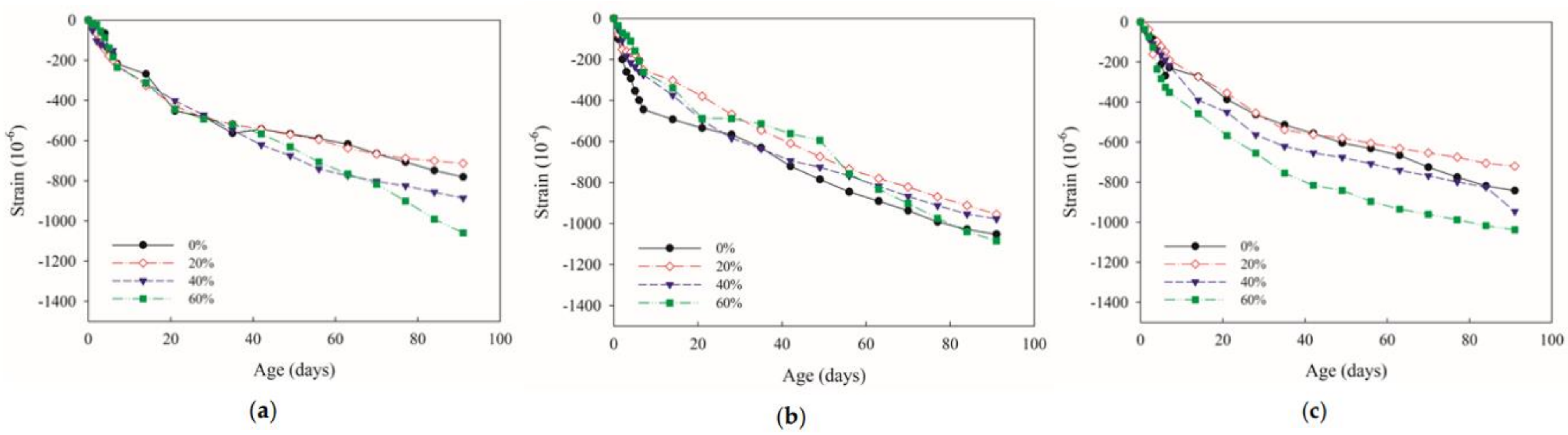

Figure 9. Drying shrinkage of various proportions with age fort different amounts of FA replacing cement at W/B ratios of (a) 0.4; (b) 0.45; (c) 0.5.

3.6. Drying Shrinkage

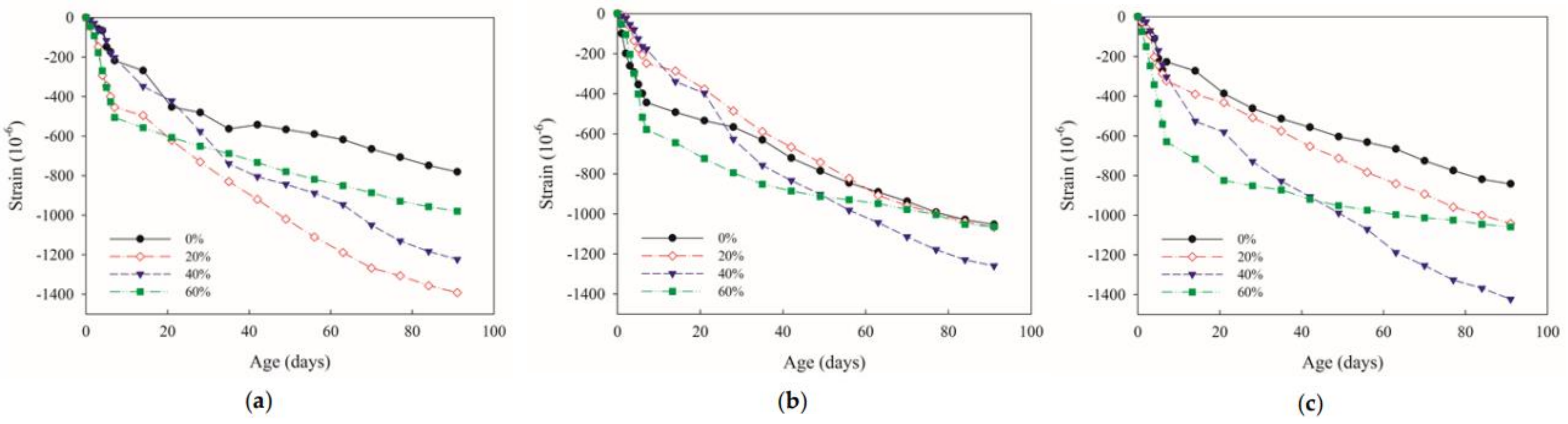

Figure 10. Drying shrinkage of various proportions with age for different amounts of FGCBA replacing cement at W/B ratios of (a) 0.4; (b) 0.45; (c) 0.5.

3.7. RCPT

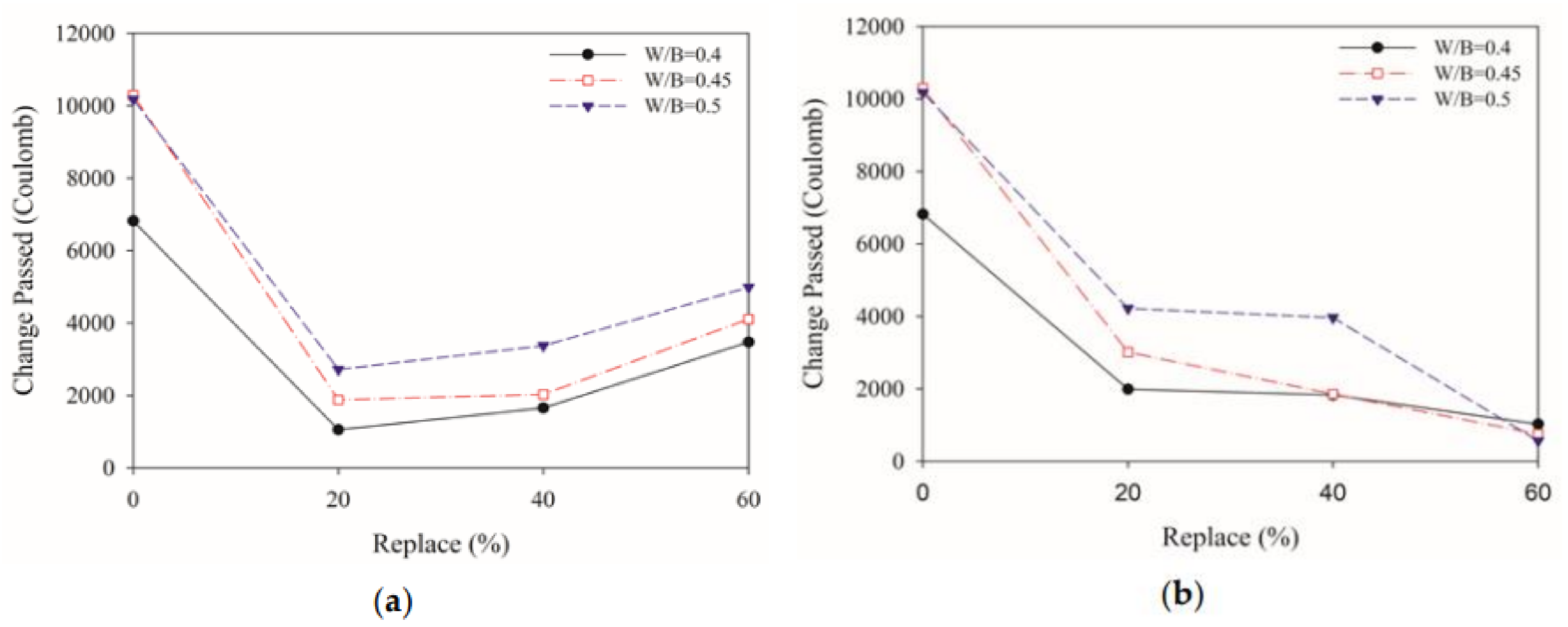

Figure 11. RCPT at different W/B ratios and cement replacement levels for (a) fly ash; (b) FGCBA.

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3.8. Absorption, Density, and Voids in Hardened Concrete

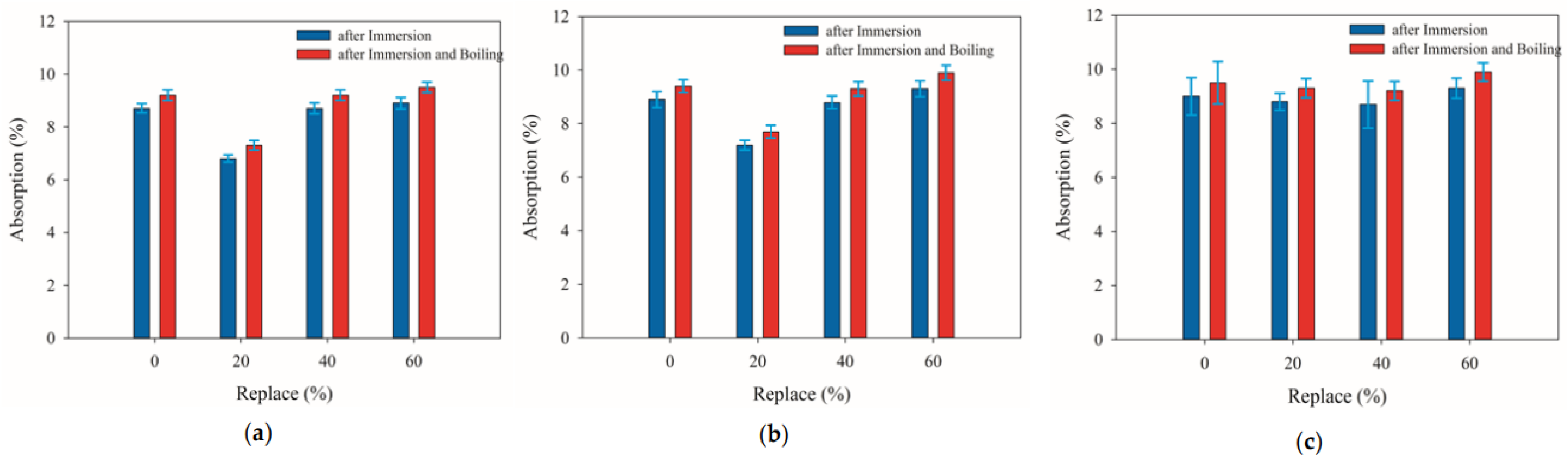

Figure 12. Water absorption of concrete with FA as cement replacement at different W/B ratios of (a) 0.4; (b) 0.45; (c) 0.5.

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3.8. Absorption, Density, and Voids in Hardened Concrete

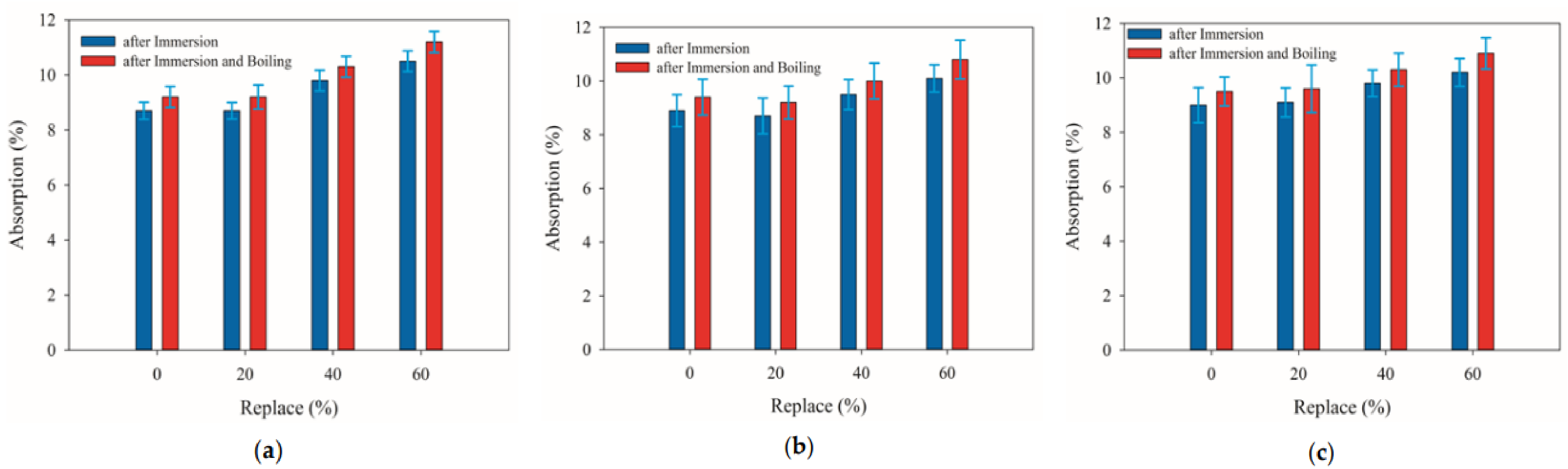

Figure 13. Water absorption of concrete with FGCBA as cement replacement at different W/B ratios of (a) 0.4; (b) 0.45; (c) 0.5.

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3.8. Absorption, Density, and Voids in Hardened Concrete

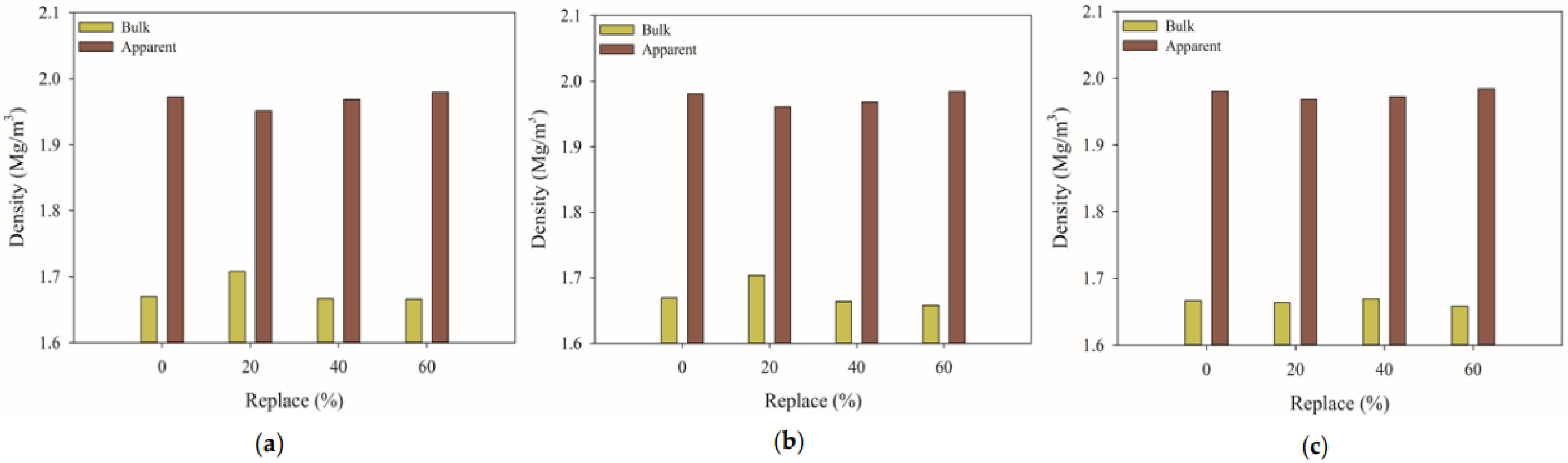

Figure 14. Density variation in concrete using FA as a cement substitute at various W/B ratios of (a) 0.4; (b) 0.45; (c) 0.5.

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3.8. Absorption, Density, and Voids in Hardened Concrete

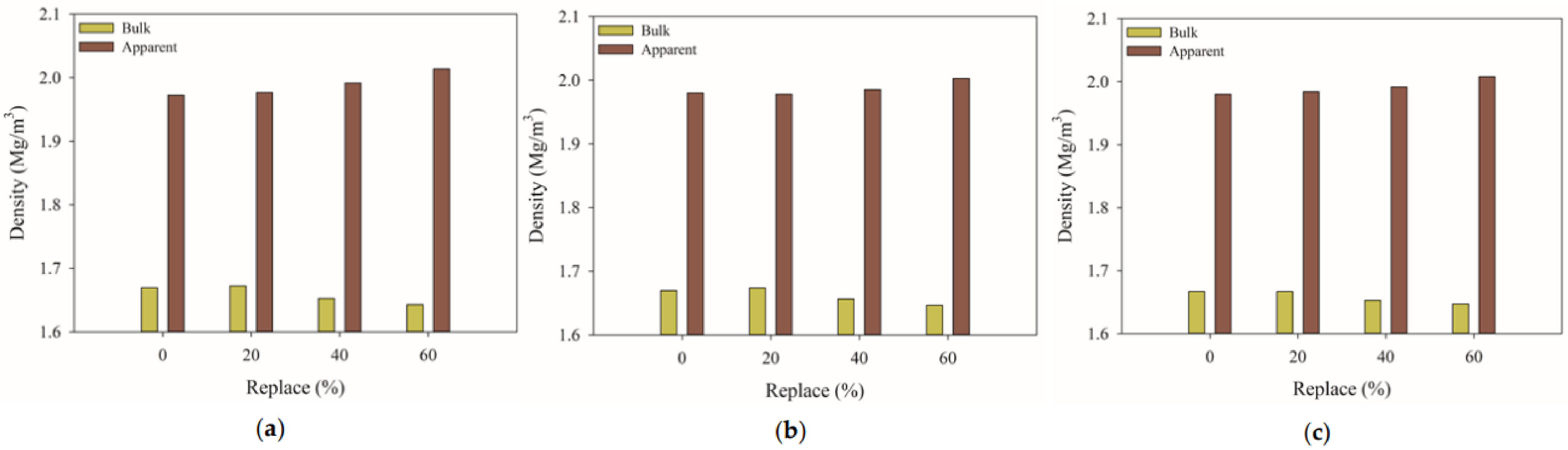

Figure 15. Density variation in concrete using FGCBA as a cement substitute at various W/B ratios of (a) 0.4; (b) 0.45; (c) 0.5.

3.8. Absorption, Density, and Voids in Hardened Concrete

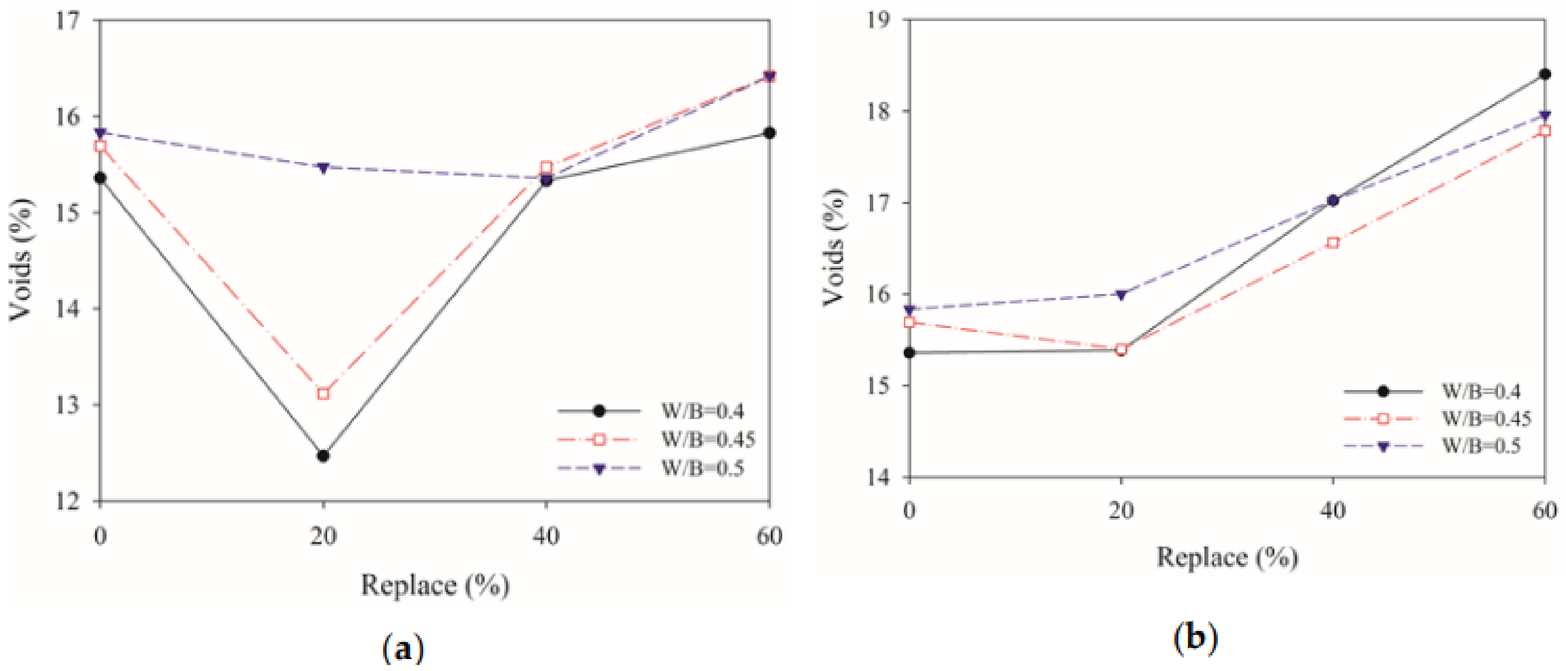

Figure 16. Voids in concrete at different W/B ratios and cement replacement levels for (a) FA; (b)FCGBA.

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Conclusions

FGCBA is promising and easy to implement:

- It has similar chemical properties to fly ash, which is already accepted in concrete production.
- It can be used in existing concrete plants by simply adding a water reducer.
- FGCBA can be stored in the same tank as fly ash, eliminating the need for separate storage.

Conclusions

- **Strength:** Both materials improve long-term strength, with fly ash being more effective at higher early strengths.
- **Workability:** Fly ash improves workability, while FGCBA only improves it up to a 20% replacement level.
- **Density and Air Content:** Both materials reduce concrete density, with fly ash creating a lighter mix.
- **Setting Time:** Both materials extend setting time, potentially requiring adjustments or faster setting admixtures.
- **Drying Shrinkage:** Fly ash increases shrinkage, while FGCBA's effect is more variable. Careful mix design is needed to ensure structural stability.
- **Chloride Permeability:** Fly ash is effective at reducing permeability up to 20% replacement. FGCBA is even more effective, especially at higher replacement levels.
- **Absorption and Density:** Higher FGCBA replacement increases absorption and voids, making the concrete more porous. Careful mix design is crucial at high replacement rates.

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