Recycling of clay brick waste for production of eco-concrete using the paste replacement and cement replacement methods

A.K.H. Kwan[1] and L.G. Li[2]

[1] Department of Civil Engineering, The University of Hong Kong (retired)

[2] School of Civil & Transportation Engineering, Guangdong University of Technology

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Executive Summary

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- Clay brick waste (CBW) is one of the largest construction wastes by volume.
- CBW has been recycled in concrete as (1) aggregate replacement after crushing, or (2) cement replacement after grinding.
- But these 2 methods have adverse effects on quality of concrete produced.
- Herein, a new method of adding ground clay bricks (GCB) to replace an equal volume of paste, called the paste replacement method, was developed.
- To compare the paste replacement and cement replacement methods, mortar mixes with GCB added as either paste or cement replacement were tested.
- Results showed that adding GCB as paste replacement improved the strength and microstructure and substantially reduced the cement content, whereas adding GCB as cement replacement decreased the strength and loosened the microstructure.

Introduction

Introduction (1)

- Production of cement for concrete would consume natural resources and energy, and release CO_2 and other hazardous gases.
- Use of natural rock and sand as aggregates would consume natural resources, and cause ecological damages.
- Numerous explorations have been carried out to reduce the usages of cement and natural aggregate.
- Some industrial wastes (or by-products), such as silica fume, fly ash, and rice husk ash are being used to replace cement.
- Some inert solid wastes, such as old concrete, old clay bricks, waste glass and mine tailing, are being used to replace natural aggregate.

Introduction (2)

- On the other hand, the amount of construction waste generated in China is about 1 billion tons per year.
- And around 40% of the construction waste is clay brick waste (CBW).
- Such a large amount of CBW, if just dumped, would occupy a large area of landfill and bring damage to environment.
- For the purpose of reducing usage of cement and natural aggregate, and increasing recycling rate of CBW, extensive research has been conducted on possible reuse of CBW as either cement replacement or aggregate replacement in concrete.
- The cement replacement method and aggregate replacement method are explained in the following.

Introduction (3)

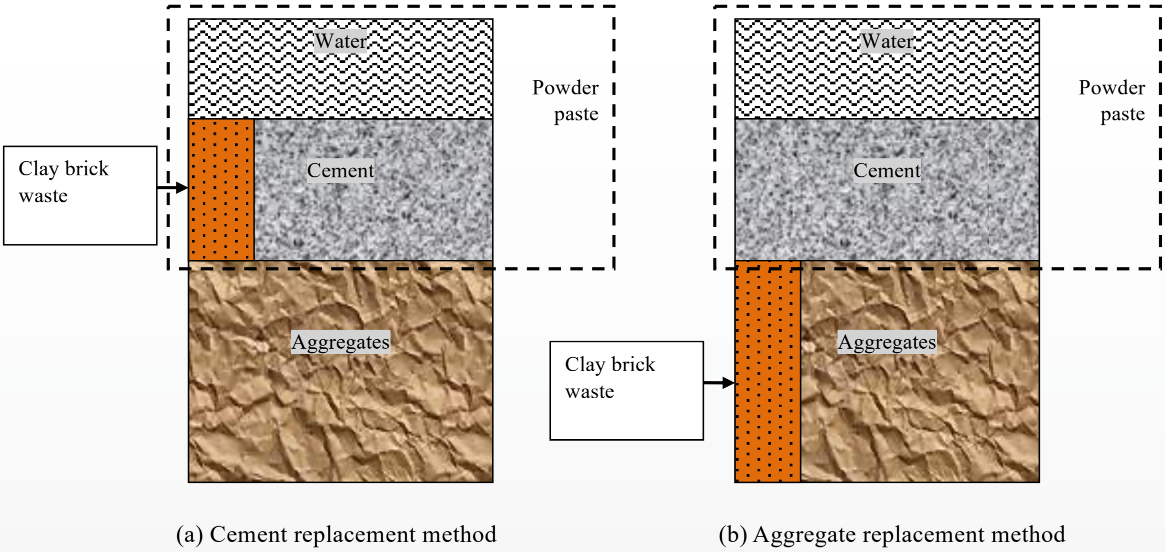


Figure 1 Clay brick waste addition methods

Introduction (4)

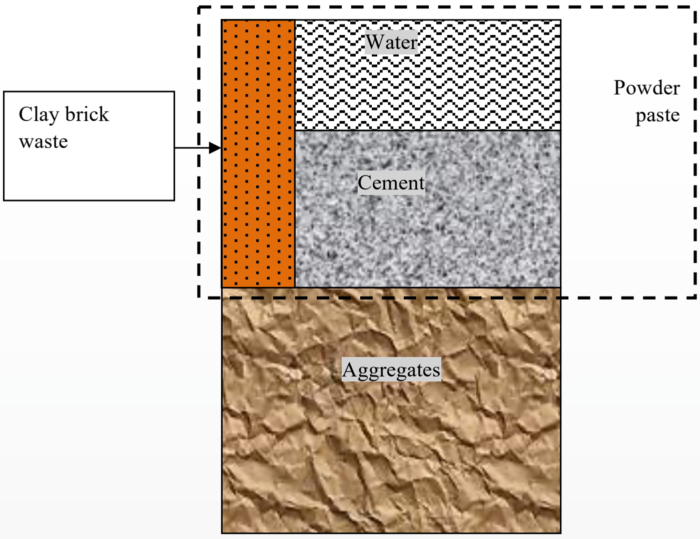
- The cement replacement method of adding CBW, after grinding to similar size as cement to become ground clay bricks (GCB), to replace a portion of the cement or cementitious materials is illustrated in Figure 1(a).
- The addition of GCB to partially replace cement can effectively reduce cement content and suppress AAR.
- However, it has been found that adding GCB as cement replacement substantially reduced the strength of the mortar/concrete produced, especially when the GCB content is relatively high.
- Hence, there is a certain limit to the allowable amount of GCB to be added as cement replacement.

Introduction (5)

- The aggregate replacement method of adding CBW, after crushing to similar size as fine or coarse aggregates to become crushed clay bricks (CCB), to replace a part or all of the natural aggregate is illustrated in Figure 1(b).
- 15% aggregate replacement would not significantly reduce the strength of concrete.
- But higher rate of aggregate replacement would significantly reduce the strength of concrete produced.
- Moreover, this method of adding CBW would not reduce the cement content.

- Hence, both the above 2 methods of reutilizing CBW do not have much advantages, except that the amount of waste to be disposed would be reduced.

Introduction (6)



(c) Paste replacement method

Figure 1 Clay brick waste addition methods

Introduction (7)

- The authors have developed a new method of reusing solid waste (or inert fillers) in mortar/concrete production, called the paste replacement method.
- In this method, the solid waste is ground to cement size and then added to replace an equal volume of the cementitious paste, as shown in Figure 1(c).
- While the cementitious paste volume and cementitious materials content are reduced, the water/cementitious materials ratio is kept unchanged.
- Previously, this method has been successfully applied to limestone fines, granite dust and marble dust.

- In present study, the paste replacement method was extended to the use of GCB in mortar/concrete.

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Materials and mix proportions

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Materials and mix proportions (1)

Materials

- OPC of strength class 42.5; river sand; third generation SP
- Ground clay bricks (GCB) produced by crushing, grinding, drying and sieving

(a) Clay bricks (b) Ground clay bricks (GCB)

Figure 2 Clay brick waste processed to become ground clay bricks

Materials and mix proportions (2)

Mix proportions

- Paste replacement method and cement replacement method separately applied for comparison.
- In the first phase, the GCB was added as paste replacement. Since the GCB has similar fineness as the cement, the GCB would intermix with the cementitious paste to form a powder paste comprising of the cementitious materials, GCB and water.
- In the second phase, the GCB was added as cement replacement. This would not change the powder volume (powder comprises of both cementitious materials and GCB), water volume and powder paste volume.
- For all mortar mixes, the powder paste volume (i.e., cementitious paste volume + GCB volume) was fixed at 60% and the aggregate volume was fixed at 40%.
- The mix proportions are presented in the following table.

Materials and mix proportions (3)

Table 1 Mix proportions of mortar mixes

Mix no.	Water (kg/m^3)	OPC (kg/m^3)	GCB (kg/m^3)	River sand (kg/m^3)	Reduction in cement content (%)
PR-0.40-5	305	762	132	1032	8.3
PR-0.45-5	321	713	132	1032	8.3
PR-0.50-5	335	670	132	1032	8.3
PR-0.55-5	347	631	132	1032	8.3
PR-0.40-10	277	693	264	1032	16.7
PR-0.45-10	292	648	264	1032	16.7
PR-0.50-10	304	609	264	1032	16.7
PR-0.55-10	316	574	264	1032	16.7
PR-0.40-15	250	624	396	1032	25.0
PR-0.45-15	263	583	396	1032	25.0
PR-0.50-15	274	548	396	1032	25.0
PR-0.55-15	284	516	396	1032	25.0
PR-0.45-20	233	519	528	1032	33.3
PR-0.50-20	244	487	528	1032	33.3
PR-0.55-20	252	459	528	1032	33.3
CR-0.40-5	333	790	35	1032	5.0
CR-0.55-5	379	654	29	1032	5.0
CR-0.40-10	333	749	71	1032	10.0
CR-0.55-10	379	620	58	1032	10.0
CR-0.40-15	333	707	106	1032	15.0
CR-0.55-15	379	585	88	1032	15.0
CR-0.55-20	379	551	117	1032	20.0

Test results

Test results (1)

Particle size distributions

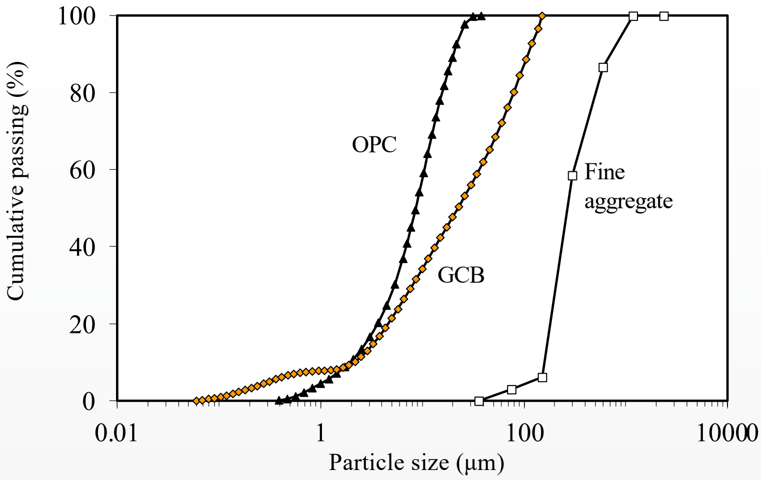

Figure 3 Particle size distributions of OPC, GCB and fine aggregate

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Test results (2)

Particle size distributions

- The median particle size of the GCB is slightly coarser than that of the OPC.
- The GCB has a much wider particle size range such that the larger size particles in the GCB are coarser than the OPC while the smaller size particles in the GCB are finer than the OPC.
- The finer portion of the GCB can fill into the voids between the OPC grains to densify the solid skeleton and increase the packing density of the powder (OPC+GCB) mixture.
- Even the coarser portion of the GCB, which is coarser than the OPC, is finer than the fine aggregate. Hence, there is a fairly wide and continuous spectrum of particles.
- Within the spectrum of particles, the voids between the larger size particles are successively filled by the smaller size particles to produce a dense solid skeleton.

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Test results (3)

SEM image of the GCB

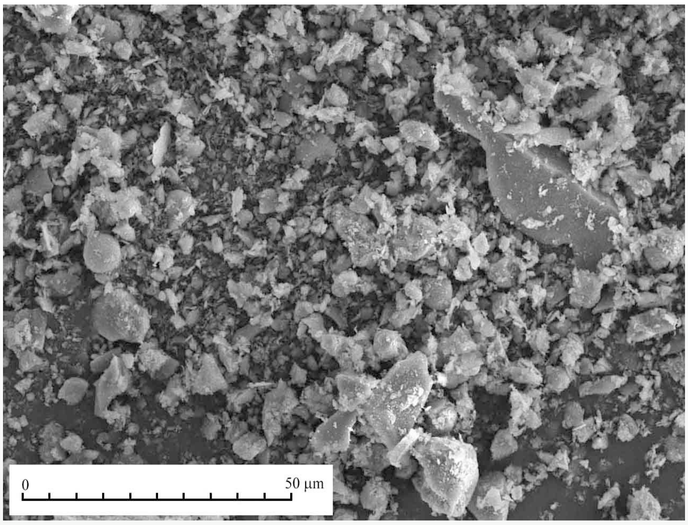


Figure 4(a) SEM image of GCB

Test results (4)

XRD pattern of the GCB

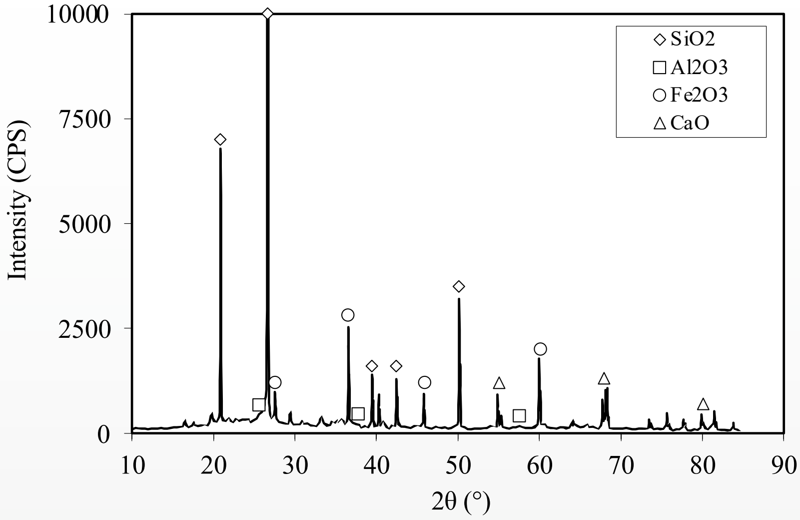
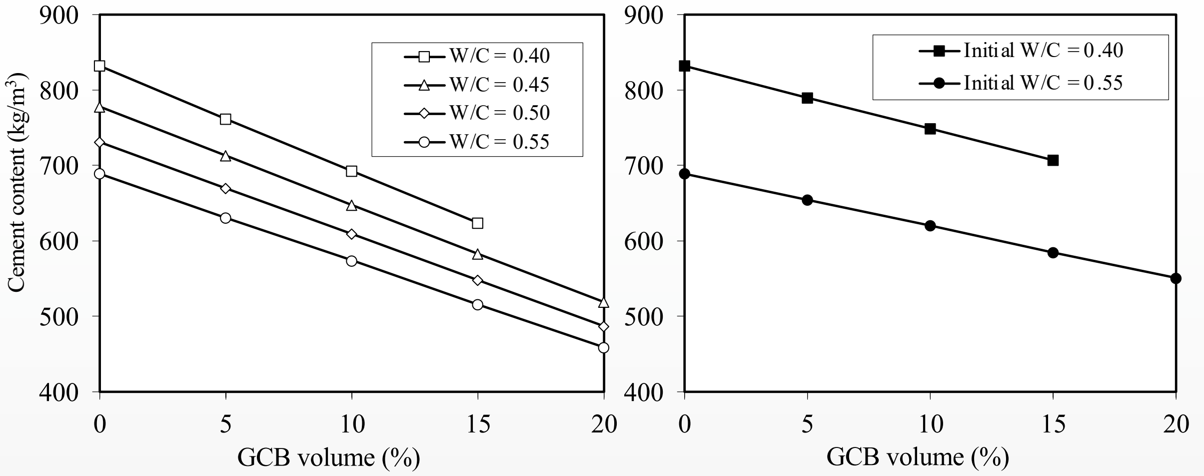


Figure 4(b) XRD pattern of GCB

Test results (5)

Cement content



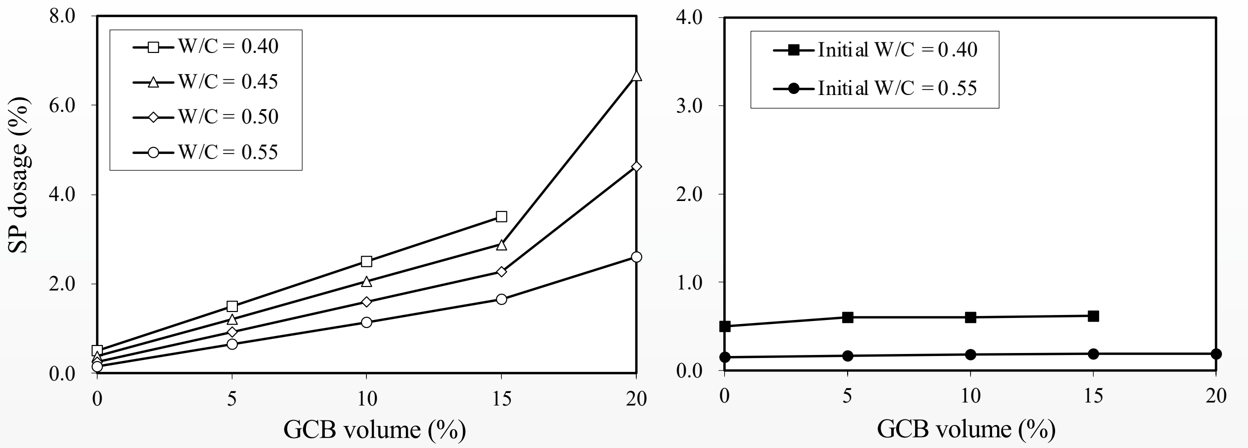
(a) GCB added as paste replacement (b) GCB added as cement replacement

Figure 5 Cement content versus GCB volume at different W/C ratios

Test results (6)

Flow spread and SP dosage

- All flow spread results are within target range. SP dosage needed is plotted in following figure.

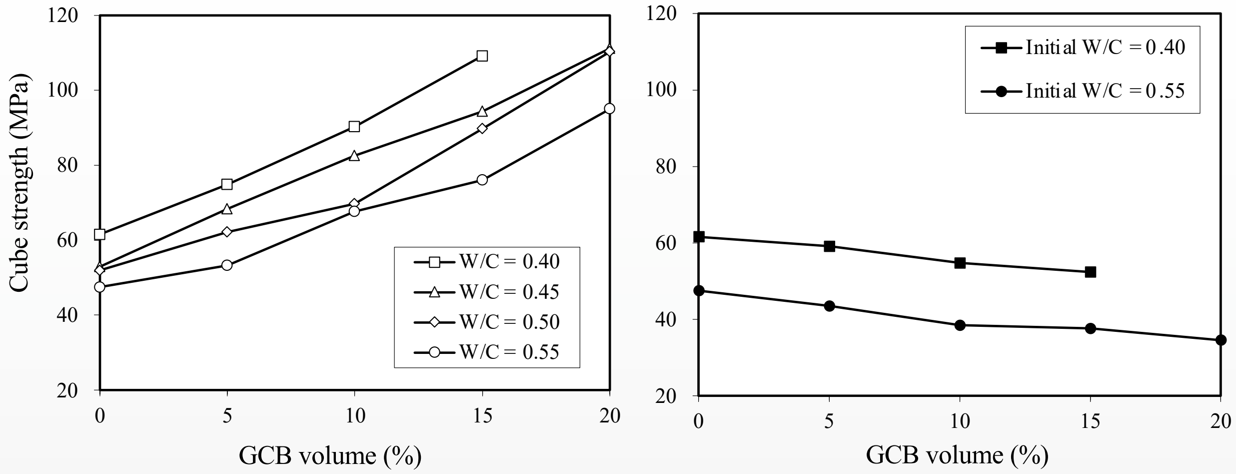


(a) GCB added as paste replacement (b) GCB added as cement replacement

Figure 6 SP dosage versus GCB volume at different W/C ratios

Test results (7)

Cube strength

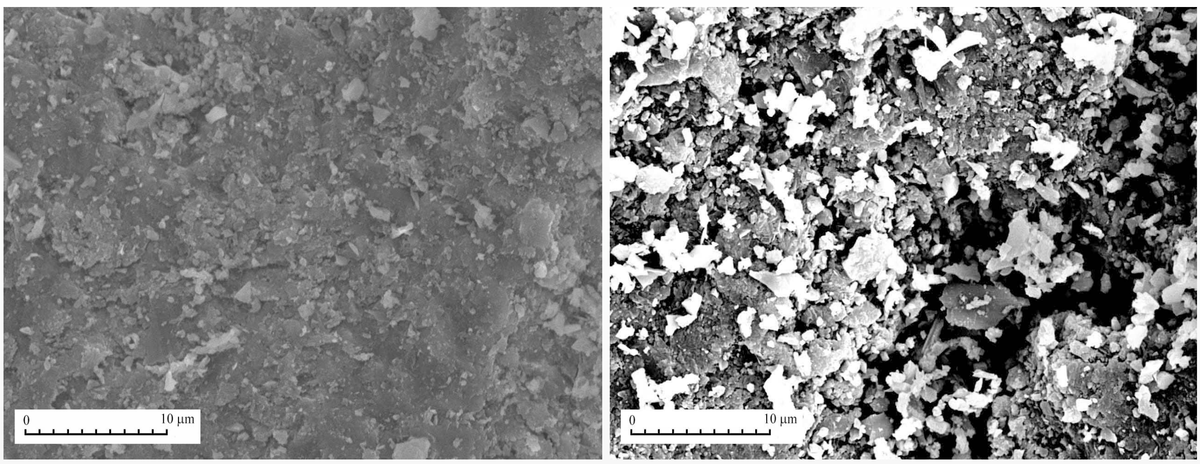


(a) GCB added as paste replacement (b) GCB added as cement replacement

Figure 7 Cube strength versus GCB volume at different W/C ratios

Test results (8)

SEM image of hardened mortar



(a) PR-0.55-20 (20% paste replacement) (b) CR-0.55-20 (20% cement replacement)

Figure 8 SEM micrographs of hardened mortar at 28-day

Test results (9)

XRD pattern of hardened mortar

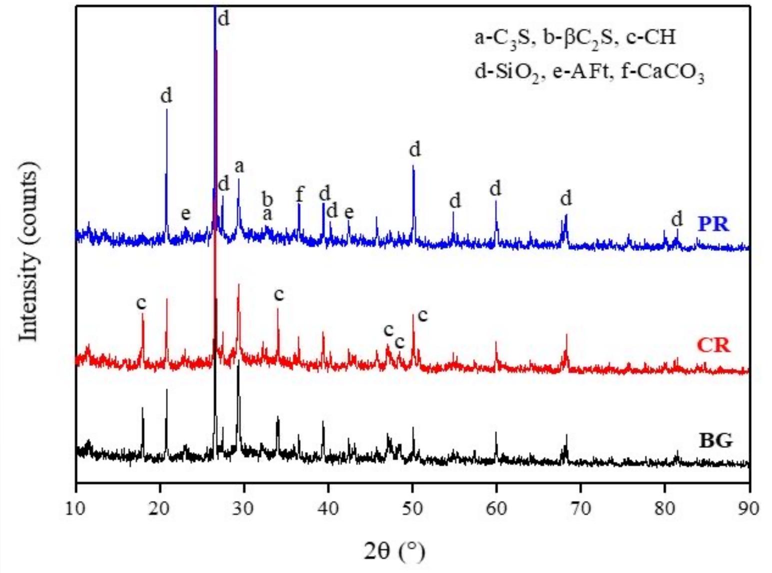


Figure 9 XRD results of hardened mortar at 28-day

Discussions

Discussions (1)

Effects on cement content, workability and strength

- Both the paste replacement method and the cement replacement method are effective in lowering the cement content.
- In the case of adding GCB as paste replacement, the workability would be decreased but the strength would be increased. The decrease in workability could be compensated by adding much more SP. However, the SP dosage could become excessive if too much GCB is added.
- In the case of adding GCB as cement replacement, both the workability and strength would be decreased. The decrease in workability is relatively small and could be compensated by adding slight more SP. However, the decrease in strength may not be tolerable if too much GCB is added.

Discussions (2)

Simultaneous changes of cement content and strength

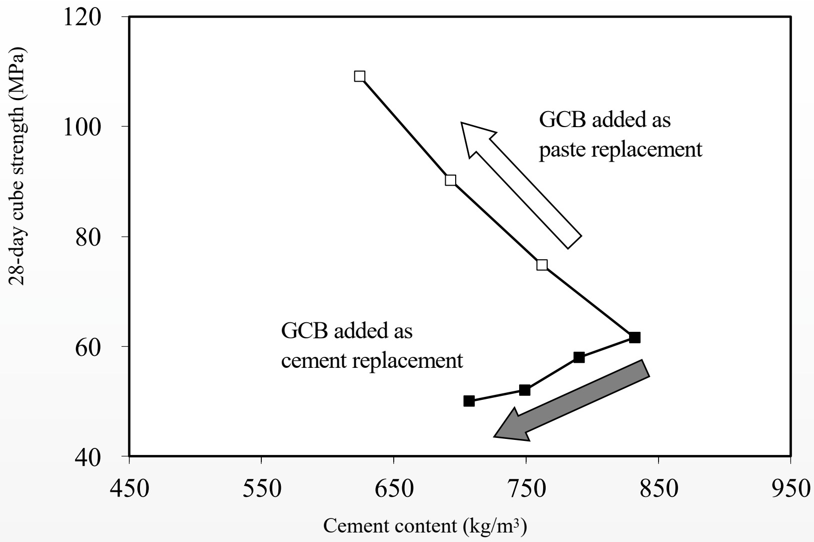


Figure 10 Cube strength versus cement content at initial W/C = 0.40

Discussions (3)

Increase in strength → decrease in member size → reduction in cement consumption

- The effectiveness in reducing the cement consumption should not be evaluated by just considering the cement content per unit volume. The change in strength should also be considered.
- If the strength is increased, then in the structural design, the member size may be reduced to decrease the concrete volume, and if the strength is decreased, then a larger member size has to be used, causing the concrete volume to increase.
- To better reflect this overall effect, it is of interest to evaluate the combined effects of the simultaneous changes in cement content and cube strength in terms of the cement content to cube strength ratio, as presented in the following table.

Discussions (4)

Table 2 Strength results and cement content to strength ratios of mortar mixes

Mix no.	28-day cube strength (MPa)				Change in cube strength (%)	Cement content to cube strength ratio ($kg/m^3/MPa$)
	Cube 1	Cube 2	Cube 3	Mean		
PR-0.40-5	74.8	74.6	75.0	74.8	+21.4	10.19
PR-0.45-5	68.4	67.7	68.8	68.3	+29.1	10.44
PR-0.50-5	61.5	63.1	62.1	62.2	+19.6	10.77
PR-0.55-5	53.2	53.5	53.1	53.3	+12.2	11.84
PR-0.40-10	84.0	88.8	98.0	90.3	+46.6	7.67
PR-0.45-10	81.6	81.9	84.2	82.6	+56.1	7.85
PR-0.50-10	72.4	69.2	67.4	69.7	+34.0	8.74
PR-0.55-10	65.3	70.2	67.4	67.6	+42.3	8.49
PR-0.40-15	97.9	114.5	115.2	109.2	+77.3	5.71
PR-0.45-15	95.7	93.3	94.3	94.4	+78.4	6.18
PR-0.50-15	89.8	88.6	90.8	89.7	+72.5	6.11
PR-0.55-15	79.2	78.2	70.7	76.0	+60.0	6.79
PR-0.45-20	113.9	111.2	108.5	111.2	+110.2	4.67
PR-0.50-20	106.0	110.4	114.4	110.3	+112.1	4.42
PR-0.55-20	95.6	94.9	94.6	95.0	+100.0	4.83
CR-0.40-5	59.9	58.2	59.0	59.1	-4.1	13.37
CR-0.55-5	46.0	41.1	43.3	43.5	-8.4	15.03
CR-0.40-10	53.0	55.6	55.9	54.8	-11.0	13.67
CR-0.55-10	37.8	37.4	40.2	38.5	-18.9	16.10
CR-0.40-15	52.8	52.3	52.1	52.4	-14.9	13.49
CR-0.55-15	37.0	36.5	39.5	37.7	-20.6	15.52
CR-0.55-20	33.7	35.0	34.9	34.5	-27.4	15.97

Conclusions

Conclusions (1)

1. The paste replacement (PR) method can greatly increase the strength (by as much as 112%), whereas the cement replacement (CR) method slightly decreases the strength. In terms of cement content reduction, both methods are effective. However, in PR method, there is a notable increase in SP demand, especially when the GCB volume is higher than 15%.

2. Physically, the addition of GCB as PR can densify the microstructure of the hardened mortar, whereas the addition of GCB as CR loosens the microstructure. This is one of the reasons for the increase in strength by the paste replacement method.

3. Chemically, the addition of GCB as PR plays a significant role in the hydration process of cement: the C-H generated during cement hydration is largely converted by the GCB to additional calcium silicate hydrate (C-S-H). This is another reason for the increase in strength by the PR method.

Conclusions (2)

4. When the GCB is added as PR, the GCB volume (as a percentage of the mortar volume) should be limited at 15% (or 20%), depending on the W/C ratio, to avoid an excessively high SP dosage.

5. When the GCB is added as CR, the GCB volume (as a percentage of the initial cementitious materials volume) should be limited at 5% to avoid excessive reduction in strength.

6. The PR method is a more promising way of reutilizing the GCB to produce eco-concrete due to the following advantages: larger GCB volume can be added thus enabling greater reutilization of waste; larger reductions in cement content and carbon footprint; substantial increase in cube strength; and substantial reduction in cement content to cube strength ratio. If the increased strength is exploited to reduce the member size in the structural design, the total cement content in the concrete structure could be further reduced.

Thanks for your attention!

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