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Properties of self-compacting concrete prepared with recycled glass aggregate

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ABSTRACT

The effects of recycled glass (RG) cullet on fresh and hardened properties of self-compacting concrete (SCC) were investigated. RG was used to replace river sand (in proportions of 10%, 20% and 30%), and 10 mm granite (5%, 10% and 15%) in making the SCC concrete mixes. Fly ash was used in the concrete mixes to suppress the potential alkali-silica reaction. The experimental results showed that the slump flow, blocking ratio, air content of the RG–SCC mixes increased with increasing recycled glass content. The compressive strength, tensile splitting strength and static modulus of elasticity of the RG–SCC mixes were decreased with an increase in recycled glass aggregate content. Moreover, the resistance to chloride ion penetration increased and the drying shrinkage of the RG–SCC mixes decreased when the recycled glass content increased. The results showed that it is feasible to produce SCC with recycled glass cullet.

1. Introduction

A huge amount of solid waste is disposed of at the landfills in Hong Kong every year and the landfill capacity is expected to be exhausted within 6–10 years time [1]. The reuse and recycling of solid waste is high on the agenda of sustainable waste management. Waste glass, especially waste glass beverage bottles, is a potential candidate for recycling [2]. Generally, in other parts of the world, it is known that most of recycled glasses collected, especially beverage bottles, are re-melted and used to reproduce new glass. However, not all the waste glasses are suitable for new glass production, because some waste glasses are contaminated with papers and other substances or colour mixed, which make these glasses not suitable for glass bottle re-production. Also, in Hong Kong there is currently no glass manufacturing industry. Hence, research is needed to find other outlets for the waste glass, especially in the construction industry.

A number of studies were conducted in the 1960s to try to use crushed waste glasses as aggregates for concrete [3–6]. In the past 10 years, the use of glass as concrete aggregates has again attracted much research interests due to high disposal costs for waste glasses and environmental regulations [7–13]. Meyer and Baxter [8,14] conducted very extensive laboratory studies on the use of crushed glasses as aggregates. They found that a practically feasible concrete mixture could be produced by using 100% crushed glass as aggregates, 80% ASTM Type III Portland cement and 20% metakaolin as cementitious materials and proper amount of superplasticizer. Chen et al. [13] investigated the properties of concrete containing various waste E-glass (glass derived from electronic products) contents. Waste E-glass particles were obtained from electronic grade glass yarn scrap by grinding. The size distribution of cylindrical glass particle was from 38 to 300 μm and about 40% of E-glass particle was less than 150 μm. Based on the properties of hardened concrete, the optimum E-glass content was found to be 40–50% by mass [13].

There are quite a number of applications of using recycled glass in the construction industry over the world. The application includes using glass in asphalt concrete (glass–phalt), normal concrete, back-filling, sub-base, tiles, masonry blocks, paving blocks and other decorative purposes [15–22]. But practical applications of using recycled glass in structural concrete are limited.

A major concern regarding the use of glass in concrete is the chemical reaction that takes place between the silica-rich glass particles and the alkali in the pore solution of concrete, i.e., alkali-silica reaction (ASR). This reaction can be very detrimental to the stability of concrete, unless appropriate precautions are taken to minimize its effects. Such preventative actions could be achieved by incorporating a suitable pozzolanic material such as fly ash, ground blast furnace slag or metakaolin in the concrete mix at appropriate proportions [23,24].

Self-compacting concrete (SCC) is considered as a concrete which can be placed and compacted under its self-weight with little or no vibration effort, and which is at the same time cohesive enough to be handled without segregation or bleeding. Previous investigations showed that the use of fly ash and blast furnace slag in SCC reduced the dosage of superplasticizer needed to obtain similar slump flow compared to concrete made with Portland cement only [25]. Also, the use of fly ash improved the rheological properties and reduced thermal cracking of the concrete produced [26]. Kim et al. [27] studied the properties of super-flowing concrete containing fly ash and reported that the replacement of

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cement by 30% fly ash resulted in excellent workability and flowability. Other researchers [28] evaluated the influence of supplementary cementitious materials on workability and concluded that the replacement of cement by 30% of fly ash can significantly improve rheological properties.

Fly ash cannot only be used to improve the fresh and hardened properties of SCC, but it can also be used to suppress the expansion due to ASR in Portland cement concrete. The duo advantages of using fly ash in SCC and recycled glass warrant a study to explore the feasible use of recycled glass aggregate in SCC which is a subject that has not been reported in the literature.

2. Experimental details

2.1. Materials

2.1.1. Cementitious materials

ASTM Type I Portland cement with specific gravity of 3.15 and Blaine fineness of 3519 cm^2/g was used. A fly ash that met the requirements of ASTM class F ash with a relatively low CaO content of <3%, Blain fineness of 3960 cm^2/g, and specific gravity of 2.31 was used. The physical properties and chemical compositions of the cement and class F fly ash are presented in Table 1.

2.1.2. Aggregates

Twenty millimetre maximum size crushed granite and river sand sourced from mainland China were used as natural coarse and fine aggregates, respectively. Table 2 presents their particle grading. The coarse and fine aggregates each had a specific gravity of 2.62 and water absorption of 0.86% and 0.87%, respectively.

10 mm and <5 mm recycled glass (RG) cullet were used in this study. The glass cullet was mainly waste beverage glass bottles and was provided by the Environmental Protection Department (EPD) of Hong Kong through a contractor who carried out the collection, washing and crushing process. The RG was a blend of three different colors of glass bottles (30% colorless, 40% green and 30% brown). The mixed RG was used as aggregates for producing the mortar bars and SCC mixes in the experimental programme. The recycled glass sand (<5 mm) had the bulk specify gravity (SSD) of 2.49, fineness modulus of 4.25 and a water absorption of 0.36. The grading of the RG aggregates satisfied the requirement for aggregates of BS 882: 1983 [29]. The particle size distribution of the RG is shown in Table 2.

2.1.3. Admixture

In this study, a superplasticizer ADVA 109, based on the new comb polymer technology, was used in all concrete mixes. The ADVA 109 contained no added chloride and weighs approximately 1.045 ± 0.02 kg/l.

2.2. Mix proportions

2.2.1. Mortar bar mixes

The potential ASR expansion of the prepared mortar bars was assessed in accordance with ASTM C1260-02 [30]. Two series of mortar bars were prepared. In Series I, OPC was used as the cementitious material. Four mortar bar mixes, which used 0%, 15%, 30% and 45% RG sand to replace river sand respectively, were prepared. In Series II, fly ash was used to replace 33% by weight of cement, and the RG sand replacement levels were the same as in Series I. The mix proportions are shown in Table 3.

2.2.2. Self-compacting concrete mixes

A total of four SCC mixes were produced, and their detailed mix proportions are presented in Table 4. These included one control mix, and three mixes made with RG to replace 10mm granite (at 5%, 105 and 15% levels), and river sand (at 10%, 205 and 30% levels), respectively.

For all SCC mixes, the amount of the cementitious materials used was generally maintained at approximately 500 kg/m^3 of concrete and with a free water-to-binder ratio of 0.37. The ratio of fine-to-coarse aggregates was about 49:51. All the SCC mixes were designed to have a 28-day compressive strength of about 60 MPa.

2.3. Casting and curing of test specimens

All the concrete mixes were mixed for 5 min in a laboratory pan mixer. Tests were conducted on fresh concrete mixes to determine slump flow, flow time, segregation resistance, *L*-box ratio, wet density and air content.

Table 1
Physical and chemical properties of cement and fly ash.

Chemical analyses (%)	ASTM Type I cement	ASTM class F fly ash
Calcium oxide (CaO)	63.15	<3
Silicon dioxide (SiO_2)	19.61	56.79
Aluminium oxide (Al_2O_3)	7.33	28.21
Ferric oxide (Fe_2O_3)	3.32	5.31
Magnesium oxide (MgO)	2.54	5.21
Sodium oxide (Na_2O)	0.13	0.45
Potassium (K_2O)	0.39	1.34
Sulfur trioxide (SO_3)	2.13	0.68
Loss on ignition	2.97	3.90
Physical properties		
Specific gravity	3.16	2.31
Blaine fineness (cm^2/g)	3519	3960

Table 2
Particle size distributions and density of aggregates.

Sieve size (mm)	River sand (% passing)	10 mm granite (% passing)	20 mm granite (% passing)	10 mm recycled glass (% passing)	Recycled glass sand (% passing)
37.5	–	–	100	–	–
20	–	–	95	–	–
14	–	100	–	100	–
10	100	94	18	99	100
5	99	21	4	18	99
2.36	96	4	–	2	64
1.18	87	–	–	–	35
0.6	70	–	–	–	20
0.3	26	–	–	–	10
0.15	2	–	–	–	5
0.075	0.6	–	–	–	1.4
Relative density (g/cm^3)	2.62	2.62	2.62	2.49	2.49

Table 3
Mix proportions of mortar bars.

Notations	RG (%)	Cement (g)	RG (g)	Sand (g)	Fly ash (g)
Series I					
Control	0	440	–	990	–
G15	15	440	148.5	751.5	–
G30	30	440	297	693	–
G45	45	440	445.5	544.5	–
Series II					
Control-F	0	440	–	844.5	145.5
G15-F	15	440	126.5	718	145.5
G30-F	30	440	253	591.5	145.5
G45-F	45	440	380	464.5	145.5

From each concrete mix, fifteen 100 mm cubes were cast for the determination of compressive strength. Twenty eighty 100-mm diameter × 200 mm cylinders were cast for the determination of splitting tensile strength, static modulus of elasticity and the resistance to chloride ion penetration. To assess the self-compactability of these mixes, half of the cylinders were cast as SCC (with no vibration/compaction applied), while the other half were cast with a vibration/compaction process similar to that of normal concrete (Nml). Six 70 × 70 × 285 mm prisms were cast for determining the drying shrinkage and alkali-aggregate reaction (ASR).

After casting, all the cast specimens were covered with plastic sheets and water-saturated burlap and left in the laboratory at 20 ± 3 °C for 24 h. The specimens were then demoulded and transferred to a standard water curing tank at 27 °C until the age of testing.

On the other hand, the mortar bars were cast according to ASTM C1260 using a water to cement ratio of 0.47. The sieved aggregates were mixed with the cementitious materials at the stipulated mix proportions. Then, the mixes were cast into steel moulds which had internal dimensions of 25 × 25 × 285 mm.

2.4. Testing of concrete mixes

2.4.1. Determination of the fresh properties of RG–SCC

2.4.1.1. Slump flow test. The slump flow test was used to evaluate the free deformability and flowability of the SCC in the absence of any obstruction. A standard slump cone was used for the test and the concrete was poured in the cone without compaction. The slump flow value is represented by the mean diameter (measured in two perpendicular directions) of concrete after lifting the standard slump cone. The measurements were repeated at 30, 60, 90 and 120 min after the initial mixing to evaluate the slump loss properties of the SCC mixes.

2.4.1.2. Segregation test. The GTM screen stability test method, developed by the French contractor (GTM) [31] was adopted to assess the segregation resistance of the fresh SCC mixes. The method consisted of taking 10 l of concrete and allowing the concrete to stand for 15 min in a bucket covered with a lid to prevent evaporation. After that, half of the concrete was poured onto a 5 mm sieve of 350 mm diameter, which sat on a sieve pan on a weigh scale. After two minutes, the mass of mortar which passed through the sieve was measured and expressed as a percentage of the weight of the original sample on the sieve.

2.4.1.3. Blocking ratio (L-box test). The *L*-box test was performed in according with EFNARC standards [31]. This test has been used to assess the flowability and passing ability of concrete. During the test, SCC was allowed to flow upon the release of a trap door from the vertical section to the horizontal section via a few reinforcement bars of a L-shape box. The height of the concrete at the end of the horizontal section was compared to the height of concrete remained in the vertical section. The ratio is usually between 0.8 and 1.0. If the ratio is less than 0.8, the viscosity of the SCC mixes is too high which would cause blockage around the reinforcement.

2.4.1.4. Air content test. The air content of the RG–SCC was determined in accordance with BS 1881 Part 114 [32].

2.4.2. Determination of the hardened properties of RG–SCC

2.4.2.1. Compressive and splitting tensile strengths. The compressive and splitting tensile strengths of RG–SCC were measured using a Denison compression machine with a loading capacity of 3000 kN. The loading rates applied for the compressive and tensile splitting tests were 200 kN/min and 57 kN/min, respectively. The compressive strength test was carried out at the ages of 1, 4, 7, 28 and 90 days while the tensile splitting strength test was carried out at the ages of 28 and 90 days.

2.4.2.2. Static modulus of elasticity tests. Static modulus of elasticity of the RG–SCC was determined on three 100 × 200 mm cylindrical specimens according to ASTM C 469-02 [33].

2.4.2.3. Drying shrinkage test. A modified British Standard Test Method (BS1881, Part 5: 1970) was used for the drying shrinkage test. For the specimens (70 × 70 × 285 mm) were prepared for the drying shrinkage test, after removing them from the curing tank after 28-day of curing, the initial length of each specimen was measured. After the initial reading, the specimens were conveyed to a drying chamber with a temperature of 55 °C and a relative humidity of 95% until further measurements at 1, 4, 7, 28, 56, 90 and 112 days after the initial measurement. Before each measurement was taken on the scheduled day, the specimens were first removed from the drying chamber and conveyed to a cooling chamber for about 4 h in order to cool the specimens to a constant temperature of 25 °C and a relative humidity of 75%. The length of each specimen was then measured within 15 min before delivering the specimens back to the drying chamber for the subsequence drying process. The procedure of drying, cooling and measuring continued until the final length measurement was recorded at 112 days.

2.4.2.4. Determination of chloride ion penetrability. The chloride ion penetrability was determined in accordance with ASTM C1202-97 [34] using 50 mm thick concrete discs obtained from the ∅100 × 200 mm concrete cylinders. The resistance of concrete to chloride ion penetration was represented by the total charge passed in coulombs during a test period of 6 h. In this study, the

Table 4
Mix proportions of SCC (kg/m^3).

Notation	OPC	PFA	20 mm	10 mm	Sand	10 mm Glass	Glass sand	Water	SP (l/m^3)	W/C
Control	375	125	422	400	860	0	0	185	8.5	0.37
G15	375	125	422	380	774	81	19	185	8.2	0.37
G30	375	125	422	360	688	162	38	185	8.0	0.37
G45	375	125	422	340	602	246	54	185	7.8	0.37

chloride ion penetrability test was carried out on the concrete specimens at the ages of 28 and 90 days.

2.4.2.5. Alkali-silica reaction. The accelerated mortar bar test was carried out in accordance with ASTM C1260 (80 °C, 1 N NaOH solution) but the duration of the ASR test was extended to 28-days (the standard test period is 14 days). The expansion of the mortar bars were measured at 1, 4, 7, 14 and 28 tested ages.

3. Results and discussion

3.1. Fresh properties

The test results of the control and RG–SCC mixes are summarized in Table 5. Table 6 lists some typical acceptance criteria for SCC in Europe [31]. Comparing the results with the European criteria, it can be seen that all RG–SCC mixes showed satisfactory properties.

3.1.1. Slump flow and blocking ratio (L-box test)

It can be seen that the initial slump flow of RG–SCC mixes was similar to the control although the dosage of superplasticizer was decreased (see Table 3). This is attributed to the weaker cohesion between the glass aggregates and the cement paste due to their smooth and impermeable surfaces. This result is similar to that of Terro [35] who reported that the slump of normal concrete was the same as that of concrete with recycled glass cullet.

The changes in slump flow of the concrete mixes with time are shown in Fig. 1. The flowability decreased with time due to the hydration of cement, which increased the cohesiveness of the cement paste. The rate of slump loss decreased with the increase in RG aggregate content. All RG–SCC mixes had lower rates of slump loss than the control.

As shown in Table 5, the blocking ratios varied from 0.84 to 0.87 for the RG–SCC mixes. The results indicate that the RG–SCC mixes prepared in this study achieved adequate passing ability and maintained sufficient resistance to segregation around congested reinforcement areas. According to the European specification [31] the blocking ratio of SCC should be between 0.8 and 1.0.

3.1.2. Segregation ratio

The segregation ratios for the control and RG–SCC mixes are shown in Table 5. It can be seen that the segregation ratio of the SCC tended to increase with an increase in the RG aggregate content. The resistance to segregation of RG–SCC mixes was lower than the control. The segregation ratio varied from 10.6% to 12.3%. The European specification [31] suggests that if the segregation ratio is between 5% and 15%, the segregation resistance of the SCC is considered satisfactory. If the segregation ratio is below 5%, the resistance is deemed excessive and is likely to affect the surface finish. On the other hand, if the segregation ratio is above 15%, and particularly above 30%, there is a strong likelihood of segregation. The results indicated that the RG–SCC mixes prepared in this study achieved adequate segregation resistance.

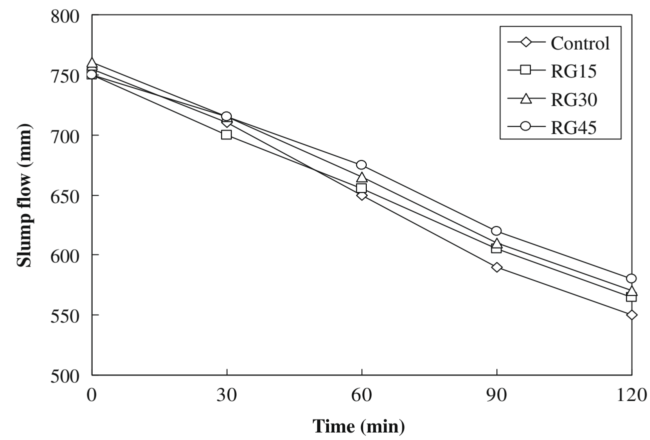

Fig. 1. Change of slump flow with time.

Table 5
Fresh properties of SCC.

Notation	Slump flow		*L*-box ratio		Air content (%)	Segregation ratio (%)	Wet density (kg/m^3)
	Final time (s)	Final diameter (mm)	Final time (s)	Ratio			
Control	42.5	755	36	0.88	3.1	10.4	2290
G15	42	750	40	0.87	2.6	10.6	2280
G30	43	760	39	0.86	2.7	11.5	2260
G45	41	750	38	0.84	2.9	12.3	2250

Table 6
General acceptance criteria of SCC [31].

Test method	Unit	Typical range of values	
		Minimum	Maximum
Slump flow	mm	650	800
GTM screen stability test	%	0	15
L-box, H_2/H_1	Ratio	0.8	1.0

Table 7
Compressive strength, splitting tensile strength and density of SCC.

Notation	Compressive strength (MPa)					Splitting tensile strength (MPa)		Density (kg/m^3)
	1-day	3-day	7-day	28-day	90-day	28-day	90-day	
Control	23.5 (±0.2)	36.6 (±0.3)	47.3 (±0.1)	67.4 (±0.2)	75.4 (±0.2)	3.42 (±0.03)	4.18 (±0.02)	2378 (±8)
G15	22.3 (±0.1)	35.8 (±0.3)	46.6 (±0.2)	66.4 (±0.4)	74.9 (±0.2)	3.26 (±0.04)	4.02 (±0.03)	2370 (±6)
G30	20.8 (±0.2)	33.6 (±0.4)	44.4 (±0.3)	64.6 (±0.2)	72.9 (±0.6)	3.19 (±0.03)	3.90 (±0.03)	2337 (±5)
G45	19.2 (±0.1)	31.2 (±0.2)	42.3 (±0.4)	61.7 (±0.3)	68.5 (±0.5)	3.03 (±0.03)	3.71 (±0.01)	2285 (±4)

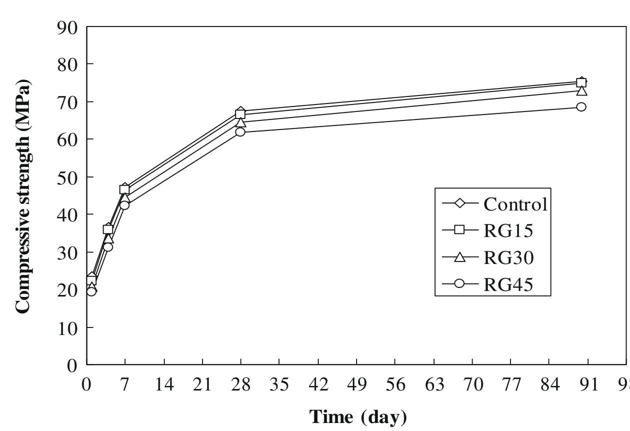

Fig. 2. Development of compressive strength of SCC.

3.2. Hardened properties

3.2.1. Compressive, tensile splitting strengths and density

The test results of the compressive strength of the control and RG–SCC mixes are summarized in Table 7 and the development of compressive strength of the concrete are shown in Fig. 2. Each presented value is the average of three measurements. It is evident in Table 7 and Fig. 2 that at all test ages, the use of RG as sand and 10 mm coarse aggregate replacement decreased the compressive strength of the SCC mixes compared with the control. The corresponding reduction in the 28-day strength for RG15, RG30 and RG 45 was 1.5%, 4.2% and 8.5%, respectively. These results are similar to that of Park et al. [36] who reported that the compressive strength of normal concrete was only slightly less than the strength of concrete made with recycled glass. This may be attrib-

Table 8
Static elasticity modulus and chloride ion penetration of SCC.

Notation	Static elasticity modulus (GPa)		Chloride ion penetration (coulombs)	
	28-day	90-day	28-day	90-day
Control	29.8 (±0.6)	32.9 (±0.4)	442 (±5)	107 (±4)
G15	29.2 (±0.5)	31.4 (±0.3)	373 (±4)	108 (±3)
G30	28.3 (±0.4)	30.2 (±0.3)	228 (±5)	108 (±4)
G45	27.2 (±0.4)	29.3 (±0.3)	176 (±5)	100 (±4)

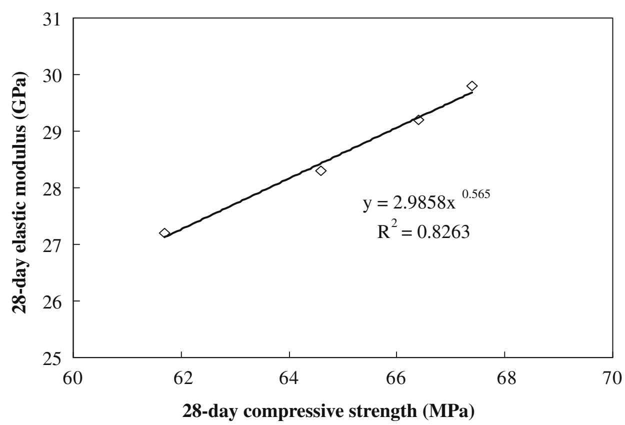

Fig. 3. Relationship between 28-day compressive strength and 28-day elastic modulus of SCC.

Table 9
Drying shrinkage of SCC at age of 112 days.

Mix notation	Recycled glass (%)	Drying shrinkage (Length change %)
Control	0	0.038 (±0.003)
G-15	15	0.036 (±0.004)
G-30	30	0.034 (±0.004)
G-45	45	0.031 (±0.003)

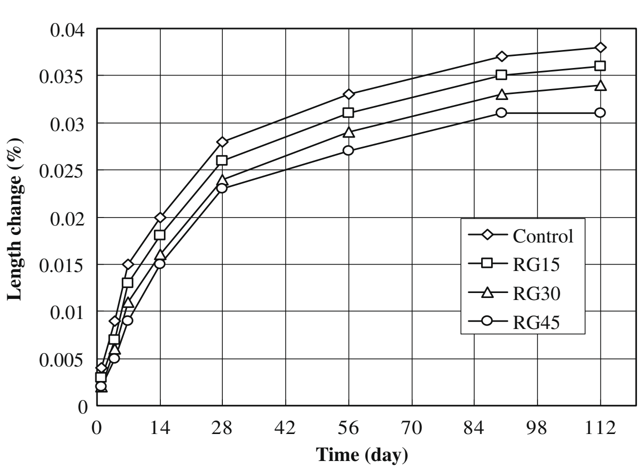

Fig. 4. Drying shrinkage curves of SCC with varying percentage of RG.

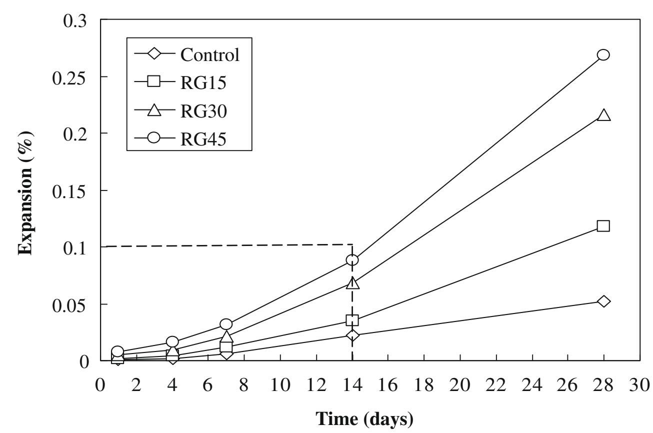

Fig. 5. Results of ASR expansion of the mortar bars prepared in Series I.

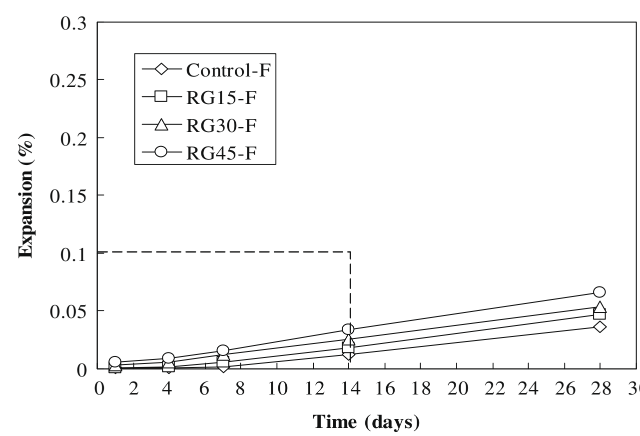

Fig. 6. Results of ASR expansion of the mortar bars prepared in Series II.

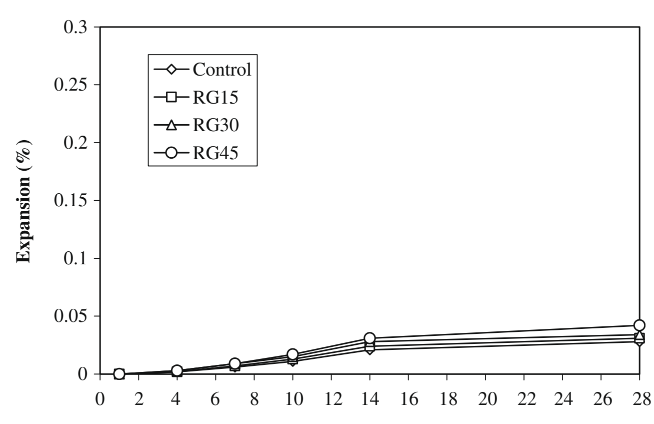

Fig. 7. Results of ASR expansion of SCC with varying percentage of RG.

Table 10
Relative properties of SCC and normally compacted mixes (SCC/Nml).

Notation	Splitting tensile strength		Static elasticity modulus		Chloride ion penetration	
	28-day	90-day	28-day	90-day	28-day	90-day
Control	0.97(±0.02)	0.99(±0.01)	0.97(±0.03)	0.99(±0.02)	1.09(±0.02)	1.07(±0.01)
G-15	0.97(±0.02)	0.97(±0.01)	0.99(±0.02)	0.99(±0.01)	1.09(±0.02)	1.08(±0.01)
G-30	0.98(±0.02)	0.97(±0.01)	0.99(±0.02)	0.98(±0.01)	1.05(±0.02)	1.08(±0.01)
G-45	0.98(±0.02)	0.98(±0.01)	0.99(±0.02)	0.98(±0.02)	1.03(±0.01)	1.01(±0.01)

uted to the decrease in bond strength between the cement paste and the RG, and the increase in FM of the fine aggregate which decreased the overall density of the concrete produced [37].

The results of the tensile splitting strength of the SCC mixes are presented in Table 7. Each presented value is the average of three measurements. The results indicate that the 28 and 90 days tensile splitting strength of the RG–SCC mixes were lower than that of the control. The RG–SCC mixes with 45% RG glass had the lowest tensile splitting strength.

It is evident from Table 7 that the density of the RG–SCC mixes decreased with the increase in RG content. This is mainly attributed to the difference in densities between the recycled glasses, natural sand and granite.

3.2.2. Static modulus of elasticity

The results of the static modulus of elasticity are presented in Table 8. Each presented value is the average of three measurements. The elastic modulus decreased with the increase in RG content.

Fig. 3 shows the relationship between compressive strength and modulus of elasticity at 28-days. The results show that there is a good correlation between the compressive strength and the modulus of elasticity for the prepared SCC mixes in this study.

3.2.3. Chloride ion penetration

The results of the chloride ion penetration are presented in Table 8. The values are the average of two measurements. The chloride ion penetrability decreased with the increase in RG content which means the resistance to chloride ion penetration increased with an increase in recycled glass content. This was due to the recycled glass cullet had lower porosity than that of river sand and natural granite. Moreover, the RG sand which had a finer particle size distribution than that of river sand might have also resulted in a better packing efficiency of the concrete at the fine scales.

3.2.4. Drying shrinkage

The drying shrinkage values measured as function of time up to 112 days are shown in Table 9 and Fig. 4. Each presented value is the average of three measurements. It can be seen that the drying shrinkage values decreased with an increase in recycled glass content probably due to the lower water absorption characteristics of glass cullet. The drying shrinkage of the concrete mixes was well below the limit of 0.075% at 56 days specified by the Australian Standard AS 3600 [38].

3.2.5. Alkali-silica reaction expansion

The results of the mortar bars test in Series I and II are shown in Figs. 5 and 6, respectively. Fig. 5 indicate that although the ASR expansion was able to meet the requirements prescribed in ASTM C 1260 (<0.1% within 14 days) when the mortar bars were prepared with 45% RG, serious expansion and cracks were observed at 28-days. In comparison, the expansion of the control mortar bars in which only river sand was used as aggregates was minimal.

The results in Fig. 6 show that all the ASR expansion of all the specimens were significantly reduced by the use of fly ash in the mortar mixes.

The ASR expansion rate of the RG–SCC concrete mixes were measured using the concrete prisms prepared using the same exposure condition as the mortar bar test method (ASTM C 1260). The results (Fig. 7) show that the concrete prisms displayed extremely small expansion even with a RG content of 45% showing the expansion was suppressed by the use of fly ash in the concrete mixes. All 28-day measurements showed less than 0.1% expansion.

3.2.6. Relative properties of SCC and normally compacted mixes

The relative properties of the SCC to that of the normally compacted mixes are shown in Table 10. The data shows the relative ratios were close to one demonstrating the produced concrete mixes were truly SCC and as the hardened properties of the mixes with and without compaction were similar. Ho et al. [39,40] suggested that if the hardened properties ratio of SCC/Nml is between 0.95 and 1.05, the SCC is considered truly SCC.

4. Conclusions

This paper has presented the experimental results of a study on the feasible use of recycled glass cullet for the production of SCC. Based on the results of this study, the following conclusions can be drawn:

1. The slump flow, blocking ratio, air content of the RG–SCC mixes increased with increase in recycled glass content. The initial slump flows of all the SCC mixes prepared in this study were at least 750 mm. The blocking ratios varied from 0.84 to 0.88.
2. The compressive strength, tensile splitting strength and static modulus of elasticity of the RG–SCC mixes decreased with an increase in recycled glass content.
3. The chloride ion penetrability of the RG–SCC mixes was significant decreased when compared with the control. The resistance to chloride ion penetration increased when the recycled glass content increased.
4. The drying shrinkage of the RG–SCC mixes decreased with an increase in the recycled glass aggregate content.
5. The overall assessment of both the fresh and hardened properties indicates it is feasible to produce SCC with recycled glass cullet.
6. The ASR expansion of all the specimens was significantly reduced by the use of fly ash.

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