ENVIRONMENTAL GREENING THROUGH UTILIZATION OF GLASS WASTE FOR PRODUCTION OF CONCRETE

Williams Kupolati [a], William Tchoundi Mbadie[a], Julius Ndambuki[a], Rotimi Sadiku[b]
[a]Department of Civil Engineering, Tshwane University of Technology, South Africa.
[b]Department of Chemical, Metallurgy and Material Engineering, Tshwane University of Technology, South Africa.
Corresponding author: kupolatiwk@tut.ac.za

 ISSN 1923-6654 (print)
ISSN 1923-6662 (online). Available at http://www.ssrn.com/link/OIDA-Intl-Journal-Sustainable-Dev.html

Abstract: The amount of glass waste generated by glass manufacturing and recycling companies creates serious environmental challenges. The utilization of glass waste in concrete to mitigate such challenges involved the adaptation of the material with respect to the fundamental requirements. This research involved the beneficial use of two types of soda-lime glass wastes in concrete, as partial replacement of cement and fine aggregate, in order to enhance the greening of the environment. The glass wastes were produced in large quantities by glass recycling companies in Gauteng, South Africa. Low alkali cement, CEM V/A 32.5N, a composite cement with 25% Fly Ash (FA) and 18% Ground Granulated Blast-furnace Slag (GGBS) was used. The two types of glass waste, namely, Superfine Waste Glass Sand (SGW), a fine residue of glass recycling processes and Ceramic Stone and Porcelain (CSP) glass waste, cullet contaminated with ceramics, stones and porcelain; were respectively used as sand and cement replacements. As collected, SGW was sieved and blended with fine sand in line with the recommendations of the South African National Standard (SANS) for sieve analysis. CSP was sorted from contaminations, through decantation, dried in the oven at 104 ^{o}C for 24 hours, grounded into powder with rod and ball mills successively; and sieved through 75µm mesh. The tests conducted include sieve analysis, particle relative densities, compacted bulk densities and loose bulk densities; in accordance with the Cement and Concrete Institute (C&CI) mix design protocol. Twenty mix proportions were designed with water-to-cement ratio of 0.7 and 75 mm slump. The first set of mixes consisted of 20%, 40%, 50% and 60% SGW replacement of sand; the second set consisted of 10%, 20% and 30% of glass powder (GLP) replacement of cement; the third set consisted of 10% GLP in combination with 20%, 40%, 50% and 60% of SGW, respectively; the fourth set consisted of 20% GLP in combination with 20%, 40%, 50% and 60% of SGW, respectively; and the fifth set consisted of 30% GLP in combination with 20%, 40%, 50% and 60% of SGW, respectively. Subsequently, cube specimens were tested at 3, 7 and 28 days for compressive strength, according to the SANS recommendations. It was found that, the glass waste were effectively adapted in concrete. SGW was adequate for blending with fine aggregates as it improved the gradation of the blend. SGW and GLP increased the workability of the fresh concretes and significantly reduced the weight of the hardened concrete by 6.5%. Glass powder reacted as early reactive pozzolanic material, as it enhanced the 3 days compressive strength of the concrete by 14% when compared to the control mix with natural aggregates. Compressive strengths obtained from the laboratory tests ranged between 18.8 MPa and 32.7 MPa, which were 65% above that of the control mix. Up to 30% of glass wastes used as cement and fine aggregate replacement, respectively, did not impair the 28-day compressive strength of the concrete. The blend with 20% GLP and 40% SGW exhibited the same 28-day compressive strength as that of the control mix value with a value of 25.86 MPa. The mix with 20% GLP and 20% SWGS exhibited the highest strength at 28 days with a value of 32.7 MPa which represented an increase of 26.5% of the compressive strength of the control mix. The research demonstrated the beneficial use of glass waste as partial replacement for cement and sand in concrete. This will appreciably reduce the amount of glass waste dumped to the landfill sites and enhance the greening of the environment, with the added advantage of preservation of virgin materials for posterity.

Keywords:Compressive strength, control mix, environ- mental greening, glass waste, virgin materials.

INTRODUCTION

The amount of glass wastes generated every year by glass recycling and manufacturing company is very high while the recycling efficiency of glass wastes is very low. The outstanding amount of glass not recycled are discarded or dumped and has many negative impacts on the environment, health and society. Between 1990 and 2009, for the two biggest South Africa's glass packaging industries, Consol Glass and Nampak Glass, one million tons of glass produced are estimated per annum [1]. Of this, less than twenty five precent of the glass containers produced were recovered and recycled and just thrity five percent of glass recycled is estimated for 2011.

It has been reported that the major challenge that faces the recycling of glass waste is the issue of contamination during the recycling activities and the contaminants include ceramics, window glasses, mirrors, plastics, tins, Pyrex glasses and wired glasses [2]. The contaminants make the recycling process more expensive than the use of raw materials. Therefore, the re-use of glass wastes in engineering applications has been investigated for the greening of the environment and the reduction of the overall carbon footprint. Many researches showed that crushed glass can be used as partial aggregate and cement replacement in concrete, for architectural and decorative applications and in some applications that do not require very high strength [3][4][5][6][7].

Despite the Alkali Silica Reaction (ASR), a reaction that occurs when mixing glass particles and ordinary Portland cement together and which produce a gel-type substance that swell in the presence of moisture [8], it was found that 30% glass waste (in finely ground form or cullet form) can be re-used (by weight), with supplementary cementitious materials (such fly ash and silica fume) or with some mitigation measures [5], in order to partially replace natural aggregate in concrete. This research investigated the re-use of two types of soda-lime glass waste in concrete, namely: SGW and CSP. The quantity of the two wastes are estimated to 50 and 60 tons per day, for SGW and CSP, respectively. SGW was re-used as sand replacement, while CSP relatively easier to sort from contaminants was finely grounded into powder in order to partialy replace cement.

MATERIALS AND METHODS

Physical tests on the aggregates and on the blends of SGW with natural sand were carried out, to determine the gradations, relative densities, compacted and loose bulk densities required for the Cement and Concrete Institute (C&CI) mix design protocol [9], in line with the SANS recommendations. Due to the brittleness of the glass particles, concretes were designed for moderate strength structures (25 MPa characteristic strength), with a water to cement ratio (W/C) of 0.7 and 75 mm slump.

The C&CI recommendations for sieve analysis and Fineness Modulus were used as a basis for the blending of SGW and natural sand. Concrete was then produced with the replacement of 0%, 20%, 40%, 50% and 60% of natural sand and/or with replacements of 10%, 20% and 30% of cement with GLP. All aggregates were air dried. Compressive strengths of 100 x 100 x 100 mm concrete cubes were tested at 3, 7 and 28 days and all the tests were carried out at the laboratory of the Department of Civil Engineering of Tshwane University of Technology (TUT) in Pretoria.

Sample collection

The material used and sampled consisted of: (a) CSP and SGW, collected from the Consol glass recycling company, Kempton Park (South Africa) as shown in Figures 1 and 2; (b) Nineteen millimeter quartzite stone and natural fine sand; (c) Afrisam composite cement, CEM V/A, 32.5N., a blend of 25% FA and 18% Ground Granulated Blast-furnace (GGBS), adequate when using aggressive aggregates [10]; (d) potable pump water that was clean and free of detrimental amounts of organics or chemical substances that may adversely affect the concrete, in line with [11]

Figure 1: Photograph of CSP

Figure 2: Photograph of SGW

Laboratory tests on aggregates

The sieve analysis was determined (in line with SABS SM 829), relative densities [12], compacted bulk densities and loose bulk densities of the sand, stone and SGW [13].

Blending of SGW and natural sand

SGW and natural sand were blended on the sieve analysis basis. Materials were combined in such way that the resulting gradations were closed to the specifications given by the South African Bureau of Standard (SABS) for sieve analysis [14]. The resulting Fineness Moduli (FM) were within the upper and lower limits of the gradation recommended for fine aggregates. SGW was found to be coarse and the sand very fine. The sand was successively replaced by 20%, 40% and 60% by SGW. From the graphical representations of the gradations as shown in Figure 6, it was observed that a 50% percent replacement of sand was closer to the medium limit and was thereof adopted as the fourth blend.

Production of GLP from CSP

Glass powder as shown in Figure 3 was obtained by the means of ball mills (Figure 4). CSP cullet (coarse particles retained on 4.75 mm) was cleaned by decantation. Firstly, CSP was grounded with rods (12 rods) to particle size of around 1 mm and secondly, the particles were furthermore grounded, into very fine particles, using metallic balls (with different diameters). At the end of the process, very fine particles were obtained, all passing through 150 µm mesh. The powder was then sieved through 75 µm mesh and the grinding process was repeated with ball mill until the required quantity was obtained. The equipment used is shown in Figure 5.

Figure 3: Glass powder

Figure 4: Ball mills

Figure 5: Milling machine

Mix design

The mix design was adjusted for stone and sand contents for each proportion of SGW and/or GLP. Twenty (20) different mixes were designed in line with the C&CI mix design protocol. The mixes with SGW and/or GLP were coded as X%SY%SAZ%, where X, Y and Z represented the percentage of GLP, SGW and sand, respectively. The mix with 10% GLP and 20% SGW was coded as 10S20SA80, as example.

Production of cubes

Each mix was designed for 1 m^3 and converted to a batch of ten liters. Ten (10) liters per batch was found enough for nine (09) cubes in line with [15], with minimization of waste. Aggregate samples were prepared according to [16] and fresh concrete according to [17] by the means of mixing and vibrating machines. The workability of the mixes was assessed by slump tests according to [18] and the cohesiveness of aggregate was checked after each slump. Slump tests were re-conducted for concrete with too high (> 100 mm) or very low (< 25 mm) slump and/or lack of cohesion. 100 x 100 x 100 mm moulds were used to produce the cube specimens. A total of 180 cubes were cast.

Curing of the specimens and compressive tests

Demoulding was done after 24 hours and cured in a batch with tap water at an ambient temperature between 23^{o}C and 24^{o}C. The surfaces of the cubes were cleaned and dried before weighted. An electro-mechanic compressive test machine was used to press the cubes, at a loading rate of 180 kN/min [19].

Analytical and presentation techniques

Calculations followed pre-established equations as specified by relevant standards. The slump, weight and compressive strength values of each mix were compared with the control mix and other mixes. Reports were laid out through Tables and Figures from Microsoft Excel (2007) [20].

RESULTS AND DISCUSSION

The physical properties of the aggregates and the sieves analysis of the blends of SGW and sand are shown in Table 1, Table 2 and Figure 6. The gradation of SGW and the sand were out of the limits specified. However, SGW enhanced the gradation of the blends. As the proportion of SGW increased from 0% to 50% and as the proportion of SGW decreased from 60 to 50%, the gradations of the blends were closer to the limits specified.

Table 1: Physical properties of aggregates

Tests		Results
Nominal maximum size of coarse aggregate SABS SM 829		19 mm
Relative density (SANS 5844: 2006)	Sand	2.57
	SGW	2.27
	CA	2.69
Compacted bulk density (SANS 5845: 2006)	Sand	1340 kg/m^3
	SGW	1189 kg/m^3
	CA	1600 kg/m^3
Loose bulk density (SANS 5845: 2006)	Sand	1420 kg/m^3
	SGW	1332 kg/m^3
	CA	1728 kg/m^3
Particle shape (Visual assessment)	SGW	Flat and angular
	CA	Angular
Surface texture (Visual assessment)	SGW	Smooth
	CA	Rough

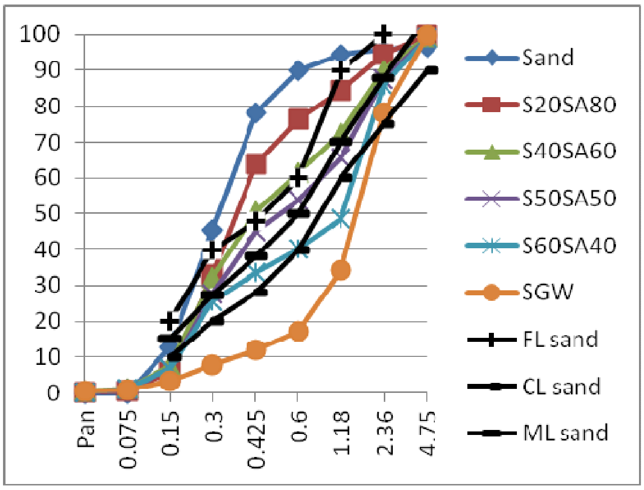

Figure 6: Gradations of the sand, SGW and the blends and fine and coarse limits of sand recommended by C&CI

Table 2: Sieve analysis of the blends of SGW and sand

Sieves	Mass on sieves, g						% cumulative retained on sieves					
	Sand	SGW	S20SA80	S40SA60	S50SA50	S60SA40	Sand	SGW	S20SA80	S40SA60	S50SA50	S60SA40
4.75	16	1.6	1.64	3.54	4	4.38	3.43	0.35	0.35	0.75	0.85	0.92
2.36	4	104	24	43	55	63	4.29	22.02	5.55	9.9	12.52	14.16
1.18	6	210	47	83	104	177	5.58	65.77	15.72	27.56	34.6	51.34
0.600	20	82	36	51	55	40	10.07	82.85	23.52	38.41	46.28	59.74
0.425	56	24	58	48	40	31	22.09	87.85	36.1	49.26	54.78	66.25
0.30	152	20	143	87	82	38	54.71	92.02	67	67.77	72.19	74.24
0.15	152	22	125	116	99	90	87.33	96.60	94.1	92.46	93.21	93.14
0.075	60	12	25	32	27	27	100	99.70	99.45	98.63	98.94	98.82
Pan	0	1.4	2.09	4.5	3.95	4.97	-	100	99.94	99.58	99.78	99.86
Total	466	480	459.64	468.04	469.95	475.35	188	356	206.24	236.85	256.65	293.54
FM (without 0.425 and 0.075 sieves)							1.88	3.56	2.06	2.37	2.60	2.9
Dust content							4.73	6.8	8.1	6.9	6.6	5.8
Class of the blended sand							fine	coarse	Medium	Medium	Medium	Medium

Mix design

Trial batches were conducted at the laboratory; in respect to the slump tests and the cohesiveness of the freshly mixed concretes. The resulting slumps, the percentages by mass of the binder pastes and the weights of the mixes adopted are shown in Table 3.

Next page

Table 3: Mix designs, slumps, percentage of paste and weights of mixes.

	Mixes	Water	Cement	GLP	CA	Sand	SGW	Slump	% of paste	Weight, Kg
Control	Designed	210	300	-	1351	470	-	0	-	
mix	Adopted	230	336	-	1331	451	-	55	24.1	2354
S20SA80	Designed	210	300	-	1320	389	97	18	-	-
	Adopted	230	336	-	1320	389	97	67	23.9	2372
S40SA60	Designed	210	300	-	1267	314	209	58	-	-
	Adopted	210	300	-	1267	314	209	58	22.2	2300
S50SA50	Designed	210	300	-	1231	275	275	79	-	-
	Adopted	210	300	-	1231	275	275	79	22.3	2291
S60SA40	Designed	210	300	-	1181	234	350	104	-	-
	Adopted	210	300	-	1160	234	350	70	22.6	2254
10GLP	Designed	210	270	30	1351	470	-	14	-	-
	Adopted	230	300	39	1351	470	-	56	23.8	2390
10S20S80	Designed	210	270	30	1320	435	48	25	-	-
	Adopted	240	315	35	1320	425	48	65	24.7	2393
10S40S60	Designed	210	270	30	1260	312	36	36	-	-
	Adopted	230	300	33	1260	336	55	55	23.6	2383
10S50SA50	Designed	210	270	30	1231	273	42	42	-	-
	Adopted	220	285	32	1231	273	63	63	23.2	2314
10S60SA40	Designed	210	270	30	1181	232	62	62	-	-
	Adopted	210	270	30	1181	232	62	62	22.5	2271
20 GLP	Designed	210	240	60	1320	384	10	10	-	-
	Adopted	240	274	69	1320	384	66	66	25.5	2287
20S20SA80	Designed	210	240	60	1320	432	12	12	-	-
	Adopted	220	263	66	1320	432	58	58	23.4	2349
20S40SA60	Designed	210	240	60	1267	310	37	37	-	-
	Adopted	220	251	63	1267	310	57	57	23	2309
20S50SA50	Designed	210	240	60	1231	272	51	51	-	-
	Adopted	220	251	63	1231	272	73	73	23.1	2309
20S60SA40	Designed	210	240	60	1181	232	68	68	-	-
	Adopted	210	240	60	1181	232	68	68	22.5	2270
30 GLP	Designed	210	210	90	1351	462	0	0	-	-
	Adopted	250	250	106	1351	462	50	50	25.1	2419
30S20SA80	Designed	210	210	90	1320	430	51	51	-	-
	Adopted	210	210	90	1320	430	51	51	18.61	2308
30S40SA60	Designed	210	210	90	1267	309	63	63	-	-
	Adopted	210	210	90	1267	309	63	63	22.23	2292
30S50SA50	Designed	210	210	90	1231	271	80	80	-	-
	Adopted	210	210	90	1231	271	80	80	22.3	2283
30S60SA40	Designed	210	210	90	1181	230	104	104	-	-
	Adopted	210	210	90	1181	230	104	104	22.5	2267

Slump test

Results from Table 3 showed that as the proportion of SGW increased, the slumps of the first trial batches with SGW increased. The values of the slumps of the first trials of the mixes with 0%, 20%, 40%, 50% and 60% SGW were 0 mm, 18 mm, 58 mm, 79 mm and 104 mm, respectively. The results also showed that the slump of the mixes had a general tendency to increase with increasing proportion of SGW and GLP. However, the slump of mixes with GLP only had a tendency to decrease with increasing proportion of GLP. The enhancement of the workability was more related to the proportion of SGW. Even though the slumps of 10S20SA80 and 10S40SA60 were remarkably higher than those of mixes with 20S20SA80 and 20S40SA60, as shown in Figure 7, the slump of mixes with 20GLP and above 40SGW were higher than mixes with 10GLP.

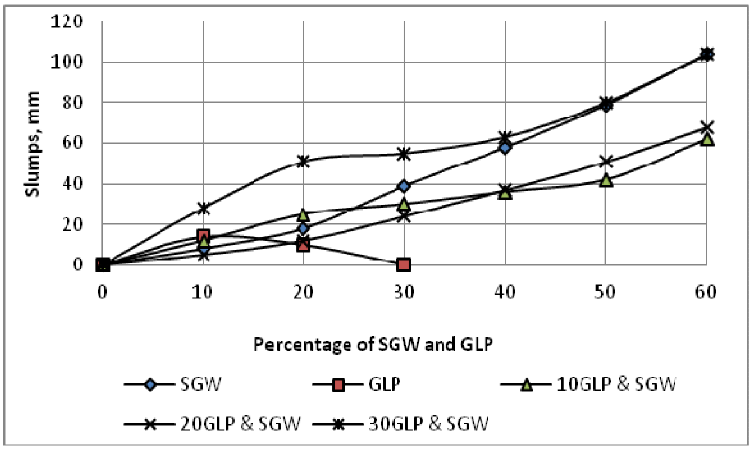

Figure 7: evolution of slump for different mixes

Cement pastes

The paste contents of the different mixes are shown on Figure 8. As the workability of the fresh mixes increased with glass content, the percentage of paste (cement, GLP and water) had a general tendency to decrease. This may be due to the to particle size of GLP that was coarser than that of the cement and that reduced of the exothermic reaction between the binder and water.

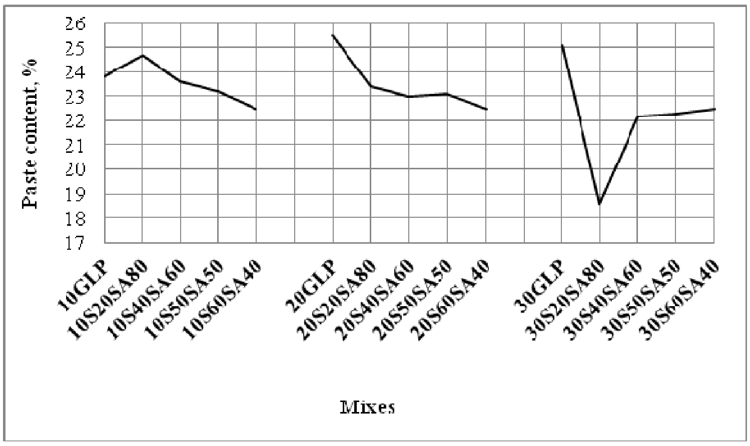

Figure 8: Paste content versus glass content

Weight of concrete cube specimens

Table 3 showed that SGW and GLP had a tendency to reduce the weight of the hardened concrete. The relative density of SGW was lower than that of the natural aggregates. Nonetheless the adjustment for sand and stone contents that increased of the weight of the mixes, hardened cube specimens with SGW (with or without GLP) was still lighter than the control mix and would have been further ligther without adjustments. As shown on Figure 9, the weight of the mixes with SGW and SGW with 10GLP, 20GLP and 30GLP, respectively, decreased from 2354 to 2254, 2390 to 2271, 2287 to 2270 and from 2419 to 2267, respectively. This represented reductions in weights of

100 kg (4.3%), 119 kg (5%), 17 kg (0.7%) and 152 kg (6.3%) per cubic meter, respectively. SGW significantly reduced the weight of 10GLP by 6.7%, when comparing 10GLP with 10S60SA40. The lowest weigth was obtained with S60SA40 and represented a reduction in weigth of 10%, when compare to the control mix. The weight of 30GLP and 10GLP were higher that of the control mix due to the adjustment for sand and stone contents, when designing.

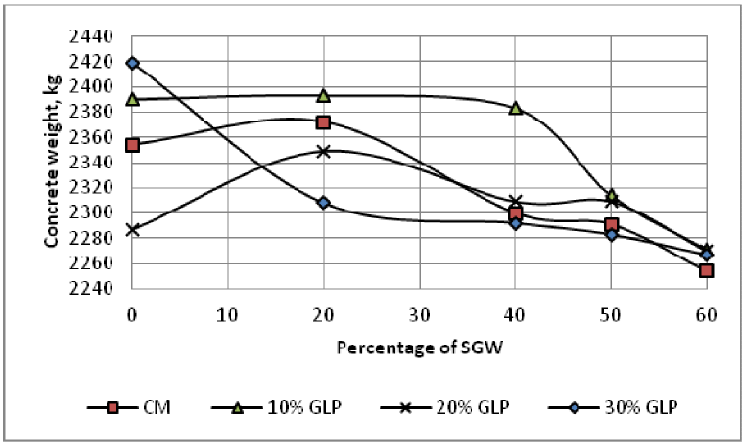

Figure 9: Weight of the concrete versus SGW content

Compressive strength

The average values of the compressive strength at 3, 7 and 28 days and the graphical representations of the mixes are shown in Table 4 and Figures 10 to 14.

Table 4: Compressive strengths at 3, 7 and 28 days

Mixture	3 days	7 days	28 days
Control mix	12.06	16.2	25.86
S20SA80	8.03	17.8	29.76
S40SA60	9.86	16.53	28.36
S50SA50	9.86	16.96	29.1
S60SA40	8.93	14.1	28.26
10GLP	14.06	18.43	29.1
10S20SA80	14	17.2	25.5
10S40SA60	11.36	15.63	25.8
10S50SA50	12.1	16.03	25.6
10S60SA40	12.26	16.6	26.8
20GLP	12.66	15.6	27.7
20S20SA80	15.63	17.3	32.7
20S40SA60	10.67	12.53	23.2
20S50SA50	10.16	11.9	22.7
20S60SA40	9.1	11.16	20.5
30GLP	6.16	13.13	25.9
30S20SA80	5.86	10.7	20.6
30S40SA60	5.76	10	19
30S50SA50	7.33	12.9	23.7
30S60SA40	5.63	9	18.8

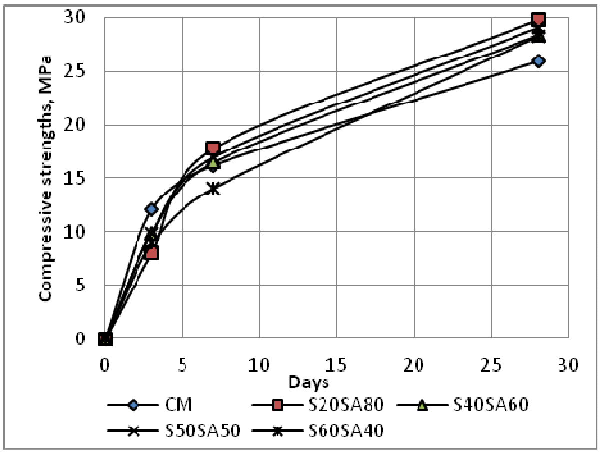

Figure 10: Compressive strength of SGW at 3, 7 and 28 days

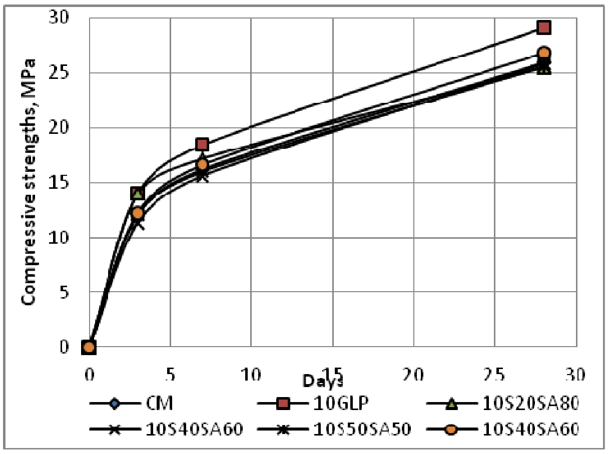

Figure 11: Compressive strength of 10SGW at 3, 7 and 28 days

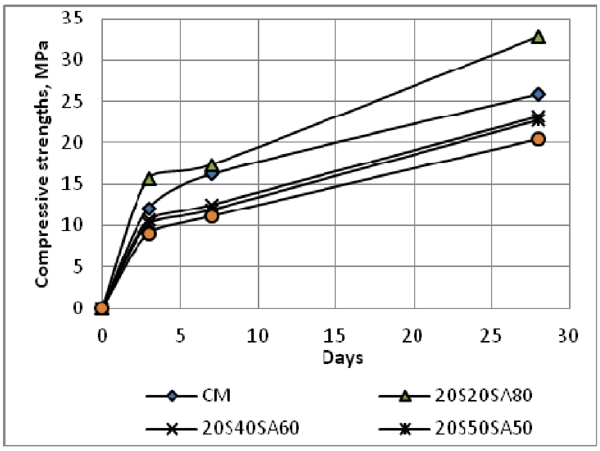

Figure 12: Compressive strength of 20SGW at 3, 7 and 28 days

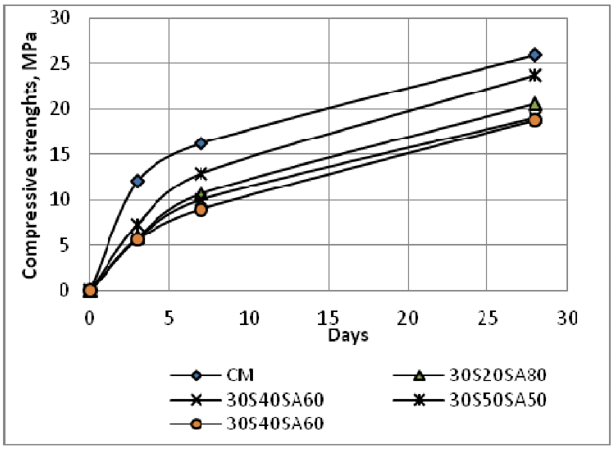

Figure 14: Compressive strength of 30SGW at 3, 7 and 28 days

Next page

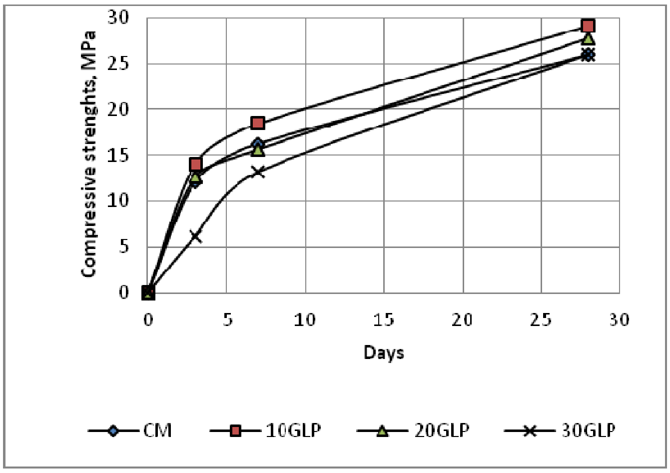

Figure 14: Compressive strength of GLP at 3, 7 and 28 days

Compressive strength at 3 days

Results from Table 4 and Figures 10 to 14 showed that at 3 days, the control mix exhibited higher strength than mixes with SGW only, but it was lower than that of the mixes with 10% GLP and 20% GLP. Glass powder reacted as early reactive pozzolanic material, as it enhanced the early age strength of the mixes. The values of the compressive strengths had a general tendency to decrease with increasing proportions of SGW and GLP. However, the incorporation of up to 20GLP improved the early age strengths of mixes with SGW and GLP. 20S20SA80 exhibited the highest strength at 3 days and the value of the compressive strength of mixes with 10GLP and 20GLP with and without SGW were higher compared to mixes with only SGW. Mixes with 30% GLP exhibited lowest values. 30S60SA40 was the mix with the lowest value of 5.63 MPa, 3 times lower than that of 20S20SA80 with a value of 15.63 MPa. All the 3 day strengths are shown on Figure 15.

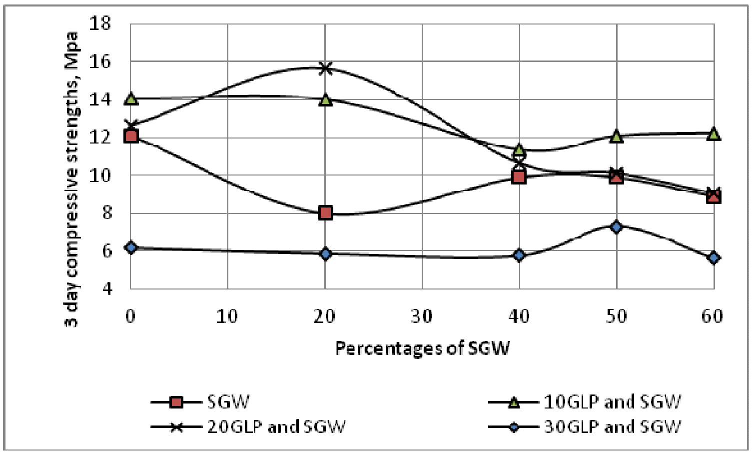

Figure 15: 3 day compressive strengths of mixes

Compressive strength at 7 days

Results from Table 4 and Figures 10 to 14 showed that, contrary to the values of the strengths obtained at 3 days, the strengths of mixes with SGW developed very fast and were high. The value of S20SA80 (17.8 MPA) increased by 10% when compared with that of the control mix (16.2 MPa), and was higher than those of the mixes with 20GLP and 30GLP with and without SGW. The highest strength was obtained with 10% GLP (18.43 MPa), representing an increase in strength of 14%, when compared with the control mix .The strengths of all the mixes with 10GLP were relatively higher than the others. As the proportion of GLP increased simultaneously with the proportion of SGW, the values of the strength became lower. 30S60SA40 still exhibited the lowest strengths. All the 7 day strengths are shown on Figure 16.

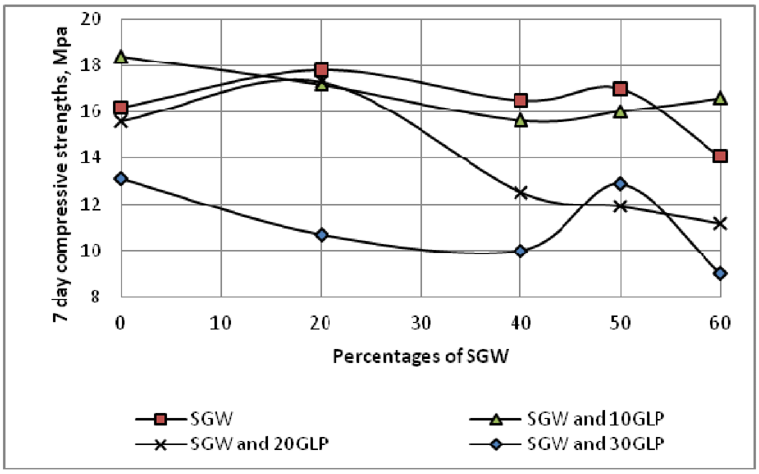

Figure 16: 7 day compressive strengths of mixes

Compressive strength at 28 days

It was observed from Table 4 and Figures 10 to 14 that SGW and GLP significantly enhanced the 28 day strengths. Overall, mixes with 10GLP and 20GLP exhibited higher strengths than the control mix. An increase in strength of 26.5% was observed with 20S20SA80 with a value of 32.7 MPa, when compared with the control mix with a value of 25.86 MPa. 10GLP and 10S20SA80 resulted to an increase in strength of 13%. The values of the compressive strengths of the mixes with 30GLP remained lower than those of the control mix. In most of the cases, the values of the compressive strength of mixes with 20SGW were higher than that of mixes with 40%, 50% and 60% SGW, followed by mixes with GLP only. All the 28 day strengths are shown on Figure 17.

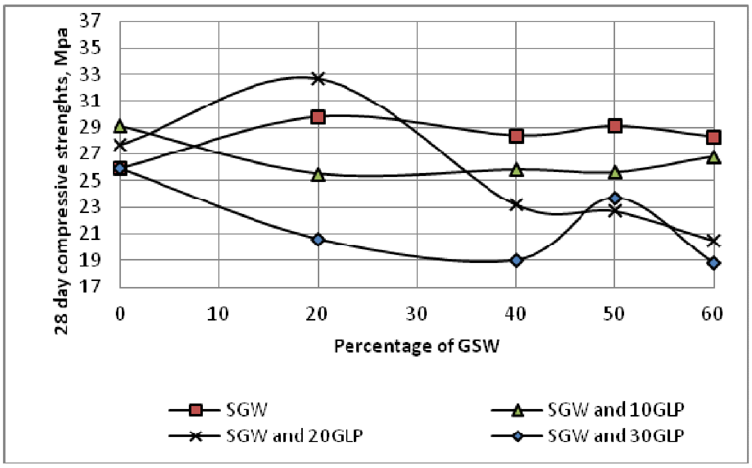

Figure 17: 28 day compressive strengths of mixes

The values of the compressive strengths were classified into three (03) different categories. The control mix was designed for a characteristic strength of 25 MPa that is within the strength requirements for moderate structural applications. The three different categories were:

i) Category 1: strength > 25 MPa
ii) Category 2: 20 MPa < strength < 25 MPa and,
iii) Category 3: strength < 20 MPa

It was found that more than 65% of the mixes resulted to a strength > 25 MPa, less than 25% with a strength between 20 MPa and 25 MPa and just 10% with a strength less than 20 MPa. 30GLP used to replace cement did not reduce the strength of the concrete. The value of 28 day strength of 30GLP of 25.9 MPa was similar to that of the control mix, with a value of 25.86 MPa. The value of the compressive strength of S60SA40 of 28.26 MPa, was far higher than that of the control mix. Overall, the replacement of 30% cement with GLP and more than 30% sand with SGW did not impair the 28 day strength of the control mix. An observation of the graphical representations showed that, the highest strength could be found within 0 to 20SGW with 20GLP as shown on Figure 17.

Table: classification of the compressive strengths

Mixes	< 20MPa	20 to 25 Mpa	> 25 MPa	Mixes	< 20Mpa	20 to 25 Mpa	> 25 MPa
CM	-	-	25.86	20%GLP	-	-	27.7
S20SA80	-	-	29.76	20S20SA80	-	-	32.7
S40SA60	-	-	28.36	20S40SA60	-	23.2	-
S50SA50	-	-	29.1	20S50SA50	-	22.7	-
S60SA40	-	-	28.26	20S60SA40	-	20.5	-
10%GLP	-	-	29.1	30%GLP	-	-	25.9
10S20SA80	-	-	25.5	30S20SA80	-	20.6	-
10S40SA60	-	-	25.8	30S40SA60	19	-	-
10S50SA50	-	-	25.6	30S50SA50	-	23.7	-
10S60SA40	-	-	26.8	30S60SA40	18.8	-	-

CONCLUSION

The research demonstrated the beneficial use of glass waste as partial replacement for cement and sand in concrete. The sieves analysis and the prescribed limits from C&CI (2011) are well indicated on how to blend the materials. The increasing proportions of glass in aggregate and powder form, increased the workability of the fresh concrete and significantly reduced the weight of the hardened concrete (up to 6.5%). As recommended in literatures, 30% of glass powder did not affect the 28 days strength of the control mix, but rather was equivalent. Strength of mixes with SGW were found to be satisfactory and showed that SGW can be re-used completely to replace sand for high strength concrete.

The compressive strength tests effectively confirmed the pozzolanic effect of GLP on concrete, as it enhanced the early age strength (3 days) and the 28 days strength of the concrete. Twenty percent (20%) of SGW as sand replacement plus twenty percent (20%) of GLP as cement replacement and ten percent (10%) of SGW plus tweenty percent (20%) of GLP resulted to an increase of the 28 days strength of the concrete cube specimens, respectively, by twenty five (25%) and thrity two percent (32%). The blends of GLP and SGW was found satisfactory up to 20% GLP and 40% SGW without reducing significantly the strength of the control mix. The enhancement of the workability can be strategically and profitably used to reduce the paste content of mixes without affecting the slump and the cohesiveness of the fresh concrete and therefore reduce the cost of cement production. The results from the research show that its implementation can significantly contribute to the greening of the environment and be a source of lucrative activities.

ACKNOWLEDGEMENT

The research is fully supported by the Tshwane University of Technology, Pretoria, South Africa. The authors also wish to acknowledge the support and cooperation of the leadership of the Department of Civil Engineering, the Department of Chemical Engineering and Consol Recycling Glass Company for its collaboration. The technical support of Messrs Derrick Coetzee, Ron Berkers and Jan Meyer and all the technical staff of the laboratory of the Department of Civil, Tshwane University of Technology are highly appreciated.

REFERENCES

[1] Consol (2011). The Glass Recycling Process. Retrieved from: http://www.theglassrecyclingcompany.co.za [accessed on: 11/07/2011]

[2] Waste Reduction and Recycling (2011): Glass Contamination, 17 June. Retrieved from http://deq.mt.gov/Recycle/Glass/GlassContamination.mcpx. [Accessed on: 22/07/2011]

[3] Reindl J. (1998). Reuse/Recycling of glass Cullet for Non-Container Uses, June 29 [on line]. Available from:http://www.epa.gov/osw/conserve/rrr/greenscapes/pubs/glass.pdf[Accessed on: 11/06/2011]

[4] Bazant, Z.P., Jin, w. and Meyer C. (1998). Fracture Mechanics of Concrete Structures, Proc. FRA MCOS – Vol. 3, pp. 1687-1693

[5] Meyer C., Egosi N., Andela C. (2001). Concrete with Waste Glass as Aggregate, in Recycling and Re-use of Glass Cullet, Dhir, Dyer and Limbachiya, Editors, Proceeding of the international Symposium Concrete Technology Unit of ASCE and University of Dundee March 19-20 [online]. Available from:http://www.seas.columbia.edu/earth/wtert/sofos/meyer_egosi_paper.pdf [Accessed on: 12/06/2011]

[6] Shayan A., Xu A. (2004).Value-added utilization of waste glass in concrete, Cement and Concrete research 34 ARRB Transport Research Ltd. Pgs 81-89 [online]. Available from: http://www.sciencedirect .com/science/article/pii/S0008884603002515[Accessed on: 12/06/2011]

[7] Turgut P., Yahlizade E.S. (2009). Research into concrete Blocks with Waste Glass, International Journal of Civil and Environment Engineering 1:4[online]. Available from: http://www.waset.org/journals/ijcee/v1/v1-4-38.pdf [Accessed on: 19/06/2011]

[8] Rear, Kenneth et al., (1994). Alkali-Aggregate Reactivity: A Summary. PCI Journal (Nov. – Dec.1994): 26–35

[9] Gill, O. (2012). Fundamentals of concrete. The C&CI design method (2nd edition). Midrand, South Africa: Cement and Concrete Institute. Page 137.

[10] South African National Standards. (2005). Cementitious materials for concrete standards, SANS 1491.

[11] South African Bureau of Standards. (1984). Standard specification for concrete masonry units, SABS 1215.

[12] South Africa National Standard. (2006). Particle and relative densities of aggregates, SANS 5844.

[13] South Africa National Standard. (2006). Bulk densities and voids content of aggregates, SANS 5845.

[14] South African Bureau of Standards. (2002). Sieve analysis, fines content and dust content of aggregates, SABS 829.

[15] South Africa National Standard. (2006). Mixing fresh concrete in the laboratory, SANS 5861-1.

[16] South Africa National Standard. (2006). Preparation of tests samples of aggregates, SANS 197.

[17] South Africa National Standard. (2006). Making and curing of test specimens, SANS 5861-3.

[18] South Africa National Standard. (2006). Slump test, SANS 5862-1.

[19] South Africa National Standard. (2006). Compressive strength of hardened concrete, SANS 5863.

[20] Microsoft Excel. (2007). MS Excel, Microsoft Corporation, USA.

ABOUT THE AUTHORS

Dr. W. K. Kupolati holds a B.Sc. (Hons) and a Ph.D. in Civil Engineering. He also holds a M. Sc. in Construction Management. He is a Senior Lecturer at the Department of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa. He is involved with research on the sustainable and appropriate use of waste materials for civil engineering infrastructure and technopreneurship. (Corresponding author: mobile phone: +27733106085; fax: +27(0)123825226; email: kupolatiwk@tut.ac.za.)

William Tchoundi Mbadie obtained a bachelor degree in Rural Engineering in 2006 at the National Advanced School of Public Works in Cameroon and a Bachelor Degree in Civil Engineering in 2008 at the University of Douala, Cameroon. He is bilingual in French and English languages; and presently undergoing a Master of Technology programme at the Department of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa under the supervision of Dr W. K. Kupolati, Prof. J. M. Ndambuki of the Department of Civil Engineering and Prof. E. R. Sadiku of the Department of Chemical, Metallurgical and Material Engineering of Tshwane University of Technology, Pretoria, South Africa. (Mobile phone: +27837283348; e-mail: wtchoundi2010@gmail.com)

Prof. J. M. Ndambuki holds a B.Sc. (Hons), an M. Sc. and a Ph.D. in Civil Engineering. He is a rated researcher with extensive research experience in the area of water resources management. His research interests include: Stochastic Optimization, Multi-Objective Optimization, Groundwater Quality and Quantity modeling, Decision Support Systems as well as Generation of Green Energy through the use of agricultural and municipal solid waste. He is also the Head, Department of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa. (Mobile phone: +27836091607; e-mail: ndambukijm@tut.ac.za)

Prof. E. R. Sadiku holds a B.Sc. (Hons) in Fibre and Polymer Science and a Ph.D. in Polymer Physics from University of Strathclyde, Glasgow, United Kingdom. He is a rated researcher with extensive research experience in the area of Polymer Technology X-ray Physics and Rheology of Polymers and Polymer Composites. He is also the Head, New Materials and Manufacturing research niche at the Faculty of Engineering and the Built Environment, Tshwane University of Technology, Pretoria, South Africa. (Mobile phone: +27722598629; e-mail: sadikur@tut.ac.za)