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The Influence of Waste Glass Slurry on the Properties of Concrete

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Abstract

The grinding of glass waste chips in a wet environment for 120 minutes gives possibility to obtain particles finer in size in comparison to glass waste chips ground in dry environment. The particle distribution analysis showed that borosilicate glass lamp waste slurry has particle size in the range of 0.713 µm to 8.088 µm, fluorescent lamp glass waste slurry - from 2.473 µm to 20.088 µm, amber glass cullet slurry - from 1.435 µm to 21.118 µm, green glass cullet slurry - from 0.903 µm to 23.125 µm, flint glass cullet slurry - from 1.511 µm to 8.932 µm. The obtained waste glass slurries show pozzolanic characteristics and using of them as a cement component in concrete might be a solution for CO_2 and accumulated landfilled glass wastes reduction. Application of waste glass slurries in concrete has a positive effect on workability of concrete mixtures and improves considerably mechanical properties of concrete at early ages. The alkali-silica reactivity (ASR) tests results indicate that the presence of finely ground waste glass in wet environment has a relatively small influence on ASR expansion.

Keywords: waste glass slurry, borosilicate lamp glass, glass cullet, concrete.

1. INTRODUCTION

Portland cement concrete has clearly emerged as the material of choice for the construction of a large number and variety of structures in the world today. The global population in the year 2050 is predicted to be between 8 and 11 billion [1]. It is estimated that annually 1000kg of concrete is produced per person on the Earth, compared with many other construction materials it possesses many advantages including low cost, general availability of raw material, adaptability, relatively low energy requirements and utilization under different environmental conditions, and also capability of tolerating the incorporation of many extraneous materials such as waste materials [2]. The production of Portland cement contributes significantly to CO_2 emissions. For every tonne of Portland cement produced approximately one tonne of CO_2 is released into the atmosphere [3]. Therefore, it is imperative that technologies be developed to reduce the production of Portland-cement clinker in rotary kilns while maintaining the target production of cements and meeting the demand of the construction industry [4]. The construction industry is required to adopt environmentally friendly practices and make judicious use of natural resources. Major contributions to sustainable development can be made by reducing the consumption of Portland cement through partially replacing it with supplementary cementitious materials (SCMs). The accumulation of waste glass in the plants represents two major problems: solid waste disposal and a negative impact to the environment. However, waste glass powder offers a highly desirable chemistry for use as a SCM [5]. Size reduction of glass to enhance its chemical reactivity is the key enabling step for converting the landfill-bound mixed-color waste glass into a valuable product capable of partially replacing cement in concrete. This highly promising concept has not, however, been picked up by the cement and concrete industry. The reason is that earlier efforts to recycle waste glass in concrete viewed crushed glass with dimensions of few millimeters as a replacement for sand in concrete [6, 7]. A coarse crushed glass used as concrete aggregate can cause alkali-silicate reactions (ASR) in hard concrete resulting in harmful expansion in the interface between the cement and glass surfaces [8, 9]. The ground glass particles (<75 µm) initiate pozzolanic reactions without harmful expansion deformations [10]. The coarse and fine aggregates can trigger ASR in concrete whereas glass powder can suppress the tendency to ASR and produce an effect similar to that of supplementary cementitious materials such as pozzolan [11]. In papers of other researchers [5-18] waste glass was ground in dry environments only. The present study is an investigation of the effects of increasing the fineness of glass powders by grinding in a wet environment and of the influence of the waste glass slurries obtained on concrete properties. The glass powders studied were borosilicate glass lamp waste (DRL), fluorescent lamp glass waste (LB) and glass cullet powders, which are used as a cement component in concrete.

2. USED MATERIALS AND METHODS

2.1. Waste glass

Special glass - fluorescent lamp glass waste chips (LB) and borosilicate glass lamp waste chips (DRL) were received from a local lamp recycling centre. Container glass chips were obtained from bottles (green (G), amber (A) and flint (F) colors) which were collected from a local glass bottle return point and manually crushed into chips in laboratory conditions, since there was no possibility to receive cullet glass from the recycling company. Waste glass chips were washed, dried and ground for 30 or 120 minutes in a wet environment in laboratory planetary ball mill Retsch PM400 (with rotation speed 300 min^{-1}) in order to obtain waste glass slurries. The chemical analysis was performed for waste glass powders ground for 30 minutes in a dry environment in a laboratory planetary ball mill and was determined in conformity with BS EN

196-2 [19] methodology. The results are summarized in Table 1. The powder fineness was obtained by automatic Blaine apparatus Zwick/Roell ToniPERM using the rapid method without the need to measure density of the powder beforehand with a pyknometer in accordance with BS EN 196-6 [20] and ASTM C204 [21].

Table 1: Chemical composition and fineness of glass powders ground for 30 minutes [22]

Bulk oxide, %mass	Glass cullet			**DRL**	**LB**	**PC Kunda**	**PC Aalborg**
	Flint	**Green**	**Amber**				
CaO	11.300	10.930	8.890	1.320	5.110	62.03	68.87
Al_2O_3	1.340	1.530	1.420	2.600	1.220	5.22	2.40
SiO_2	69.610	67.800	69.260	71.140	65.520	17.93	23.16
K_2O	0.562	0.550	0.507	1.702	1.881	1.76	0.06
Na_2O	11.208	11.092	11.436	3.301	12.354	0.20	0.25
Fe_2O_3	0.080	0.360	0.430	0.170	0.110	2.97	0.30
MnO	0.008	0.018	0.018	0.006	0.011	0.14	0.02
MgO	0.462	1.584	3.078	0.615	2.946	4.06	0.81
TiO_2	0.028	0.062	0.052	0.006	0.027	0.36	0.07
SO_3	0.126	0.036	0.012	0	0.143	3.76	2.23
P_2O_5	0.021	0.023	0.026	0.023	0.038	0.44	0.33
Fineness, m^2/kg	502	463	542	608	542	388	358

2.2. Waste glass slurries

Waste glass chips with total volume of material of 500 grams in each of 4 containers were ground for 30 or 120 minutes in a wet environment with water to glass proportion 1:1 by weight. Ten different waste glass slurries were obtained (see Figure 1).

Figure 1 Waste glass slurry samples

The particle size distribution of the Portland cement and ground waste glass powders / slurries was measured on Malvern Mastersizer 2000 equipment. Three repeat measurements were carried out on each sample and averaged. The results are shown in Table 2.

Table 2: Waste glass slurry particle size distributions

Volume mean diameter, μm / Glass slurry	**$d_{(0.1)}$**	**$d_{(0.5)}$**	**$d_{(0.9)}$**	Volume mean diameter, μm / Glass slurry	**$d_{(0.1)}$**	**$d_{(0.5)}$**	**$d_{(0.9)}$**
LB 1/1/30	1,958	9,172	37,393	**A 1/1/120**	1,435	5,357	21,118
LB p 30	2,878	20,652	104,317	**G 1/1/30**	1,618	6,931	25,455
LB 1/1/120	2,473	8,970	20,088	**G p 30**	4,581	33,437	163,642
DRL 1/1/30	1,296	4,200	11,825	**G 1/1/120**	0,903	3,780	23,125
DRL p 30	4,952	36,586	159,143	**F 1/1/30**	1,474	5,771	21,062
DRL 1/1/120	0,713	2,835	8,088	**F p 30**	4,852	34,789	165,415
A 1/1/30	1,690	6,325	34,536	**F 1/1/120**	1,151	3,306	8,932
A p 30	4,133	24,863	124,420				

- A1/1/30 – Glass cullet of amber color slurry ground for 30 minutes in planetary ball mill in a wet environment
- A p 30 – Glass cullet (amber color) powder ground for 30 minutes

2.3. Concrete mixture compositions

Portland cement CEM I 42.5N from “Kunda Nordic” (Estonia) was applied as a binding agent. Natural local washed gravel (2/12mm) and natural sand (0.3/1mm and 0.3-2.5mm) were applied as rough/fine aggregates. Cement was substituted with waste glass slurry at levels of 20% and 30%. The control concrete mixture and ten different concrete mixtures with each of the glass powder slurries were mixed in a power-driven rotary mixer with a moving bottom (but with no blades or paddles). The aggregates and water amount were kept constant. Concrete mixtures did not contain a plasticizing agent. Concrete mixtures were made in batch sizes of 10.3 liters. The mixture compositions are summarized in Table 3. At first all dry components were mixed for a one minute in the drum mixer, and then the waste glass slurry and remaining water were added during mixing process.

Table 3: Concrete mixture compositions

Materials	Control mixture	Waste glass slurry mixture
Portland cement CEM I 42.5 N	410	330
Gravel 2/12 mm	1000	1000
Sand 0.3/2.5 mm	650	650
Sand 0/1 mm	120	120
Waste glass slurry (20%)	---	160
Water	200	120
Water/cement ratio	0.49	0.49

2.4. Preparation of specimens, Abram slump test and compressive strength

As soon as the mixing was finished, an Abram slump test was carried out for each mixture in accordance with LVS EN 12350-2:2009 [23]. The results are shown in Table 4. Specimens were cast in 100x100x100 mm plastic moulds which conform to standard LVS EN 12390-1:2013 [24]. The moulds were cleaned and lightly coated with form oil before the casting procedure. Concrete was compacted on a vibrating table. After that, the specimens were covered with polyethylene wrap and left to set. After 24 hours the specimens were removed from the moulds and cured in water (at a temperature of +20±2°C) for 28 days and then were placed in a curing chamber (at a temperature of +20±2°C and relative humidity of ≥95%) until the tests were carried out. Compressive strength of concrete specimens was determined at the age of 7, 28 and 90 days for the concrete mixtures in accordance with LVS EN 12390-3:2009/AC:2011 [25].

2.5. Alkali-silica reactivity (ASR)

Alkali-aggregate reaction test was performed according to RILEM TC 106-2"Detection of potential alkali-reactivity of aggregates – the ultra-accelerated mortar - bar test" [26] for concrete specimens with different waste glass slurries ground for 120 minutes. Portland cement CEM I 42.5N from "Kunda Nordic" (Estonia) and CEM I 52.5 "Aalborg" (Denmark) were applied as binding agents. Portland cement was substituted at levels of 20% and 30% with waste glass slurries. Prismatic specimens 40 x 40 x 160 mm were prepared (see Figure 2). The 24 ± 2 h old specimens were hardened in water at 80°C for the next 24 h and immediately after that the specimens' initial lengths were measured. Concrete specimens were kept in 1 M NaOH solution at a temperature of 80°C and ASR expansions were measured for duration of 14 days. Reference specimens were kept in water at a temperature of 80°C for 14 days in order to simulate similar conditions as in the alkali solution. The compressive and flexural strength reduction was determined at the age of 14 days for specimens kept in both NaOH solution and water.

Figure 2 ASR test concrete specimens with glass powder slurries

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1. Cement substitution with waste glass slurries

According to the obtained particle size distribution analysis results (see table 2), it is evident that grinding of waste glass chips in a wet environment considerably increases the fineness of particles. The best results are obtained for DRL (0.713 – 8.088 μm) and F (1.511 – 8.932) glass powder slurries ground for 120 minutes. As it can be seen, the DRL and F powders ground for 30 minutes in a dry environment have a larger particle size compared to those ground in a wet environment for 30 minutes.

In the previous study [27] it was observed that sedimentation of DRL and LB glass powder slurries ground up to 30 minutes occurs much faster than of slurries ground up to 90 minutes, and due to that reason the slurries should be incorporated into the concrete mixture straight after grinding. Taking into account that the longer the waste glass chips are ground in water, the better is the workability of the slurry obtained, therefore, in the present study a grinding time of 120 minutes was chosen in order that the slurries could be used even after several days. However, as the experimental programme showed, shaking of slurries is necessary before their incorporation into the concrete mixture. The slurries obtained from the 30 minutes grinding process have a short term settling effect and harden after just one or two days.

It was determined experimentally that cement substitution with up to 20% glass waste powder slurry gives a compressive strength of the obtained concrete equal to that of concrete obtained from the same concrete composition but without cement substitution. The compressive strength of the concrete mixtures up to the age of 90 days and cone slump test results are summarized in Table 4.

Table 4: Comparison of determined results for control and waste glass slurry concrete mixtures

	Control mixture	Glass powder slurries (grinding time 120 minutes) mixtures									
		DRL1	DRL2	LB1	LB2	A1	A2	G1	G2	F1	F2
Cement substitution level	---	20%	30%	20%	30%	20%	30%	20%	30%	20%	30%
Cone slump, mm	105	95	107	112	122	100	112	100	110	110	118
Compressive strength, MPa											
7 days	45.8	52.1	44.3	41.9	32.6	48.5	39.1	49.3	39.0	50.3	41.2
28 days	57.3	65.2	56.9	54.3	42.9	63.1	52.5	63.5	53.9	64.1	54.5
90 days	71.9	75.1	71.4	67.2	66.3	71.1	63.2	72.2	64.0	73.1	65.4

It was observed that the concrete mixtures containing waste glass slurries have improved mixture workability in comparison with the control concrete mixture. LB and F waste glass slurries have the best performance on concrete mixture workability. As can be seen from the Table 4, all mixtures with waste glass slurry have cone slump higher than control mixture except the DRL1 mixture. Usually borosilicate glass lamp waste powder has a detrimental effect on workability and decreases the setting time but considerably increases the compressive strength of the finished concrete. That can be explained by the chemical composition and fineness of this waste material. Cement substitution with up to 20% glass waste powder slurry in the concrete mixtures DRL1, A1, G1 and F1 gives a compressive strength of the obtained concrete equal to control mixture at the age of 7, 28 and 90 days. Experimental results indicate that it is possible to achieve more environmentally friendly concrete compositions with low cement content utilizing non-recyclable and container waste glass that gives significant cost-savings in the production of Portland cement with CO_2 emissions reduction into the atmosphere.

3.2. Alkali-silica reactivity (ASR)

Ultra accelerated ASR tests results are given in Figure 3 and Figure 4. ASR tests were performed for concrete specimens with DRL, LB slurries with CEM I 45N Portland cement (Figure 3) and with A, F, G and CEM I 52.5 (Figure 4).

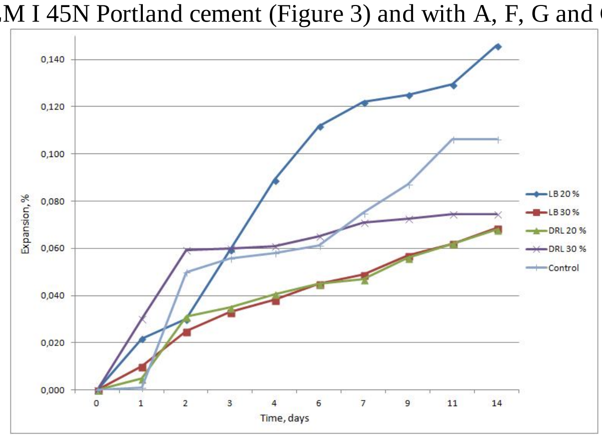

Figure 3 ASR test results for DRL and LB

Final relative expansion for concrete mixtures with waste glass slurries was in the range from 0.041% to 0.146%. The concrete specimens with Aalborg CEM I 52.5 cement and waste glass slurries A, F and G showed the lowest expansion –

0.041% to 0.096%, the concrete specimens with CEM I 42,5 and waste glass slurries DRL and LB – 0.068% to 0.146%. The lowest expansion was for the mixture with amber glass cullet – 0.041%.

The compressive and flexural strength reduction was determined at the age of 14 days for specimens kept in both NaOH solution and water. The flexural strength reduction for specimens with waste glass slurries was in the range 2.3% to 16.1% and the compressive strength reduction from 1.2% to 19.4%. The highest compressive strength reduction was for DRL mixtures and the lowest was for F mixtures.

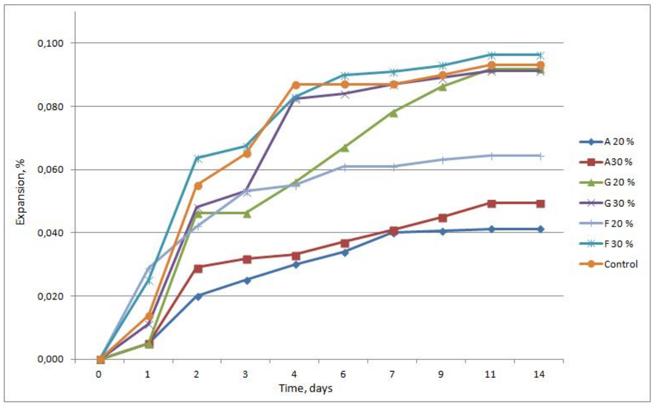

Figure 4 ASR test results for A, G and F

4. Conclusions

The aim of the experiments was to clarify the influence of waste glass slurry applied as a cement component in concrete on the concrete properties. The grinding of glass waste chips was handled in a wet environment for 120 minutes that gave possibility to obtain rather fine particles in comparison to conducted research in this field. The experimental programme results showed that waste glass slurries themselves have pozzolanic characteristics and using them as a cement component in concrete improves workability and improves considerably the mechanical properties of concrete at early ages. The ASR tests results indicate that the presence of finely ground waste glass in a wet environment has a relatively small influence on ASR expansion. The application of waste glass in concrete could be a solution for CO_2 emissions and landfilled waste glass reduction.

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