Construction Science

doi: 10.2478/v10311-012-0004-z

2012 / 13

The Usage of Fluorescent Waste Glass Powder in Concrete

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Abstract. **Typical problem for Baltic States is recycling of glass; glass wastes are mainly dumped into landfill. Landfills of non-recyclable fluorescent lamp glass do not provide an environment-friendly solution for these wastes. In the present research waste borosilicate (DRL) and leaden silicate (LB) glass chippings after fluorescent lamp crushing were ground and used as micro filler as partial substitution of cement therefore reducing landfill pollution and CO_2 emissions into the atmosphere. Waste glass powder additional grinding time was in the range of 30min to 90min in order to increase fineness. Superplasticizer was used in order to raise compressive strength of concrete.**

***Keywords*: micro filler, fluorescent waste glass, plasticizer, compression strength**

INTRODUCTION

Glass is a material which has an ancient history. Glass production was already known in ancient Egypt since 9000 year B.C., it was used in decorations and jewellery. From ancient Egypt glass making craft passed to ancient Rome in the 1 century B.C. Glass production was very limited till 18 and 19 century due to its high cost. Nowadays glass is one of the most popular materials due to progressive growth of urbanization and industrialization which leads to continuous growth of production and consumption of different products. Unfortunately, increased production of glass causes simultaneously the growth of the amount of glass waste. Disposal of this waste is a complex problem for many countries in the world. Many governmental and non-governmental organizations are dealing with this problem, but in spite of the efforts, the recycling of glass in many countries is insufficient. For example, in 2005 in the USA the amount of waste increased to 12.15 million tonnes and only 2.18 million were recycled [1]. In Poland the amount of waste glass was around 900 thousand tonnes in 2004 and 300 thousand tonnes were recycled [2]. Typical problem for the Baltic States is that many glass producing and recycling companies have bankrupted and only part of the imported glass is exported for recycling; therefore there is no complete statistics on glass waste. According to the data of 2009 42,6 thousand tonnes of glass were imported to Latvia and the recycling of glass waste was 12,5 thousand tonnes [3]. Another problem is with non-recyclable waste glasses like fluorescent lamp glasses which contain heavy and toxic metals and therefore landfills do not provide an environment-friendly solution for these wastes. There is only one demercurisation company in the Baltic States which yearly partially recycles from 300 to 500 tonnes of fluorescent lamp glass. Recycled fluorescent glass is exported to fluorescent lamp producers and part of this non-recycled waste can be utilized in concrete production. Recycling of glass has numerous indirect benefits such as reduction in landfill cost, saving in energy, and protecting the environment form possible pollution effects.

In the sixties, many studies were devoted to the use of crushed glass waste as an aggregate for concrete production [4-6]. This aggregate was also applied in road construction. The glass waste was also used for production of glass tiles and bricks, wall panels, glass fibre, agriculture fertiliser, landscaping reflective beads and tableware [7]. The properties of glass seemed comparable to those of large aggregate in terms of constitution, strength and durability, and the larger size of the glass meant lower processing costs. These early attempts however, were unsuccessful due to the alkali–silica reaction (ASR) which takes place in the presence of the amorphous waste glass and concrete pore solution with marked strength reduction and simultaneous excessive expansion [8].

Due to high disposal costs of glass wastes, the use of glass as concrete aggregate has again attracted the attention of researchers [9-13]. Recent studies have shown that the particle size of glass is a crucial factor for ASR reaction to occur [14]. In particular, aggregate fineness favours ASR expansion since the ASR reaction is a surface area dependant phenomenon. It was found that if glass was ground to a particle size of 300μm or smaller, the ASR induced expansion could be reduced. The data reported in the literature shows that if waste glass is finely ground under 75μm, this effect does not occur and mortar durability is guaranteed [8].

The benefits of developing alternative or supplementary cementing materials as partial substitution for ordinary Portland cement (OPC) powder are described by Malhotra and Mehta [15], who divide them into ecological, economic, and engineering categories. Ecological or environmental benefits of alternative materials include (1) the diversion of non-recycled waste from landfills for useful applications, (2) the reduction in the negative effects of producing cement powder, namely the consumption of non-renewable natural resources, (3) the reduction in the use of energy for cement production and (4) the corresponding emission of greenhouse gasses. The economic benefits of using alternative materials are best realized in situations where the cost of the alternative material is less than that of cement powder while providing comparable performance. Calculating this cost the source of the alternative material, its transportation and processing must be considered, as well as savings through diversion, such as tipping fees and landfill management costs. The engineering or technical benefits of alternative materials are realized when a specialized use for such material may be developed, such that the use of the alternative material is more desirable than use of concrete made with OPC alone [18].

Non-recycled waste glass due to specific chemical composition still constitutes a problem in solid waste disposal. Fluorescent lamp glass causes a disposal problem because it is not biodegradable and landfill is not the best environment-friendly solution for its disposal. Yearly from 300 to 500 tonnes of fluorescent lamps are partially recycled in Latvia. Mostly they are recycled for production of the same fluorescent lamps. Another good suggested solution is to use glass waste as micro filler which partially substitutes cement by weight in concrete [17,20]. Micro filler is one of most expensive mix components, its cost may make up a half from cement cost. Micro filler substitution by waste products gives possibility to achieve economic effect and solve environmental protection task simultaneously. Application of glass waste as a micro filler in concrete was investigated by many researchers in the previous years [8, 16-20].

METHODS

An experimental study was carried out to investigate the effects on the mechanical properties of concrete of partial substitution of cement with waste glass – borosilicate (DRL) and leaden silicate (LB) glass chippings obtained from fluorescent lamps from local utilization company. The chemical composition is shown in Table 1.

TABLE 1

The chemical composition of DRL and LB waste glasses

	DRL	LB
SiO_2	74.2	69.07
PbO	0	20,02
B_2O_3	16.63	0
Al_2O_3	1.65	1,03
Fe_2O_3	0.16	0,19
CaO	2.09	1,39
MgO	0	0
Na_2O	3.82	8,02
K_2O	0.93	1,17
Total	99.48	99,72

Ordinary Portland cement CEM I 42.5N from “Kunda Nordic” (Estonia) was applied as a binding agent. Cement conforms to standard EVS EN 197-1:2002 “Cement – Part 1: Composition, specifications and conformity criteria for common cements”. Natural local aggregates were used for mix preparation. Coarse and fine sand combination was applied as fine aggregate of a concrete. All concrete mixes were made with Sikament 56 polycarboxylat based plasticizer (except the control mix). Fluorescent waste glass was additionally ground for 30min and 90 min in order to raise reactivity.

A total of 20 different concrete mixes were prepared. One of them was a control mix with no waste glass substitution (named CTRL); another was a control mix with plasticizer and no waste glass substitution (named CTRL+); 4 – with DRL (DRL20, DRL30, DRL40 and mix DRL40-1 with different water amount) and 4 with LB (LB20, LB30, LB40 and mix LB40-1 with different water amount) non additionally ground waste glass and plasticizer; 4 – with grDRL- additionally ground waste glass for 30 min and plasticizer (grDRL20, grDRL30, grDRL40, grDRL40-1 with different water amount) and 4 – with grLB additionally ground waste glass for 30 min and plasticizer (grLB20, grLB30, grLB40, mix grLB40-1 with different water amount) and 2- with additionally ground waste glass for 90 min and plasticizer (marked as grDRL20(90) and grLB20(90)). Cement was substituted with waste glass at 3 levels – 20%; 30%; and 40%; the aggregates were kept constant, water amount varied. Details for different mixes are shown in Table 2.

TABLE 2

Concrete mix compositions, kg/m^3.

Mixture type	W/C ratio	Portland cement CEM I 42,5 N	Gravel (2,0-12,0 mm)	Natural sand (0,3-2,5 mm)	Quartz sand (0-1,0 mm)	Waste glass	Plasticizer	Water
CTRL	0,49	410	1000	650	120	0	-	200
CTRL+	0,40	410	1000	650	120	0	4.1	165
DRL 20	0,40	330	1000	650	120	80	4.1	165
DRL 30	0,40	290	1000	650	120	120	4.1	165
DRL 40	0,40	250	1000	650	120	160	4.1	165
DRL 40-1	*0,43*	250	1000	650	120	160	4,1	175
LB20	0,38	330	1000	650	120	80	4.1	155
LB 30	0,38	290	1000	650	120	120	4.1	155
LB 40	0,38	250	1000	650	120	160	4.1	155
LB 40-1	*0,42*	250	1000	650	120	160	4.1	172
grDRL 20	0,40	330	1000	650	120	80	4.1	165
grDRL 20(90)	0,40	330	1000	650	120	80	4.1	165
grDRL 30	0,40	290	1000	650	120	120	4.1	165
grDRL 40	0,40	250	1000	650	120	160	4.1	165
grDRL 40-1	*0,35*	250	1000	650	120	160	4.1	144
grLB 20	0,38	330	1000	650	120	80	4.1	155
grLB 20(90)	0,38	330	1000	650	120	80	4.1	155
grLB 30	0,38	290	1000	650	120	120	4.1	155
grLB 40	0,38	250	1000	650	120	160	4.1	155
grLB 40-1	*0,33*	250	1000	650	120	160	4.1	136

All concrete mixes were mixed in a power-driven rotary mixer with a moving bottom (but with no blades or paddles). The capacity of most of mixes was 10.3 litres and some were made in 3.2 litre capacity by manually. The mixing procedure was the following:

- Mixing of the dry ingredients for 120 s;
- Adding 70% of the total water with plasticizer and mixing for 60 s;
- Adding the rest of the water and mixing for 60 s.

As soon as the mixing finished, Abram slump test was carried out for each mix in accordance with LVS EN 12350-2:2009 “Testing fresh concrete – Part 2: Slump test” (see Fig. 1).

Fig. 1. Slump test of concrete control mix (135mm)

Specimens were cast in 100x100x100 mm plastic or steel moulds (see Fig. 2), which conform to standard LVS EN 12390-1:2009 "Testing hardened concrete – Part 1: Shape, dimensions and other requirements for specimens and moulds".

Fig. 2. Fluorescent waste glass concrete specimens

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 pellicle and left to set for 48 hours. Then they were removed from moulds and cured in water (with temperature +20±2°C) for 7 days and in curing chamber (with air temperature +20±2°C and relative humidity ≥95%, see Figure 1) for other 21 days or until testing, thus conforming to LVS EN 12390-2:2009 "Testing hardened concrete – Part 2: Making and curing specimens for strength tests".

To evaluate the hardened concrete properties compressive strength test was carried out. Before the test, the specimens were dried in an oven for 20 min in 50ºC temperature. The testing was done according to LVS EN 12390-3:2009 "Testing hardened concrete – Part 3: Compressive strength of test specimens" (see Figure 3). Compression testing machine with the accuracy of ±1% was used; the rate of loading was 0,7 MPa/s. Compressive strength test was conducted up to 112 days. Three specimens per mix for each age were prepared and the mean compressive strength value was calculated. The concrete strength containing ground waste glass was compared with the concrete control mix.

RESULTS

The results for fresh concrete properties – slump test – are summarised in Table 3.

TABLE 3

Slump test results for each mixture.

Mix type	Slump, mm	Slump class	Mix type	Slump, mm	Slump class
CTRL	135	S3	grDRL 20	110	S3
CTRL+	180	S4	grDRL 20 (90)	130	S3
DRL 20	100	S3	grDRL 30	>220	S5
DRL 30	220	S5	grDRL 40	>220	S5
DRL 40	>220	S5	grDRL 40-1	--*	--*
DRL 40-1	--*	--*	grLB 20	100	S3
LB20	78	S2	grLB 20 (90)	160	S4
LB 30	188	S4	grLB 30	>220	S5
LB 40	>220	S5	grLB 40	>220	S5
LB 40-1	--*	--*	grLB 40-1	--*	--*

*-- due to mix's capacity of 3.2 liters slump test has not been done.

It is evident from the slump test data that DRL waste glass contributed to workability of concrete more than LB waste glass did, as the slump of DRL was generally 1..1,5 times greater than the slump of LB. This could be explained by the differences in DRL and LB particle size and shape, chemical composition.

The data show that with increasing of waste glass content, the slump decreased for both waste glass types, and for both non-ground and additionally ground waste glass. With increasing waste glass content the workability of mixtures increased. Mixes containing glass powder with additional grinding were more fluid, than mixes containing glass powder without additional grinding. This could be explained by the fact that the water absorption qualities of waste glass DRL are influenced more by the fineness of the particles in comparison with LB.

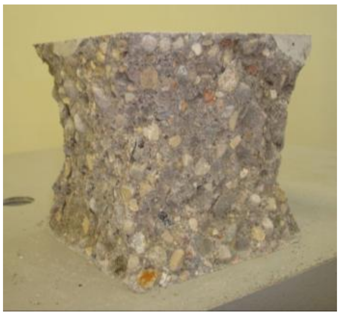

Fig. 3. DRL concrete specimen after test

Concrete cubes' strength tests were carried out after 7, 28, 56, 84 and 112 days. After 7 days of hardening, the first part of samples was tested on compression strength (Figure 3). Before the test, the specimens were dried in an oven for 20 min in 50°C temperature. Three tests per mix for each age were carried out – to measure the compressive strength. The testing was done according to LVS EN 12390-3:2009 "Testing hardened concrete – Part 3: Compressive strength of test specimens". Compression testing machine with the accuracy of ±1% was used; the rate of loading was 0.7 MPa/s

According to the data in Table 4, the increase of strength of concrete mix with plasticizer in comparison to mix without it was 26% almost at all ages except at the age of 56 days with 18% strength increase.

Figure 4 shows that concrete with 20% and 30% DRL substitution have a bit higher overall results in comparison with control mix CTRL+ and with 40% DRL substitution. DRL 40 mix fared worse than other mixes during 28 days of hardening and after 56 days it was almost equal to DRL 20. DRL 30 showed the best results therefore the optimal cement substitution level could be around 30% in concrete.

Investigation showed that early strength levels of mixes with DRL waste glass substitution are considerably lower in comparison with control concrete mix, but this is expected, as the strength improvements from pozzolanic reactions are mostly seen at later ages, in this case – at 56 days and especially at 112 days, when the differences are much smaller than at the early stages.

Figure 5 shows that concrete leaden silicate waste glass LB substitution have slightly worse results in comparison with control mix CTRL+ at early age and only mix LB 20 at later age showed a bit higher result as control mix. In comparison with borosilicate waste glass LB mixes showed worse results at all ages except the mix with 20% leaden silicate waste glass substitution at the age of 112 days. Additional research must be done in order clarify why LB waste glass mixes have such difference: (i) either it is Pb influence, (ii) either it is particles size influence, (iii) either Na content in LB is larger and it reacts with SiO_2 and therefore slows down hydration process. The optimal cement substitution level with leaden silicate waste glass could be around 20% in concrete.

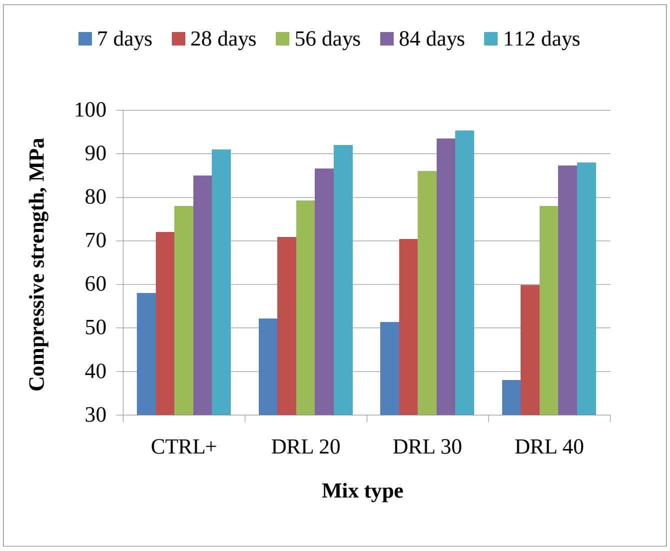

Fig. 4. Influence of DRL waste glass content and curing time on the concrete compressive strength.

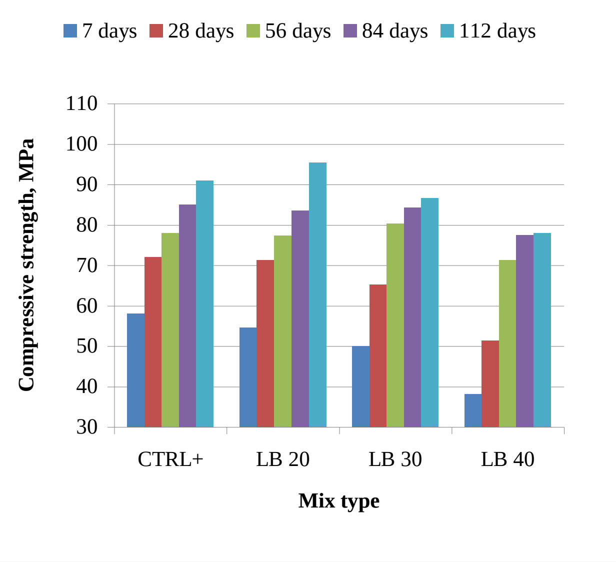

Fig. 5. Influence of LB waste glass content and curing time on the concrete compressive strength.

Figures 6 and 7 show that with additional grinding of waste glass powder for 30 minutes results of compressive strength of concrete mixes are improved in comparison to mixes with waste glass which was ground from chippings to powder during 10 minutes. From the results shown in Table 4 it is possible to see that additional grinding for 90 minutes didn't bring any good improvement to overall results. In fact the results of mixes with 20% DRL and LB substitution were lower than results of mixes with 20% DRL and LB and 30% DRL and LB substitution.

In Figure 6 it is possible to see that grDRL 20 performed the best results at all ages for this experiment series in comparison to control mix. grDRL 30 showed better results at later ages and the highest result at the age of 112 days – 108MPa in comparison to all experiment series in the present study.

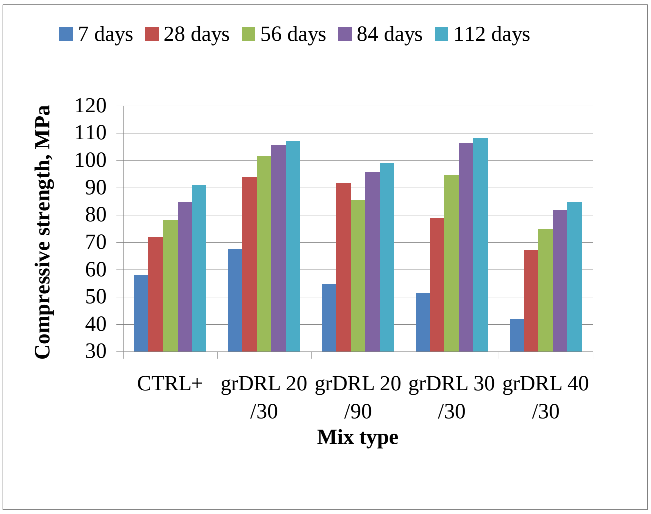

Fig. 6. Influence of additionally ground DRL waste glass content and curing time on the concrete compressive strength.

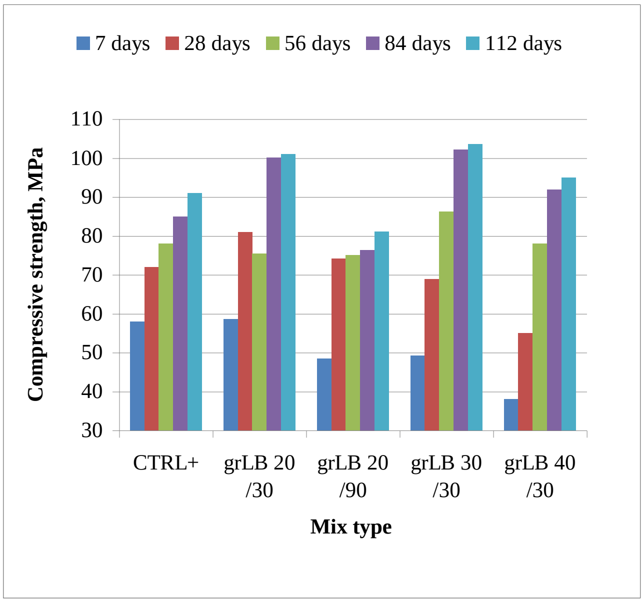

Fig. 7. Influence of additionally ground LB waste glass content and curing time on the concrete compressive strength.

In spite of the obtained tendencies of strength development, the differences between strength results are low (within 3 - 8%).

Additionally ground LB waste glass also showed interesting results, as seen in Figure 7. The best strength was achieved at 30% waste glass content, with compressive strength at 104 MPa being higher than that of control concrete (91 MPa).

Grading analysis showed that non ground glass powder had particle size in the range from 2 μm up to 70 μm and Blaine test showed that surface area for borosilicate glass is 2310 cm2/g and for leaden glass is 2360 cm2/g. The substitution of 20% and 30% is beneficial, probably due to the improvement in the particle packing as well as the pozzolanic reaction. It could be observed that the strength achieved with 20% and 30% cement substitution gave the highest results in compressive strength.

TABLE 4

Compressive strength test results

Glass powder type and % of cement substitution	W/C ratio	Additional grinding time, min	Compressive strength, Mpa				
			7 days	**28** days	**56** days	**84** days	**112** days
CTRL	0.49	-	46	57	66	68	69
CTRL +	0.45	-	58	72	78	85	87
DRL 20	0.40	0	52	71	79	87	92
DRL 30	0.40	0	51	70	86	94	95
DRL 40	0.40	0	38	60	78	87	88
DRL 40-1	0.43	0	31	48	-*	-*	-*
LB 20	0.38	0	55	71	77	84	95
LB 30	0.38	0	50	65	80	84	87
LB 40	0.38	0	38	51	71	77	78
LB 40-1	0.42	0	32	46	-*	-*	-*
grDRL 20	0.40	30	68	94	102	106	107
grDRL 20(90)	0.40	90	55	92	86	96	99
grDRL 30	0.40	30	51	79	95	107	108
grDRL 40	0.40	30	42	67	75	82	85
grDRL 40-1	0.35	30	53	78	-*	-*	-*
grLB 20	0.38	30	59	81	75	100	101
grLB 20(90)	0.38	90	49	74	75	76	81
grLB 30	0.38	30	49	69	86	102	104

grLB 40	0.38	30	38	55	78	92	95
grLB 40-1	0.33	30	53	73	-*	-*	-*

*- due to mix's capacity of 3.2 litres concrete specimens have not been made.

CONCLUSIONS

The properties of the fresh concrete mix and the properties of the hardened concrete considerably depend on fineness of DRL & LB glass powder. Loss of mix workability (during first 40 minutes) took place for all types of concrete mixes with waste glass. It was observed that the concrete mixes containing ground glass had more viscous consistency in comparison with control concrete mix.

Mixes containing borosilicate glass powder required a little bit more water than mixtures with leaden glass powder for obtaining the similar workability. Mixes containing glass powder with additional grinding were more fluid, than mixes containing glass powder without additional grinding.

Tests revealed that all the mixes of glass concrete had higher strengths than the control concrete mix except that the strength of the concrete mix containing 40% of fluorescent waste glass and only was higher of control mix by 11% after 56 days of curing. From results it is observed that the size effect indicating that the smaller is the size of glass, the higher is the strength of concrete mix. The tendency towards a decrease in compressive strength with an increase in the mixing ratios up to 40% may be due to the decrease in adhesive strength between the surface of waste glass aggregates and the cement paste. However, with decrease of w/c ratio the compressive results for 40% cement substitution are satisfactory.

The mix with the additionally ground waste glass powder and superplasticizer showed the increase of compressive strength by 30%. The best compressive strength results were achieved for mixes with 20% and 30% substitution of DRL and LB waste glass powders additionally ground for 30 min. It was observed that additional grinding of waste glass in dry environment for 90 min didn't give higher results. The results of compressive strength for mixes with 30% waste glass powder substitution showed higher values than control concrete mix but lower for mixes with 40% waste glass powder substitution. The compression strength for mixes with 40% waste glass powder substitution (30 min additional grinding time and decreased w/c ration) showed approximately the same result as mixes with 20% waste glass without additional grinding. Therefore it is possible to conclude that additional grinding increases glass powder fineness and considerably helps to save quantity of cement on cubic metre of concrete. It is a more friendly solution for the environment since CO_2 emission in cement industry is 0.65-0.92 tons of CO_2 per ton of produced cement [19].

The results of the present study show great potential for the utilization of fluorescent additionally ground waste glass in concrete as a partial substitution for expensive materials such as silica fume, fly ash and cement.

ACKNOWLEDGEMENT

Financial support of the ERAF project Nr. 2010/0286/2DP/ 2.1.1.1.0/10/APIA/ VIAA/033 „High efficiency nanoconcretes" is acknowledged.

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Patricija Kara, Aleksandrs Korjakins, Kirils Kovalenko. Fluoriscentā stikla atkritumu izmantošana betonā

Liels daudzums atkritumu un blakusproduktu rodas ražošanas procesos, pakalpojumu nozarē un no sadzīves atkritumiem. Tipiska problēma Baltijas valstīs ir tā, ka daudzi stikla ražošanas un pārstrādes uzņēmumi bankrotēja un tikai daļa no importētā stikla tiek eksportēta otrreizējai pārstrādei, pārējais stikls tiek aprakts poligonos, bet sakarā ar poligonu trūkumu, izgāztuves kļūst arvien grūtāk pieejamas. Ir vēl viena problēma - tādu nepārstrādājamo stikla atkritumu kā dienasgaismas spuldžu stikls, kurš satur smagos un toksiskos metālus, un tādēļ izgāztuves nav videi draudzīgs risinājums. Baltijas valstīs ir tikai viens demerkurizācijas uzņēmums, kas katru gadu daļēji pārstrādā no 300 līdz 500 tonnām fluoriscentās dienasgaismas lampas. Pārstrādāts fluoriscentais stikls tiek eksportēts luminiscento spuldžu ražotājiem, un daļu no šiem atkritumiem var izmantot betona ražošanā. Šajā pētījumā atkritumu borsilikāta DRL) un svina silikāta (LB) stikla lauskas pēc drupināšanas tika papildus samaltas un izmantotas kā mikro pildviela, daļēji aizstājot cementu, tādējādi taupot dabīgās izejvielas un samazinot CO_2 izmešu daudzumu atmosfērā. Stikla atkritumu pūderi papildus samala (diapazonā no 30 līdz 90 minūtēm), lai palielinātu smalkumu. Plastifikatoru izmantoja, lai palielinātu betona stiprību spiedē. Betona maisījumi ar papildus malto stikla pūderi un plastifikatoru parādīja pieaugumu spiedes stiprībā par 30%. Labākos spiedes stiprības rezultātus sasniedza maisījumi ar papildus samalto stikla pūderi DRL un LB 30 minūšu laikā, aizstājot cementu par 20% un 30% no svara. Papildus malts DRL uzrādīja labākus rezultātus vēlākā vecumā un augstāko rezultātu 112 dienu vecumā - 108MPa, salīdzinot to ar visiem eksperimenta sērijas rezultātiem šajā pētījumā. Papildus malts LB stikla pūderis arī parādīja interesantus rezultātus, labākā stiprība spiedē tika sasniegta 104 MPa ar 30% atkritumu stikla saturu, pārsniedzot kontroles maisījuma stiprību (91 MPa).

Патриция Кара, Александр Корякин, Кирил Коваленко. Использование переработанного флуоресцентного стекла в бетоне.

Большое количество отходов и побочных продуктов образуется в результате производственных процессов, сферы услуг и твердых бытовых отходов. Типичной проблемой для стран Балтии является банкротство компаний по производству и переработке стекла. Только часть импортируемого стекла отправляется на экспорт для переработки, остальное сбрасывается на свалку, но с нехваткой свалок, земля для наполнения становится все более и более недоступной. Другая проблема заключается в не предназначенных для переработки отходов стекла, как люминесцентного стекла, которое содержат тяжелые и токсичные металлы и, следовательно, свалки не обеспечивают экологическое решение для этих отходов. В странах Балтии есть только одна демеркуризационная компания, которая ежегодно частично перерабатывает от 300 до 500 тонн люминесцентного лампочного стекла. Вторичное флуоресцентное стекло экспортируется для производителей флуоресцентных ламп и часть этих отходов может быть использована в производстве бетона. В настоящем исследовании был использован дополнительно помолотый порошок боросиликатного (DRL) и свинцового стекла (LB), полученный после дробления флуоресцентных ламп и помола осколков. Порошок был использован в качестве микронаполнителя, частично заменяя цемент и, следовательно, сокращая количество выбросов CO_2 в атмосферу. Дополнительное измельчение проводилось в диапазоне от 30 минут до 90 минут для того, чтобы увеличить степень помола.

Порошок и пластификатор были использованы в целях повышения прочности бетона на сжатие. Бетонные замесы с дополнительно помолотым стекльным порошоком и пластификатором показали увеличение прочности на сжатие на 30%. Лучший результат был достигнут для замесов с 20% до 30% заменой ДРЛ и LB, которые были помолоты дополнительно в течение 30 минут. Молотый DRL в течение 30 минут дал лучшие результаты в более позднем возрасте, и самый высокий результат был получен в возрасте 112 дней - 108MPa по сравнению со всеми результатами в настоящем исследовании. Молотое LB стекло также дало интересные результаты, самый высокие результаты были достигнуты с 30% содержанием стекольного порошка, с прочностью на сжатие в 104 мПа, которая превысила прочность контрольного замеса бетона (91 МПа).