CONCRETE WITH MICROFILLER OBTAINED FROM RECYCLED LAMP GLASS

Genadij Shakhmenko[1], Aleksandrs Korjakins[2] and Girts Bumanis[3]

[1] *Riga Technical University , Kalku str. 1 LV-1658, Riga, Latvia. E-mail: gs@apollo.lv*
[2] *Riga Technical University , Kalku str. 1 LV-1658, Riga, Latvia. E-mai: aleks@latnet.lv*
[3]*Riga Technical University , Kalku str. 1 LV-1658,Riga, Latvia. E-mail girtx@inbox.lv*

Abstract: Lamp glass rational utilization problem is actual over the world. The main aim of the work is to develop technology for utilizing waste of lamp bore-silicate glass as micro-filler for traditional and self-compacting concrete. Ground glass effect is investigated and compared to traditional micro fillers of concrete.

The best compressive strength results are achieved by using silica fume combination with additionally ground glass as complex admixture. Concrete mixes containing silica fume and ground bore-silicate glass perform long-term hardening effect, which may be explained by puzzolanic reactions with cement components.

The experimental program has been elaborated for investigation of ground glass material as micro filler for self-compacting concrete. Flowing characteristics of mix are tested using modern EN standards.

Obtained results confirm a possibility of applying a ground bore-silicate lamp glass as effective alternative micro filler for traditional and self-compacting concrete mixtures.

Key words: bore-silicate glass, waste, micro-filler, concrete, compressive strength, self-compacting concrete

1. Introduction

Glass rational utilization problem is actual over the world. Glass waste application as a filler in concrete was investigated by many researchers in previous years (Siddique 2008, Jin *at al* 2000, Shao *at al* 2000). Glass is silicate material, containing different oxides, the main component is silicate oxide SiO_2 in amorphous state. Several types of glass, such as soda-lime silicate, alkali-silicate, bore-silicate glass are producing in the world. The object in this research is bore-silicate glass remaining after fluorescence lamp utilization. In accordance with European Committee design use of simple incandescent lamp should be restricted till 2012. Therefore the problem of utilization a fluorescent lamp will be more topical in Europe after some years. Although large part of glass waste nowadays is soda-silicate glass, its collecting and recycling procedures are worked out satisfactory, lamp glass can not be utilized by traditional way.

One of the ways of glass waste utilization is application of it as concrete filler. Some investigations indicate that ordinary glass can be used not only as passive filler in concrete, but also as an active component that initiate reaction with cement minerals. A coarse crushed glass used as concrete aggregate can cause the alkali-silicate reactions in hard concrete, resulting in harmful expansion in interface between cement and glass surface (Shayan and Xu 2006, Shayan 2002). It is proved that ground glass particles (<75 µm) may be beneficial component in concrete. In this case glass micro-filler initiate puzzolanic reaction and harmful expansion deformations don't occur (Schwarz and Neithalath 2008). Investigations of micro-structure have shown that glass powder form a dense concrete matrix and improve concrete properties.

At present new types of concrete products have been introduced in building industry, such as Pumping concrete, Self-Compacting Concrete (SCC), High Performance Concrete (HPC), High Strength Concrete (HSC) and Ultra High Performance Concrete (UHPC). These are complex multi-component mix systems. Special requirements for aggregate grading are to be taken into account and especially fine particles (so called "micro filler") content should be controlled. Micro filler improves mix workability and provides particle dense packing in hydrated cement paste. Dolomite, limestone powder, fly-ash and silica fume are usually used as micro-filler in modern concrete mixes. Micro-filler is one of most expensive mix component, it cost may make up a half part from cement cost. Micro-filler replacement by waste products gives possible to achieve economy effect and to solve environmental protection task simultaneously. Thus lamp glass waste utilization in concrete is very actual task in concrete technology.

The aim of this work is to investigate possibilities to use ground lamp bore-silicate glass waste as micro-filler for conventional plastic concrete mixes and for Self-Compacting concrete.

2. Lamp glass utilization product

The object of this study is recycling material obtained from bore-silicate lamp glass utilization. Lamp recycling process includes lamp classification, glass separation, cleaning from harmful components and grinding. The waste product is white glass powder (GP) having grain size smaller than 0.4 mm. Investigation of chemical composition and grading analyses of received waste product was carried out preliminary. Chemical analysis results of glass waste are summarized in Table 1. The product contains 74.3 % of silicium oxide SiO_2, and 16.6 % of bore oxide B_2O_3, thus material is classified as bore-silicate glass.

Table 1. Chemical composition glass waste

Components	Content (% by mass)	Tolerance, ± %
SiO_2	74.25	0.5
PbO	0	0.5
B_2O_3	16.63	0.5
Al_2O_3	1.65	0.3
Fe_2O_3	0.16	0.05
CaO	2.09	0.2
MgO	0	0.2
Na_2O	3.82	0.1
K_2O	0.93	0.1
Total	99.48	-

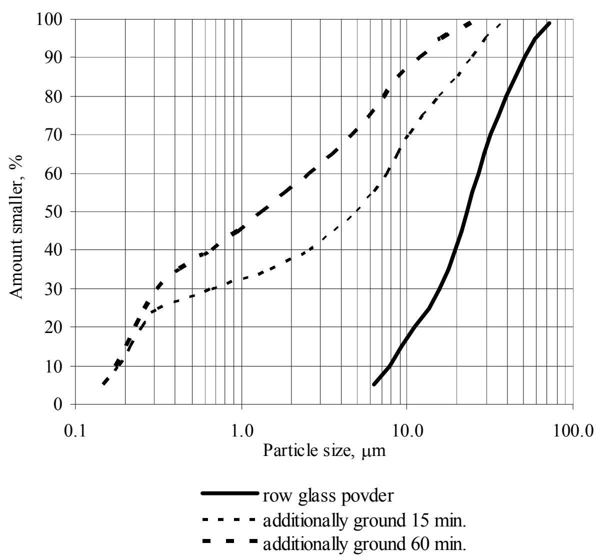

Fig 1. Glass powder grading curves

Particle size distribution of material was made by laser diffraction analysis method. Testing materials was dispersed in water using ultrasonic bath. Three samples of each type glass waste have been tested. Obtained grading curves are shown in Figure 1. Grading analyze shows that material contains wide particle size in range from 2 µm up to 70 µm. In order to increase glass reactivity material was additionally ground in planetary ball mill Retsch PM400. Grading composition analysis indicates on considerable increase in fine particle content after powder additional grinding (Fig. 1).

3. Concrete mix preparation

During experimental work lamp glass powder was added to conventional concrete mixes and Self-Compacting concrete mixes.

Laboratory mixes were designed close to concrete mix commonly used in industry. Normal moderate hardening portland cement CEM I 42.5 N was applied as binding agent. Natural local dolomite based aggregate has been used for mix preparation. Coarse and fine sand combination was applied as fine aggregate of a concrete. Proportions between aggregates were calculated in order to obtain the best grading curve of aggregate, taking into account optimum range curves in accordance with DIN 1045. Modern concrete technology provides controlling not only aggregate grading curve, but also fine particle content, which is necessary to provide satisfactory mix workability. For example, in order to obtain pumpable concrete, recommended fine particle content (< 0.125 mm) is 375…450 kg/m^3. Modern advanced concretes such as self-compacting, high strength and high performance concrete are very susceptible for content of micro-filler admixture. In case of Self-Compacting concrete paste content (cement + water + micro filler) must be 35 ... 43 % by volume. Due to this fact the investigation of ground glass waste influence on the properties of concrete is very important task for improving the concrete technology.

The first part of experimental work provides cement replacing by glass powder.

Effect of glass powder additional grinding is investigated in the second part.

The third part of experiments provides use of combined micro fillers in conventional concrete mixes.

In the last part Self-Compacting mixes was produced. Traditional micro filler (powdered dolomite) was replaced and compared with alternative GP micro filler.

Concrete mixes was prepared in laboratory drum mixer (capacity 50 l). The dry ingredients were weighed and mixed for a one minute, 70 % from designed water content was added during next 1 minute. Super plasticizer and remaining water has been added to the mix during mixing as last component.

Mixes were tested for workability using slump test for conventional concrete. Water dosage is selected to provide cone slump in range 50 ... 100 mm. Modern workability determination methods were used for Self-Compacting concrete, such as cone flow and L-box methods.

Standard testing samples cubes 100 x 100 x 100 mm were produced for investigation the mechanical characteristics of the material. Concrete mixtures were cast into the oiled steel moulds and compacted at the vibrating table. After two days samples was dismantled. The standard hardening conditions (temperature +20^{o}C, RH > 95 %) were provided for the samples. Sample measurements and testing were performed after ageing period in the standard conditions.

The samples were tested on compression strength in conformity with LVS EN 12390-3:2002. The compressive strength was tested by testing machine with accuracy $\pm$1%, the rate of loading was 0.7 MPa/sec.

4. Mix compositions, testing results and discussions

4.1. Cement replacement with glass powder in conventional concrete

In the first series of samples cement was partly replaced by glass powder (GP). Four mixes were prepared, where 0, 10, 20, 40 % of cement was replaced. Mix proportions are summarized in Table 2. Glass filler influence on compressive strength of concrete is shown in Fig. 2. Experimental results indicate decreasing the compressive strength of concrete where part of cement was replaced by grinded glass filler. Required water content differs fractionally for all mixes. The effect of strength decreasing can be interpreted by increasing in water cement ratio.

Table 2. Mix proportions with glass powder admixture as cement replacement

	S0	S10	S20	S30	S40
Cement CEM I 42.5 N	380	342	304	266	228
Gravel 2/10 mm	1000	1000	1000	1000	1000
Sand 0.3/2.5 mm	650	650	650	650	650
Sand 0/1 mm	120	120	120	120	120
Glass powder	0	38	76	114	152
Water	214	213	213	214	216

It was observed the concrete mixes containing ground glass has more tacky consistency in comparison with conventional concrete mix. Mixtures with glass require little bit more water for obtaining the similar workability.

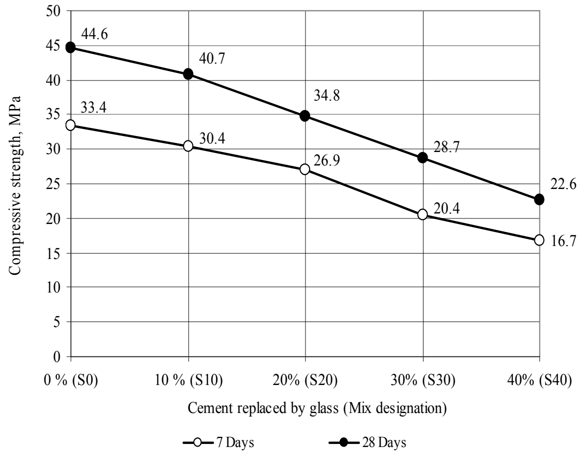

Fig 2. Cement replacement by ground lamp glass: compressive strength test results

4.2. Additionally ground glass

Glass powder additionally was ground 15, 30, 45 and 60 minutes in planetary ball mill. Prepared material was used for mix making in amount 80 kg in cubic meter (Table 3).

Table 3. Mix proportions with additionally ground glass powder

	SG0	SG15	SG30	SG45	SG60
Cement CEM I 42.5 N	330	330	330	330	330
Gravel 2/10 mm	1000	1000	1000	1000	1000
Sand 0.3/2.5 mm	650	650	650	650	650
Sand 0/1 mm	120	120	120	120	120
Glass powder	80	80	80	80	80
Grinding time, min	0	15	30	45	60
Water	219	212	210	205	202
Density, kg/m^3	2328	2339	2336	2342	2343

Produced samples were tested after 7 and 28 days, compressive strength results are shown in Figure 3. Obtained results indicate that extra ground glass powder improve mix workability as result water reduction can be achieved. Glass grinding has negligible effect on mix density (2328 kg/m^3 for mix with raw glass powder and 2343 kg/m^3 for mix with 60 min ground glass). The difference of density does not exceed 1%.

Considerable increasing in compressive strength is obtained, especially after 28 days hardening. This effect may be explained by activating of puzzolanic reactions caused by glass additional grinding and increasing of specific surface.

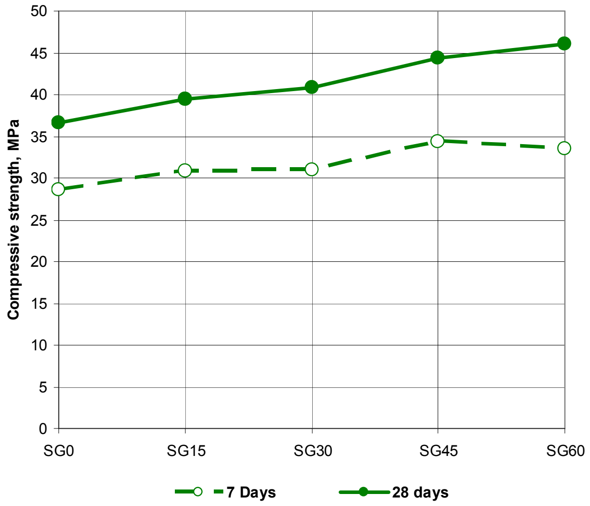

Fig 3. Influence of additionally grinded lamp glass: compressive strength test results

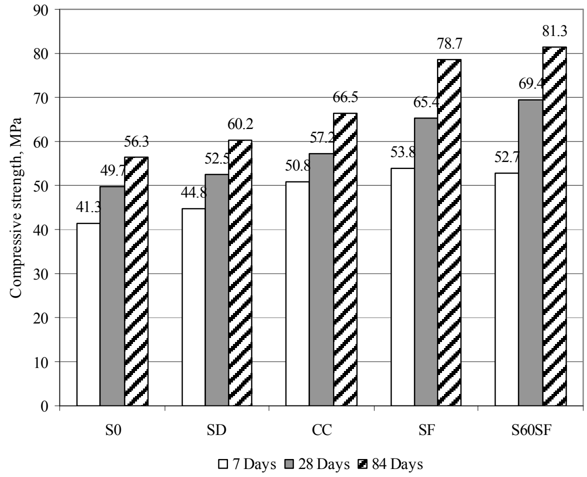

Fig 4. Effect of different and complex micro fillers

4.3. Conventional concrete with complex admixtures

In this experiment effect of different micro fillers are compared. The following micro fillers are used: dolomite powder (SD), silica fume (SF), glass powder (S0), complex admixture containing additionally ground glass powder and silica fume in proportion 1:1 (S60SF) and mix with additional cement content instead of micro filler (CC). Mix proportions are summarized in Table 4. Comparing obtained results (Fig. 4), the minor effect on compressive strength is observed in case of raw glass powder (mix S0) and dolomite powder as micro filler (mix SD).

The best compressive strength results in all ages were achieved by using silica fume as micro filler (SF) and silica fume combination with additionally ground glass as complex admixture (S60SF). These compositions perform the best compressive strength of concrete (about 80 MPa) after 84 days hardening process. Mixes SF and S60SF may be classified as high strength concrete.

Table 4. Mix proportions with combined micro filler

	S0	**SD**	**CC**	**SF**	**S60SF**
Cement CEM I 42.5 N	380	380	380	380	380
Gravel 2/10 mm	1000	1000	1000	1000	1000
Sand 0.3/2.5 mm	650	650	650	650	650
Sand 0/1 mm	120	120	120	120	120
Ground glass	80				
Extra ground glass (60 min.)					40
Dolomite powder		80			
Additional cem. as micro filler			80		
Silica fume				80	40
Superplasticizer	4.7	4.7	4.7	4.7	4.7
Water	214	213	214	216	200

4.4. Glass micro filler in Self-Compacting concrete

Self Compacting concrete was elaborated and practically applied for the first time in Japan. Conception of Self Compacting concrete was worked out in the 1990th by professors of Tokyo University H. Okamura and K. Ozava (Okamura and Ozawa 1995). The main specific components of SCC concrete are superplaticizer and significant amount of micro filler powder as mix stabilizing agent. SCC concrete mix fills formworks without consolidation and concreting process become very simple. In the same time nowadays in Europe the rate of SCC concrete not exceed 5% from total volume of produced concrete. Restricting factors are lack of experience, incomplete specifications, availability and cost of micro fillers.

The first laboratory mix (SCC1) Self Compacting concrete is filled with traditional micro filler dolomite powder. In second mix SCC2 traditional micro filler is completely replaced by glass powder. Third mix contains additionally ground (60 min.) glass powder. Micro filler content 190 kg in cubic meter is constant for all 3 mixtures. Mix proportions and obtained compressive strength values are summarized in Table 5.

It must be emphasized, that traditional concrete mix consistency determination methods (for example cone slump method) are inapplicable for Self Compacting concrete. In this case a new consistency determination methods are used: cone flow test (Fig. 5) and L-box test (Fig. 6). These methods indicate mix flowing and self-leveling capacity, these methods are approved as future European standards (Draft prEN 12350-8, Drafr prEN 12350-10).

Concrete mixes with glass powder are characterized with good flowability, high homogenity and reduced segregation risk. SCC2 concrete containing raw glass powder has 11% lower compressive strength then concrete SCC1 with dolomite powder. Additionally, ground glass powder increases strength by 11% comparing to standard mix.

Table 5. Mix proportions and concrete strength for Self Compacting concrete

	SCC1	SCC2	SCC3
Cement CEM I 42.5 N	420	420	420
Coarse aggregate 2/20 mm	850	850	850
Sand 0/4 mm	574	574	574
Dolomite powder	190		
Glass powder		190	
Extra ground glass (60 min.)			190
Superplasticizer	6.5	6.5	8.5
Water	195	210	200
Paste content (% by vol.)	40.7	42.3	41.2
Cone flow, mm	740	820	756
Passing ability (PA=H2/H1)	0.88	0.96	0.90
Compressive strength, MPa (28 days)	67.9	60.2	75.4

Fig. 5 Cone flow test (mix SCC2)

Fig. 6 L-box test (mix SCC1)

5. Conclusions

Bore-silicate glass waste is investigated with aim to use this material for producing concrete.

Cement replacement by roughly ground bore-silicate glass powder reduce compressive strength of conventional concrete. Workability of concrete mix containing glass filler is good and mix has tacky consistency.

Additionally (60 min.) ground glass powder demonstrates compressive strength increasing by 27% comparing with mix based on raw glass powder. Long-term hardening effect may be explained by activating of puzzolanic reactions with cement components. The best effect (44% strength improvement) gives complex admixture additionally ground GP with silica fume.

Bore-silicate lamp glass powder succesfully may be used as effective micro-filler for Self-Compacting concrete as replacing material of expansive traditional micro filler.

Durability and physical properties of concrete containing glass powder must be investigated in the future in a more detailed way.

Acknowledgement

The financial support of Ministry of Education and Science of Republic of Latvia and Riga Technical University is acknowledged.

References

Jin W., Meyer S., Baxter S. 2000 Glassconcrete – concrete with glass aggregates. *ACI Material Journal*, 97(2): 208 – 213.

Schwarz N., Neithalath N. 2008. Influence of a fine glass powder on cement hydration: Comparision to fly ash and modeling the degree of hydration. *Cement and Concrete Research*, 38: 429-436.

Shao Y., Lefort T., Moras S., Rodriguez D. 2000. Studies on concrete containing ground waste glass. *Cement and Concrete Research*: 30, 91-100.

Shayan A. 2002. Value-added utilisation of waste glass in concrete. In *Proc. of IABSE symposium*, Meulborne, 2002, 384-385 (abstract, full paper in CD).

Shayan A., Xu A. 2006. Performance of glass puzzolanic material in concrete: A field trial on concrete slabs. *Cement and Concrete Research*, 36: 457-468.

Siddique R. 2008. Waste materials and by-products in Concrete. Berlin, 427 p. ISBN 978-3-540-74293-7

Okamura, H., Ozawa, K. 1995. Mix design for self-compacting concrete. *Concrete library of JSCE,* 25: 107 – 120.

The European guidlines for self-compacting concrete. Specification, production and use. Brussels, 2005., 63 p.

Draft prEN 12350-8. Testing fresh concrete – Part 8: Self-compacting concrete–Slump-flow test. Brussels, 2007. 8 p.

Drafr prEN 12350-10. Testing fresh concrete – Part 10: Self-compacting concrete – L-box test. Brussels, 2007. 7 p.

Drafr prEN 12350-9. Testing fresh concrete – Part 9: Self-compacting concrete – V-funnel test. Brussels, 2007. 6 p.