# BORE-SILICATE GLASS WASTE OF LAMP AS A MICRO-FILLER FOR CONCRETE

# LAMPU BORSILIKĀTA STIKLA ATKRITUMU PIELIETOJUMS BETONĀ KĀ MIKROPILDVIELAS

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## 1. Introduction

Investigations on glass waste utilization and applying this one as a filler in concrete mixes have been investigated by many researchers in previous years [1, 2]. 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 study is bore-silicate glass remaining after fluorescence lamp utilization. Glass rational utilization problem is actually over the world. 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.
On of a way of glass waste utilization is application of it as concrete filler. Previous investigations indicate, that glass can be used not only as filler in concrete, but also as an active component in concrete that initiate reaction with cement minerals. A coarse crushed glass used as concrete aggregate can issue the alkali-silicate reactions in the hard concrete, resulting harmful expansion in interface between cement and glass surface [3]. In the same time it is proven that grinded glass particles (<75 μm) may be beneficial component in concrete. Glass micro-filler initiate puzzolanic reaction and harmful deformations in this case doesn't exist [4].
At present new types of concrete products heve been introduced, such as Pumping concrete, Self-Compacting Concrete (SCC), High Performance concrete (HPS) e.t.c have been introduced. The new types of concrete are multi-component mix systems. Special requirements for aggregate grading must be taken into account and especially fine particles (so called "micro filler") content should be controlled. 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, such as ground glass waste, is very actual task nowadays.
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.

## 2. Materials

The object of this investigation is recycling material obtained from bore-silicate lamp glass. Lamp recycling process includes lamp classification, glass separation, cleaning from harmful components and grinding. The waste product is white powder 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.

Chemical composition glass waste **Table 1**

| Components | Content (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 | - |

Particle size distribution of material was made by laser diffraction analysis method. Testing materials was dispersed in water using ultrasonic bath. Three samples of glass waste have been tested and minimal difference between results has been observed. 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.

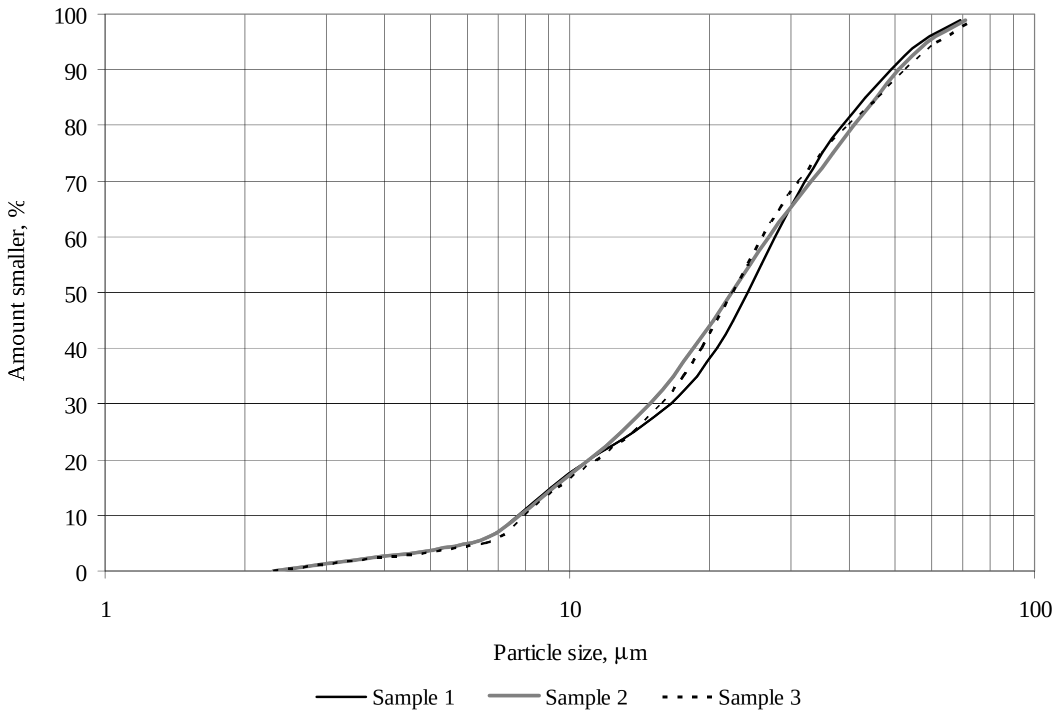



**Fig.1.** Distribution of granulometric curve of ground lamp glass particles

## 3. Mix compositions and sample testing

The program of this study provides carrying out experiments on the base of conventional concrete mixes having strength class from C20/25 … C35/45. Laboratory mixes were designed close to concrete mix commonly used in industry as a pumping concrete. Normal moderate hardening Portland cement CEM I 42.5 N was applied as binding agent. Dolomite based natural gravel has been used for preparation of mixtures. Coarse and fine sand combination was applied as fine aggregate of a concrete. Proportions between aggregates was elaborated 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 pumpabilited mix of 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. Due to this fact the investigation of ground glass waste influence on the properties of concrete is very important task for improving a concrete technology.

The experimental work consists on three parts. Cement has been replaced by ground glass in the first part of experiments. Four mixes have prepared, where of 0, 10, 20, 40 % of cement has been replaced. In the second series of samples the glass powder has been added to concrete as sand replacement. In the third stage the ground glass and different micro-fillers have been applied in different proportions in concrete mixes.

Mix proportions are summarized in Table 2, Table 3 and Table 4.

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 has been added to the mix during mixing as last component.
Mixes were tested for workability using slump test. Water dosage is selected to provide cone slump in range 50 ... 100 mm.
It was observed the concrete mixes containing ground glass has more tacky consistency in comparison with conventional concrete mix. In the same time mixes with glass requires little bit more water for obtaining the similar workability.
Standard testing samples cubes 100 x 100 x 100 mm have been produced for investigation the physical and mechanical characteristics of the concrete. Concrete mixtures have been 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 %) have been provided for the samples. Sample measurements and testing have been performed after the 7, 28, 84 and 112 day ageing period in the standard conditions.
The samples have been tested on compression strength in conformity with LVS EN 12390-3:2002. The compressive strength has been tested by testing machine with accuracy ±1%, the rate of loading was 0.7 MPa/sec.

**Table 2**

Mix proportions with ground glass 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 |
| Ground glass | 0 | 38 | 76 | 114 | 152 |
| Water | 214 | 213 | 213 | 214 | 216 |

**Table 3**

Mix proportions with ground glass admixture as sand replacement

| | **SC0** | **SC5** | **SC10** | **SC20** | **SC30** |
|---|---|---|---|---|---|
| Cement CEM I 42.5 N | 350 | 350 | 350 | 350 | 350 |
| Gravel 10/20 mm | 520 | 520 | 520 | 520 | 520 |
| Gravel 2/10 mm | 485 | 485 | 485 | 485 | 485 |
| Sand 0/4 mm | 725 | 725 | 725 | 725 | 725 |
| Ground glass | 0 | 17.5 | 35 | 70 | 105 |
| Water | 200 | 200 | 200 | 200 | 217 |

**Table 4**

Mix proportions with different micro-fillers

| | **S0** | **SD** | **S60** | **CC** | **SF** | **S60SF** |
|---|---|---|---|---|---|---|
| Cement CEM I 42.5 N | 380 | 380 | 380 | 380 | 380 | 380 |
| Gravel 2/10 mm | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| Sand 0.3/2.5 mm | 650 | 650 | 650 | 650 | 650 | 650 |
| Sand 0/1 mm | 120 | 120 | 120 | 120 | 120 | 120 |
| Ground glass | 80 | | | | | |
| Dolomite powder | | 80 | | | | |
| Additionally (60 min.) ground glass | | | 80 | | | 40 |
| Additional cement as micro-filler | | | | 80 | | |
| Silica fume | | | | | 80 | 40 |
| Superplasticizer | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 |
| Water | 214 | 213 | 213 | 214 | 216 | 200 |

## 4. Results and discussions

In the first series of samples cement was partly replaced by glass filler. 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 ground glass filler. Required water content differs fractionally for all mixes. The effect of strength decreasing can be interpreted by increasing in water cement ratio.

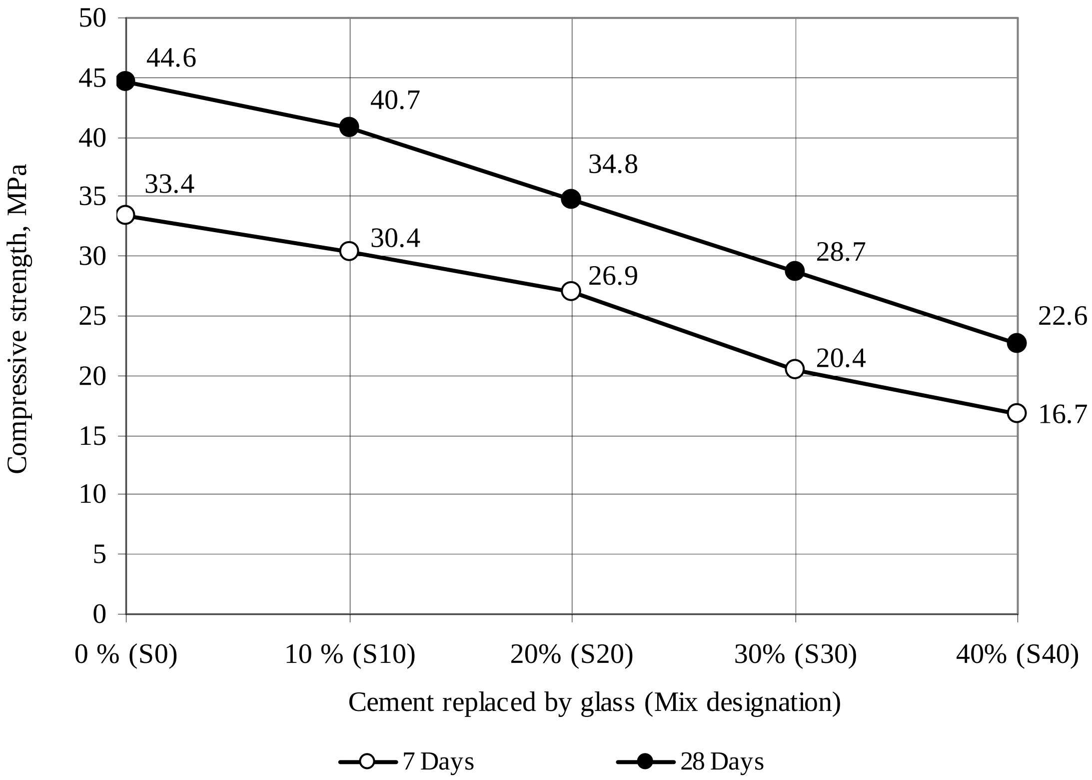



**Fig. 2.** Cement replacement by grounded lamp glass: compressive strength test results

In the second series investigation sand has been partly replaced by glass filler. Results obtained from the tests of specimens show nonessential affect of glass filler on concrete compressive strength after 7 and 28 days hardening. It must be noted that effect of glass filler become apparent after 112 days of hardening (increasing of the compressive strength). This behavior of material can be explained by puzzolanic reactions between glass and cement components during long-term hardening process.

The next stage of investigations devoted to evaluation and comparing influence of glass filler and other traditionally used fine materials, such as dolomite powder and silica fume on the mechanical properties of concrete. All concrete mixtures contain micro-filler in amount 80 kg/m$^3$ as well as superplasticizer (Tab. 4). The first basic mix (S0) contains bore-silicate glass filler (LGP). Mixes SD and SF comprise dolomite powder or silica fume fillers correspondingly. In the framework of experiment the effect of additional glass grinding was investigated. Bore-silicate glass powder was additionally ground in laboratory planetary ball mill during 60 minutes. Additionally ground glass was used as micro-filler in mix S60. Mix S60SF presents complex filler containing additionally ground (during 60 minutes) glass and silica fume in proportion 1:1. In mix CC micro filler was replaced by additional amount of cement, this composition was used to compare the effect of different micro fillers. Compressive strength results are summarized in Figure 3.

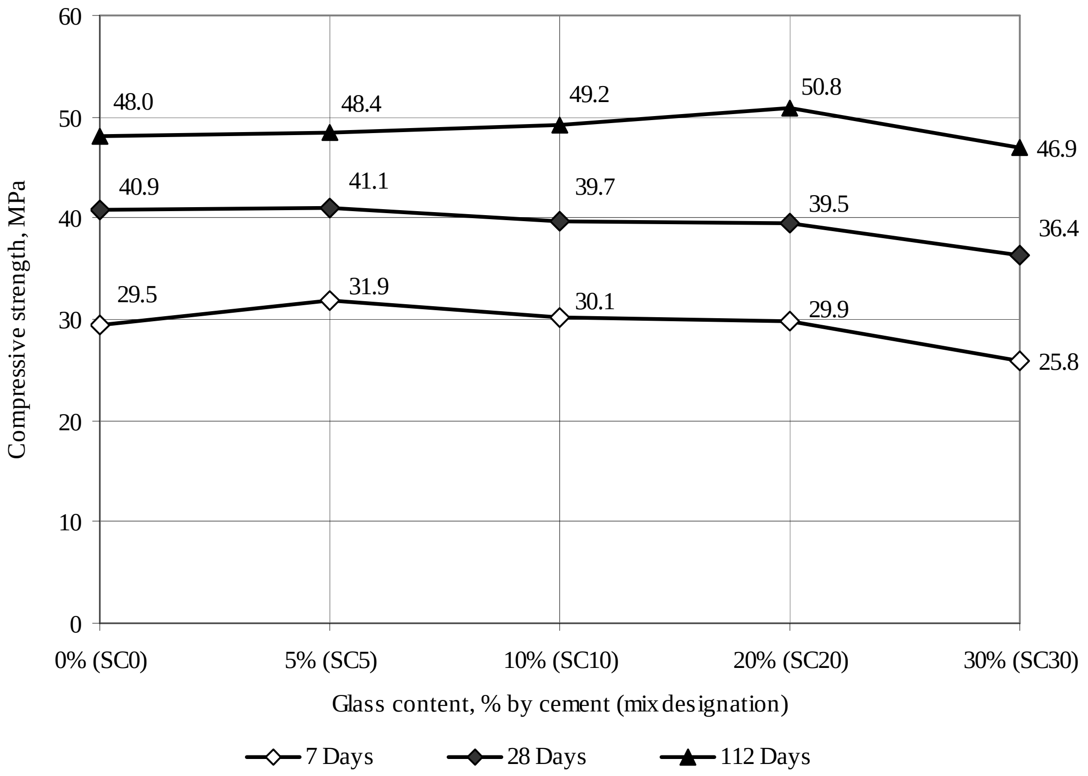



**Fig. 3.** Sand replacement by grounded lamp glass: compressive strength test results

Comparing obtained results (Fig. 4), the minor effect on compressive strength is observed in the case of untreated glass powder (mix S0) and dolomite powder as micro filler (mix SD).

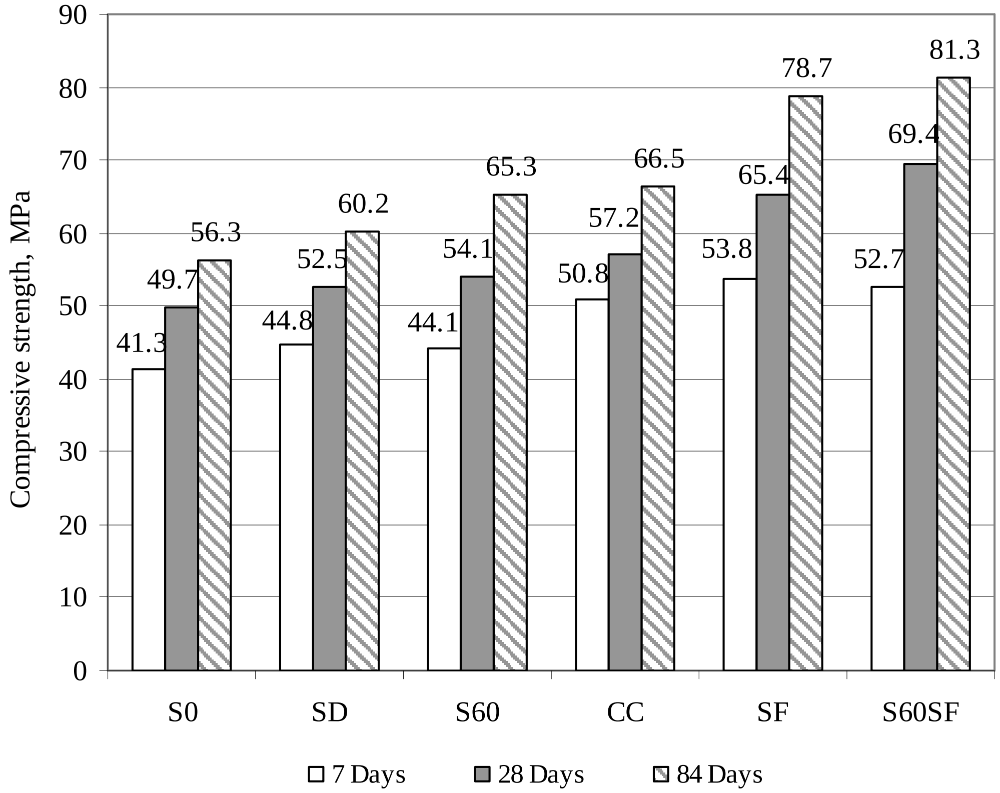
The experimental results indicate a good positive effect of additionally ground glass filler, especially after long term hardening. For example, adding 80 kg/m$^3$ of ground 60 minutes in the planetary ball mill glass (mix S60) gives the same effect after 84 days as adding the same amount of cement (mix CC).

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 112 days hardening process. Mixes SF and S60SF may be classified as high strength concrete in accordance with standard LVS EN 206-1:2000 classification.

It may be summarized, that one of the effective ways of bore-silicate glass waste utilizing in concrete is applying the ground glass, as active micro filler. Grinding process increase specific surface of material, thus additional activation of puzzolanic reactions and hardening processes could be achieved. It may be supposed glass additional grinding can issue changing a size of particles and packing of micro filler material. Ground glass particle shape, packing and grading curves in micro level should be investigated particularly in future.

Ground glass filler may be used as admixture in small amount (20...100 kg/m$^3$) for plain concrete with aid to improve workability, for example in ready-mix technology for pumpable concrete. Additional investigation should be made in this direction.

Durability characteristics such as freeze-thaw resistance, water permeability and chemical resistance of concrete with content of ground glass have been not investigated till now and are subject for future research.




*Mix designations:*
SO – Glass filler standard;
SD – Dolomite powder (grinded dolomite);
S60 – Glass filler additionally grinded during 60 minutes;
CC – Microfiller replaiced by additional cement amount;
SF – Silica Fume;
S60SF - Glass filler additionally grinded during 60 minutes combination with Silica Fume (50/50).

**Fig. 4.** Effect of different micro fillers: compressive strength test results

## 6. Conclusions

Bore-silicate glass waste has been investigated with aim to use this material for producing concrete. Glass has been ground in the different rate and applied as fine filler and micro-filler in concrete mix replacing traditional sand or cement correspondingly.
Replacement of cement by fine ground reduced compressive strength of concrete. Workability of concrete mix containing glass filler is good, but mix has tacky consistency.
By replacing traditional sand by ground glass as filler to concrete mix in range 5 ... 20 % glass filler by cement mass the mechanical characteristics of concrete can be improved and mix workability can be achieved.
Concrete mixes containing ground bore-silicate glass perform long-term hardening effect, which may be explained by puzzolanic reactions with cement components.
Bore-silicate glass may be used for producing concrete as fine filler replacing traditional sand and as micro filler after activation by additional grinding replacing cement or as admixture.

**Aknowlegements**

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**Šahmenko G., Korjakins A., Būmanis Ģ. Lampu borsilikāta stikla atkritumu pielietojums betonā kā mikropildvielas.**
*Lampu stikla racionālās utilizācijas problēma ir aktuāla visā pasaulē. Darbā tiek pētīta iespēja izmantot samaltus borsilikāta lampu stikla atkritumus kā mikropildvielu parastām betonam. Tika veiktas trīs eksperimentu sērijas. Bija izgatavoti betona testēšanas paraugi, kuri pārbaudīti uz spiedi 7, 28 un 84 (112) dienu vecumā. Pirmā eksperimentu sērijā daļa no cementa tika aizvietota ar samaltu stiklu. Rezultātā konstatētas betona stiprības samazināšanās atbilstoši aizvietota cementa daudzumam. Otrā eksperimentu sērijā stikls pievienots virs cementa kā smilts aizvietotājs. Rezultātā tika novērots stiprības neliels pieaugums, ka arī maisījuma iestrādājamības uzlabošanās sastāviem, kas satur 5 līdz 20 % samalta stikla. Trešajā eksperimentu sērijā tika salīdzināti betoni ar samalto stiklu un citām tradicionālām mikropildvielām, kā arī pētīts efekts no stikla papildus samalšanas. Eksperimentālie rezultāti parādīja labu pozitīvu efektu, kas dod stikla pulvera papildus samalšana. Augstākie spiedes stiprības rādītāji (ap 67 MPa 28 dienu vecumā un 80 MPa 112 dienu vecumā) iegūti sastāvam ar mikrosilīciju un ar kompleksa piedevu mikrosilīcijs ar papildus samalto stiklu attiecībā 1:1. Sastāviem, kas satur mikrosilīciju vai samalto stiklu, ka arī tās kombinācijas konstatēts ievērojams stiprības pieaugums ilgstošā cietēšanas periodā, kas norāda uz pucolāna reakcijām ar cementu. Veikto eksperimentu rezultātā var secināt, ka samaltais lampu borsilikāta stikls var tikt izmantots kā efektīva piedeva betonam, bet to plašākai izmantošanai ir nepieciešams detalizēti izpētīt daļiņu granulometrisko sastāvu mikro līmenī, papildus samalšanas iespējas un iegūta betona ilgmūžības īpašības.*

**Šahmenko G., Korjakins A., Būmanis Ģ. Bore-silicate glass waste of lamp as a micro-filler for concrete**
*Lamp glass rational utilization problem is actually over the world. The possibilities for use lamp bore-silicate glass as concrete micro-filler have been investigated in this work. Tree experimental series was carried out. Experimental standard concrete samples was prepared and tested after the 7, 28, 84 (112) day ageing period in standard condition. The first part of experiments provides using ground glass as cement replacement. Experimental results indicate decreasing in compressive strength when part of cement was replaced by ground glass filler. The second experimental series presents adding glass filler additionally to cement as sand replacement. Experimental results indicate nonessential strength increasing after 7 and 28 days hardening for mix containing 5 ... 20 % ground glass by cement. The next stage of investigations provides to compare behavior of glass filler and other traditionally used fine materials, effect of glass additional grinding also was investigated. The experimental results indicate that glass powder additional grinding gives positive effect on strength characteristics. The best compressive strength results (approx. 67 MPa in 28 days and 80 MPa in 112 days) were achieved by using silica fume as micro filler and silica fume combination with additionally ground glass as complex admixture. Concrete mixes containing microsilica and ground bore-silicate glass perform long-term hardening effect, which may be explained by puzzolanic reactions with cement components. Summarizing results of investigation it may be concluded that ground bore-silicate lamp glass succesfully may be applied as microfiller for concrete. In the same time additional investigations on micro filler grading and grinding conditions must be made in future. Obtained concrete durability characteristics also must be investigated.*

**Шахменко Г., Корякин А., Буманис Г. Использование отходов лампового боросиликатного стекла в качестве микронаполнителя бетона.**

*Утилизация отходов флуоресцентных ламп является серьезной проблемой в Европе и во всем мире. В данной работе исследуется возможность использовать перемолотые отходы лампового боросиликатного стекла в качестве микронаполнителя для обычного бетона. Были проведены 3 серии экспериментов. Готовились бетонные образцы, которы испытывались на прочность при сжатии в разные сроки твердения. В первой серии часть цемента замещалось молотым стеклом. В результате наблюдалось понижение прочности соответственно замещенной доли цемента. В случае добавки молотого лампового стекла сверх массы цемента (в количестве до 20%) наблюдалось незначительное увеличение прочности, а так же улучшение удобоукладываемости смеси. В третьей серии сравнивались бетоны с миконаполнителем из молотого стекла и с традиционными микронаполнителями, а так же исследовалась возможность дополнительного домола стекла. Установлено, что дополнительный домол стеклянного порошка положительно влияет на прочностные характеристики бетона. Наилучшие прочностные характеристики получены для состава с микросиликой и комплексной добавкой микросилика с домолотым стеклом 1:1 – около 67 в возрасте 28 дней и 80 MPa - 112 дней. Для составов с молотым стеклом наблюдался значительный прирост прочности после 28 суток твердения, что указывает на пуццолановые реакции между молотым стеклом и цементом. Как заключение отмечено, что молотое ламповое боросиликатное стекло может быть хорошей добавкой в бетон, но для эффективного его применения неоходимо более детально исследовать гранулометрию частиц в микро диапазоне, возможности дополнительного домола, а так же исследовать долговечность полученного материала.*