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Recycling of Glass Wastes in Latvia – Its Application as Cement Substitute in Self-Compacting Concrete

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The rate of treated waste glass within the last 10 years has risen up to 25% due to improved waste glass collecting system in Latvia, however the glass waste recycling infrastructure is still up to date issue due to absence of local recycling companies. Application of glass wastes as cement substitute has significant effect on the properties of concrete making it eco-friendly construction material with several benefits like: decrease of accumulated glass wastes in landfills, the reduction of non-renewable natural resource consumption, the reduction of cement content up to 20–30% and the reduction of greenhouse gas emission. In the present investigation was evaluated the effectiveness of ground soda-alkaline earth-silicate glass coming from low pressure mercury-discharge lamp waste chips, borosilicate glass coming from incandescent light bulb waste chips, soda-lime glass cullet coming from beverage containers on workability, compressive strength and frost resistance of self-compacting concrete.

Keywords: *glass wastes, SCC.*

1. Introduction

Recycling of glass wastes in Latvia

Approximately 50,000 tonnes of glass packaging waste is generated annually in Latvia (see table 1). There are no recycling facilities for glass in Latvia (ec.europa.lv), most of the glass waste is landfilled or exported by several companies dealing with preparation of glass for re-use to the neighbor countries. The opportunities for the recovery and recycling of different packaging waste vary between the countries. In Latvia, there is the only one lamp recycling centre in the Baltic States located in Liepaja, which in 2012 recycled 159 tonnes of lamp glass waste (see Fig. 1).

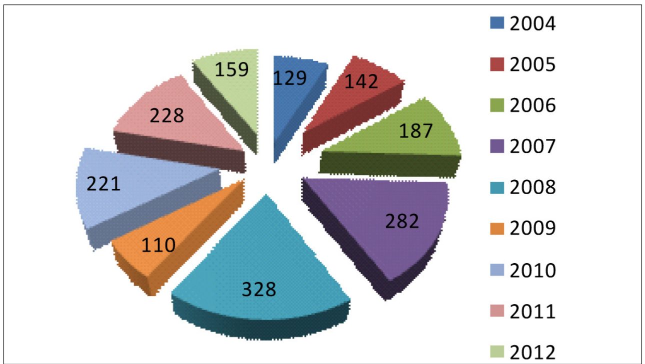

Fig. 1. *Incandense lamp and fluorescent tubes recycling statistics (www.meteo.lv)*

In Estonia, glass packaging factory exists (Jarvakandi klaas), but it requires a very good quality (the quality from the glass collected through the deposit system is good, but the quality from the glass collected through the containers is mostly not good enough (mixed glass)) and does not accept the green glass. Some of the glass is used to produce street pavements, stones etc, the rest is still exported. Several other recycling projects are in a certain stage, getting 50% support from the EU Cohesion program. But they are still unable to proceed, as there is no clarity around the waste sector is still too big for the financial institutions to provide rest of the financing (ec.europa.ee). There are four glass recycling companies in Lithuania (CJSC "Kauno stiklas", JSC "Warta Glass Panevėžys", CJSC "Alytaus keramika", CJSC "Stikloporas") which have quite a high glass recycling capacity (54.7 kt/a) (ec.europa.lt), thus, this waste is even imported.

In conjunction with economic growth and increased consumption, packaging amounts (defined as all products made of any materials of any nature to be used for the containment, protection, handling, delivery and presentation of goods that, when discarded) ending up in waste streams during all this time were increasing. Packaging waste was generated along with municipal waste (household and commercial waste). Due to a lack of a separate collection system, packaging waste has mainly been disposed of at

Table 1. *Packaging waste recycling statistics in Latvia within 2003–2011 years (Statistical reports 2005–2013)*

Year	Latvian purchased glass packaging waste (t)	The imported glass packaging waste (t)	Exported glass packaging with goods (t)	Generated glass packaging waste (t)	Reused glass packaging waste (t)	The collected glass packaging waste (t)	Glass packaging waste exported for recycling (t)	Glass packaging waste recycled in Latvia (t)	The total volume of recycled glass packaging (%)	Reclaimed glass packaging waste (t)	Reclaimed glass packaging volume (%)
2003	32585	45034	15826	62193	29010	15829	3333	12523	26	15856	26
2004	44416	55817	18307	73771	27201	24014	7474	14503	30	11851	16
2005	260	4	110	58565	----	----	5786	21558	47	----	----
2006	9682	19445	16609	63639	5173	----	10970	23998	55	----	----
2007	9202	30592	4555	78973	87	----	13122	22917	46	10	----
2008	----*	----	----	66788	----	----	15324	35424	----	----	----
2009	----	----	----	44323	----	----	6692	19690	----	----	----
2010	----	----	----	51896	----	----	7648	24704	----	----	----
2011	----	----	----	51967	----	----	7731	26814	----	----	----

* ---- data is not reflected in the reports

landfills. Although certain steps to promote recovery and recycling have been taken, comprehensive reporting on the whole packaging waste management chain has not been performed. The total amount of separately collected packaging waste was less than 5% of the total municipal waste stream in 2002. And that indicated a weakness in the existing reporting/collection system. When, for example, Estonia introduced an excise tax on beverage packaging in 1997, with the goal of increasing recovery and recycling, due to high tax rate, almost all of the companies fulfilled packaging waste recovery targets.

In 2003 a new instrument – a deposit system for glass bottles - to increase reuse of refillable glass packaging was introduced in Latvia. The packaging waste management system in Latvia became based on the "producer responsibility" principle - producers and importers are required to organise the packaging waste management system. There were recently founded packaging management organisations whose aim is to improve the situation by establishing separate collection systems also promoting the collection and primary sorting of packaging waste due to that mostly depends on the goodwill and awareness of the public, as so called habit of each citizen to sort wastes at the first place. In 2013 waste sorting (mainly waste glass and plastics) has become more popular in Latvia than it was in the previous years. This is evidenced by presence of special waste separation containers and drop-off points for wastes in Latvia. However, there is still absence of factories that could recycle glass wastes and Latvian recycling infrastructure is based mostly on limited operations like: waste glass collection, sorting and export to EU. As there is absence of data in statistics, as it can be seen from Table 1, there is no complete statistics on waste glass collected and recycled amount in Latvia, according to the regulations the total amount which should be recycled yearly is 50%, and that is shown but other items are not reflected in the last year reports.

According to Eurostat statisticdata available, the amount of collected waste glass (container) from 2008 to 2011 year increased approximately 2 times. This can be explained by the fact that Latvian population became more interested in the clean environment, more information about sorting and recycling were delivered to the public. Also Eurostat statistics shows progress for 2010 in Latvia, the amount of collected glass was 8848 t and the amount of treated glass waste was 2800 t and that is 30%, which is better result than in 2002. In 2012 were collected around 9200 t of waste glass (container glass and other separately collected glass), 22 t were treated and 49 t were disposed in landfills. The rest of waste glass was, probably, exported to other countries: Lithuania, Belorussia, Ukraine and Poland. However, amount of collected waste container glass decreased in 2012, while the total amount of collected waste glass increased.

Application of waste glass powder as cement substitute in self-compacting concrete

Rapid depletion of resources and concerns over degradation of the environment has led to a growing emphasis on sustainable development (Meyer, 2002). As a result, the construction industry is required to adopt environmentally friendly practices and make judicious use of natural resources. The most important political development over recent years has been the increasing commitment by industrialised countries to reduce CO_2 emissions (Damtoft *et al.*, 1999). Portland cement production is third largest contributor of CO_2 emissions after the energy and transportations sectors (Hansen *et al.*, 2007). For every tonne of Portland cement produced, cement plants generate approximately one tonne of carbon dioxide (Davidovits, 1993). The concrete industry can address growing environmental and energy concerns by minimizing the cement content in concrete required to meet the required performance levels; this goal can be accomplished by replacing as much of Portland cement as possible with pozzolanic supplementary cementitious materials (SCMs) (Meyer, 2009).

Recycling of glass waste by converting it to aggregate not only saves landfill space but also reduces the demand for extraction of natural raw material for construction activity (Rakshvir and Barai, 2006). If 30% of Portland cement is replaced with waste glass in good structural concrete made with 320 kg/m^3 of Portland cement then CO_2 emissions into atmosphere will be reduced from 0.41 to 0.29 tonnes of green house gas emissions. A number of research studies have been performed within the last years. Park et al. (2004) reported that the compressive, tensile, and flexural strengths of concrete containing waste glass as fine aggregate demonstrated a decreasing tendency with increase in the mixing ratio of the waste glass. Dyer (2001) reported that cullet from container glass clearly undergoes a pozzolanic reaction when combined with Portland cement up to 30 % replacement in concrete without any long term detrimental effects. The influence of supplementary cementitious materials like fly ash and waste glass has impact on workability and can significantly improve rheological properties. The effects of particle size on reactivity of pozzolanic SCMs and glass has been demonstrated (Day, 1994; Shi, 2001), where increased fineness led to an increase in early age compressive strength, even in the absence of activators. In some cases, the compressive strength of specimens made with glass powder as an SCM demonstrated a higher compressive strength than those made with an equivalent amount of fly ash (Shao et. al., 2000; Schwarz, 2008).

Concrete durability to a large extent depends on its mechanical strength, which in turn depends on the concrete mixture proportions as well on the placing conditions. In fact, concrete mechanical strength increases by decreasing the mixing water for a given cement amount, but the less the water is in the concrete mixture, the more the concrete placing is difficult due to its workability loss. Self-compacting concrete with a certain amount of very fine glass particles as a filler, together with a viscosity modifying agent able to keep fresh concrete viscous enough to avoid bleeding and segregation (Corinaldesi and Moriconi, 2005). One of the commonly used filler to increase packing density is condensed silica fume which is a relatively high cost material. In the recent years waste glass powder ground to particle size less than 100 μm (no alkali-silica reaction had been detected with particle sizes up to 100 μm (Corinaldesi et al., 2005)) in a dry environment or in a wet environment to receive finer particle size (Kara, 2013) becomes quite popular material to substitute cement and aggregates.

Wood ash used as a partial replacement for ordinary Portland cement at replacement levels up to 10 % by total binder weight can produce structural grade concrete or mortar with acceptable strength properties (Ban and Ramli, 2011). A major portion (approximately 70 %) of the wood waste ash produced is landfilled as a common method of disposal. As wood waste ash consists of highly fine particulate matters, which can be easily rendered airborne by winds, such a means of waste disposal may result in subsequent problems, namely, respiratory health problems to residents dwelling near the disposal site of the ash material. Hence, disposal of wood waste ash by means of landfilling require a properly engineered landfill which have implications in terms of the cost of disposal.

2. Materials and Methods

A commercial Portland cement CEM I 42.5N (Bogue calculation from XRD C_3S – 5.4, C_2S – 19.3, C_3S – 51.7, C_4AF – 9.9, gypsum – 5.0) was used. Portland cement compressive strength at the age of 28 days was 55 MPa, initial setting time 102 min, final setting time 202 min.

Fig. 2. *Container glass recycling process in laboratory conditions*

Portland cement was substituted at 2 levels – 20 % and 30 % with waste glass powder or bottom ash per mass of Portland cement. Soda-alkaline earth-silicate glass (named as LB) coming from low pressure mercury-discharge lamp waste chips, borosilicate glass (named as DRL) coming from incandescent light bulb waste chips, soda-lime glass cullet (named as A – amber colour glass bottles, G – green colour glass bottles, F – flint colour glass bottles) coming from beverage containers crashed manually under laboratory conditions were used for production of waste glass powder (see Fig. 2).

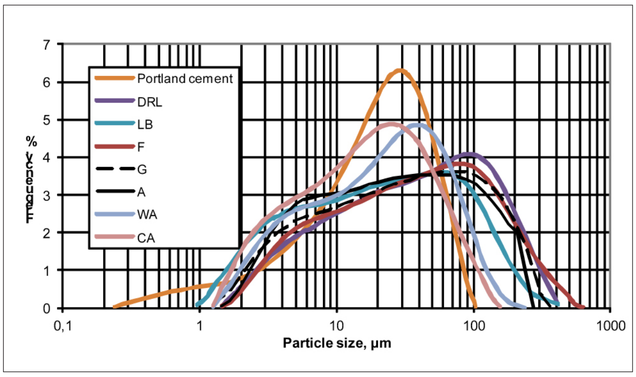

Fig. 3. *Grading curves of waste glass powders, bottom ashes and Portland cement used in the study*

Waste glass chips were washed, dried and ground for 30 minutes into powder in laboratory planetary ball mill Retsch PM400 (with rotation speed 300 min^{-1}). Sika ViscoCrete D 132-2 plasticizing agent was employed for preparing concrete mixes at a dosage of 1.8 % by weight of cement. Local gravel and sand from natural sources were used in the experimental work. The used gravel had

Table 2. *The chemical composition and fineness of glass waste powders, ashes and Portland cement*

Name	Bulk oxide, mass (%)											Fineness m^2/kg
	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	MnO	MgO	TiO_2	SO_3	P_2O_5	
Portland cement	20.31	4.13	3.26	60.64	0.51	1.07	0.05	2.06	0.34	2.95	0.12	389
DRL glass powder	71.14	2.60	0.17	1.320	3.30	1.70	0.006	0.62	0.006	0	0.023	608
LB glass powder	65.52	1.22	0.11	5.11	12.35	1.88	0.01	2.95	0.027	0.14	0.038	542
Flint glass powder	69.61	1.34	0.08	11.30	11.21	0.56	0.008	0.46	0.028	0.13	0.021	502
Green glass powder	67.8	1.53	0.36	10.93	11.09	0.55	0.018	1.58	0.06	0.04	0.02	463
Amber glass powder	69.26	1.42	0.36	10.93	11.43	0.55	0.02	3.08	0.06	0.04	0.02	542
Wood ash	40.69	14.1	8.29	13.5	0.43	1.34	0.178	3.49	0.631	0.55	0.745	660
Coal ash	59.93	3.59	1.91	20.42	1.27	5.36	0.47	3.5	0.193	0.02	1.72	849

a nominal maximum size of 11.2 mm. The used sand had a nominal size of 1mm and 2,5mm. Bottom coal ash (named as CA) and wood ash (named as WA) were obtained from local sources in Latvia. The chemical composition and fineness of waste glass and bottom ashes measured in conformance with EN 196-6 (Blaine method) are given in Table 2. Particle size distribution of waste glass powders, ashes and Portland cement is shown in Figure 3.

Fifteen different SCC concrete mixtures were produced: one reference mixture, 10 mixtures with 20% and 30% Portland cement substitution with waste glass (DRL/LB/amber/green or flint) and 4 mixtures with 20% and 30% Portland cement substitution with bottom ash (coal or wood) (see Table 4). All mixtures were essentially self-compacting concrete and the mixture composition was constant for all mixtures, w/c = 0.4 was applied for reference mixture and water/binder = 0.4 was applied for mixtures with Portland cement substitution with waste glass powder or ashes. Reference mixture composition (kg/m^3): cement – 450, silica fume – 80, sand 0.3/2.5mm – 600, sand 0/1mm – 360, gravel 4/11.2mm – 700, water – 180, plasticizer – 8. The mixing of concrete batches was performed in the spiral vortex concrete mixer for 3 minutes (see Fig. 4).

Tests were conducted on fresh concrete to determine the slump flow (BS EN 12350-8:2010), L box ratio (LVS EN 12350-10:2010) and V – funnel values (BS EN 12350-9). For each concrete mixture, three 100·100·100 mm concrete specimens were cast into the steel moulds for the determination of compressive strength. After casting all concrete specimens were covered with polyethylene wrap. After 36 hours specimens were removed from the moulds and cured in water tank for 28 days in a curing chamber (at temperature +20±2°C and relative humidity ≥95%) until the tests were carried out. Compressive strength of concrete specimens was determined at the age of 7, 28 and 90 days according to LVS EN 12390-3:2009.

The frost resistance tests were carried out in accordance with ГОСТ 10060.0-95, ГОСТ 10060.1-95, ГОСТ 10060.2-95 and ГОСТ 26134-84. Accelerated frost test method was used and strength losses in the specimens were measured recording the ultrasonic velocity changes; further details of the specimen preparation and method description are available in (Kara, 2013). Concrete specimens which were subjected to frost tests had prismatic shape with internal dimensions of 60·60·180 mm. Three specimens per each mixture were prepared.

All specimens were marked with measuring points – 4 points forming two diagonals on two opposite long sides of the specimens and 1 centre point on each short side in order to record the ultrasonic velocity in the same places. One diagonal length is 15 cm, which is a tuner base at the same time (distance between the contact elements) for portable tester "UK-1401" (see Fig. 5). For the most accurate results, the ultrasonic velocity of each diagonal was measured 3 times.

The concrete specimens were saturated in 5% salt-water at a temperature of 18 ± 2°C for 3 days, on 4th day ultrasonic pulse velocity and weight measurements were performed before freeze-thaw cycling. Specimens freezing procedure was carried out in accordance with ГОСТ 10060.1-95 in the climatic chamber ILKA KTK-800 (VEB Maschinenfabrik Nema Netzschkau, 1988) at a temperature –18 ± 2°C and thawing in 5% salt-water at a temperature of 18 ± 2°C. Decrease of ultrasonic velocity and mass of the specimens were recorded after 8th, 13th, 20th, 30th and 45th cycle. If the decrease of ultrasonic velocity didn't exceed 5% and decrease of weight didn't exceed 3%, it is considered that the specimen has passed number of cycles and frost resistance tests were continued.

Fig. 4. *Concrete batch mixing in the spiral vortex concrete mixer*

Fig. 5. Prismatic shape concrete specimens for frost resistance test

3. Results and Discussion

In order to have better overview of the effect on concrete mixture workability of application of different waste glass powders and ashes as Portland cement substitutes Vicat needle penetration measurements were carried out on cement pastes containing waste glass powders and ashes according to BS EN 196-3 and performed on ZWICK/Roell ToniSet automatic Vicat needle instrument. The results are shown in Table 3 and indicate that waste glass powders and ashes have a retarding effect on setting. It can be seen that the substitution of Portland cement at levels from 20% to 30% with waste glass can significantly increase the workability of concrete, especially for concrete mixtures with 30% Portland cement substitution. This attributed to the weaker cohesion between the glass aggregates and the cement paste due to their smooth surfaces. In the case of the paste containing F glass (20%), the initial setting time was delayed by 11 minutes relative to the reference CTRL paste. In the case of the paste containing LB glass (20%), the initial setting time was delayed by 31 minutes relative to the reference CTRL paste. F glass performed worse workability and LB glass performed the best workability in comparison to other four glasses.

It was observed that concrete mixture with DRL waste glass powder is always more viscous than concrete mixture with LB waste glass powder. Initial setting time of LB cement paste was delayed for 14 minutes in comparison to DRL cement paste. In the case of the paste containing bottom ashes, the initial setting times were delayed up to 51 minutes when the level of substituted cement was lower and was 20%. It could be described by high water absorption of bottom ashes in concrete mixture, especially of coal bottom ashes.

All concrete mixtures had slump flow over 600 mm (see Table 4) and did not exhibit segregation except mixture 7 where w/c could be lower. L-box ratios (see Table 4) varied from 0.83 to 0.90, the results indicates that SCC mixtures with waste glass powder prepared in this study achieved adequate passing ability and maintained sufficient resistance to segregation. The V-funnel test time was 3.5–6 s, the best time for LB glass and worse time for DRL glass concrete mixture.

Table 3. *Setting time of cement paste mortars with Portland cement substitution with waste glass powders and ashes*

Cement paste mortar's type	Substitution level, %	Setting time	
		Initial time, h	Final time, h
CTRL	0	1:42	3:22
DRL	20	1:59	3:54
DRL	30	2:20	3:15
LB	20	2:13	3:26
LB	30	2:28	3:56
F	20	1:53	3:45
F	30	2:14	3:07
A	20	2:10	4:11
A	30	2:23	3:43
G	20	2:09	3:13
G	30	2:17	3:33
WA	20	2:33	3:21
WA	30	2:04	3:05
CA	20	2:07	3:02
CA	30	1:40	4:49

The tests results for compressive strength are summarized in Table 4. Each given value is the average of three measurements. It can be seen that the use of recycled glass waste and bottom ash as a Portland cement replacement decreases the compressive strength of the SCC mixtures compared with the reference mixture, except for mixtures with DRL glass for all ages and amber glass at the age of 28 and 90 days. Park et al. (2004) found that addition of 30% of waste glass to concrete caused a decrease of 4% in compressive strength, compared with its reference mixtures. In the present investigation the decrease of compressive strength at the age of 28 days was up to 8% for concrete mixture with waste glass powder (30%). The equal compressive strength of concrete mixture with DRL waste glass powder (20%) to reference mixture could be attributed to the effect of pozzolanic reactions and the high degrees of strength enhancement were obtained when the pozzolanic effect became significant at the late age of 90 days. As it can be seen that a smaller particle size of the ground glass resulted in a higher activity of glass with lime, however the workability of concrete mixture with DRL waste glass powder was lower, compressive strength was higher in comparison to other concrete mixtures in this investigation. The bottom ash concrete mixtures performed lower compressive strength results in comparison to waste glass concrete mixtures. However, as it can be seen coal bottom ash always perform better compressive strength results and worse workability, when wood bottom ash perform better workability which is quite important for SCC concrete mixtures, in turn the compressive strength for mixtures with wood bottom ash might be raised by addition of several chemical admixtures.

Mineral admixtures in frost-resistant concrete especially with the large water requirements are undesirable. At the same time, it can be seen that concrete with non-

Table 4. Fresh and hardened properties of SCC mixtures with waste glass powder and bottom ash as a Portland cement component in concrete

Mixture	Name of substitute of Portland cement	Portland cement, kg/m³	Substitute of Portland cement, kg/m³	Slump flow diameter, mm	V-funnel test	L-box ratio	Compressive strength, MPa			Frost resistance class
							7d	28d	90d	
CTRL	-	450	0	620	5	0.87	52	73	87	F200
2	DRL	360	90	620	6	0.84	51	74	88	F150
3	DRL	315	135	635	5	0.86	49	71	82	F100
4	LB	360	90	635	4	0.87	41	63	78	F100
5	LB	315	135	650	3.5	0.89	37	54	63	F50
6	F	360	90	640	5	0.87	44	65	80	F100
7	F	315	135	660	4	0.90	42	60	69	F50
8	A	360	90	625	5	0.86	44	65	79	F100
9	A	315	135	645	4	0.87	42	60	70	F50
10	G	360	90	620	5	0.85	43	64	78	F100
11	G	315	135	630	4.5	0.86	41	62	70	F50
12	WA	360	90	615	5	0.84	43	62	73	F100
13	WA	315	135	620	4	0.85	39	60	61	F50
14	CA	360	90	610	5	0.83	48	68	81	F100
15	CA	315	135	605	4	0.84	46	64	73	F50

large maintenance of waste glass powders (in case of SCC concrete mixtures) may be satisfactory for frost resistance.

Table 5. Decrease of ultrasonic pulse velocity, %

Concrete mixture	Number of freeze-thaw cycles for the frost resistance class determination				
	F50	F75	F100	F150	F200
	8	13	20	30	45
CTRL	-0.5	0	-1.8	-3.7	-4.9
2	-0.9	-2.17	-3.5	-5.0	-
3	-1.75	-3.56	-4.89	-	-
4	-1.95	-3.87	-5.0	-	-
5	-4.5	-	-	-	-
6	0	-2	-4.9	-	-
7	-4.9	-	-	-	-
8	-2.0	-2.0	-5.0	-	-
9	-4.9	-	-	-	-
10	-1	0	-4.8	-	-
11	-4.9	-	-	-	-
12	-1.0	-2.0	-5.0	-	-
13	-4.7	-	-	-	-
14	-1.0	-2.0	-4.9	-	-
15	-4.5	-	-	-	-

The results (see Table 5) show that all mixtures belong to 1st or 2nd class: 1st class – non-large frost resistance (F = 50 to 150) and 2nd class – large frost resistance (F = 150 to 300). The experiments showed that addition of waste glass powder decrease the frost resistance however by proper mixture composition selection and application of waste glass powder the frost resistance can be significantly improved.

4. Conclusions

In the present investigation designed SCC concrete mixtures with waste glass powders as Portland cement substitute demonstrated reasonable improvement on workability, compressive strength and frost resistance. The slump flow, flow ratio, and V-funnel of recycled glass SCC mixtures increased with the increase of recycled glass powder content. The best results for concrete workability were performed with soda-alkaline earth-silicate glass coming from low pressure mercury-discharge lamp waste chips as cement component in concrete. The flow ratios varied from 0.83 to 0.90. The compressive strength of recycled glass powder SCC mixtures decreased with the increase of recycled glass powder content (addition of 10% of waste glass powder by weight approximately decreases compressive strength for 10 MPa). The difference in results for different waste glass powders could be explained by its chemical composition and fineness, when fineness sometimes even more important for SCC concretes. Addition of waste glass powder in concrete performed satisfied results and can be considered as one of the option to reduce accumulated waste in Latvia, where glass recycling problems are still up-to-date.

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