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POTENTIAL OF USAGE OF SELF COMPACTING CONCRETE WITH ADDITION OF RECYCLED CRT GLASS FOR PRODUCTION OF PRECAST CONCRETE ELEMENTS

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Abstract. *The electronic and electric waste (e-waste) quantities have been sharply increasing since the beginning of the 21st century. A significant portion of e-waste is composed of glass originating from the cathode ray tubes of the TV-set screens and computer monitors (CRT glass) which, due to the complexity of the recycling process and its chemical composition is very hazardous and represents a huge environmental problem. One of the modes of recycled CRT glass application is for making of self-compacting concrete (SCC). The paper investigated various properties of fresh and hardened SCC where CRT glass played the role of powdery mineral admixture. SCC made in such a way, with satisfactory physical-mechanical characteristics is suitable for production of various precast concrete elements. In order to monitor the durability of experimental concrete in actual conditions, several curbs were experimentally placed in the course of reconstruction of a street in Niš.*

Key words: *E-waste, environment, CRT glass, SCC concrete, precast concrete*

1. INTRODUCTION

Electronic industry is one of the most important and fast growing industries in the world. Its growth and development in the recent decades created numerous jobs, accelerated technological development and simultaneously contributed to generation of considerable e-waste due to phasing out of electronic devices. E-waste, as it is termed in literature, increases considerably faster than other solid waste in the world [1].

Computer monitors and TV sets with cathode ray tubes have not been sold in Europe since 2011. However, these devices are still present in the households, and it is estimated that the landfills in Europe annually receive between 50000 tons and 150000 tons of obsolete CRT screens. Fernanda Andreola et al [2] anticipated that the quantity of collected CRT glass at the annual level will not be reduced in the future period.

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The CRT waste recycling process is very important, in environmental terms. There are two possible systems of cathode tube recycling – open and close loop recycling (Figure 1). The close loop recycling comprises recycling of old screens and production of new CRT devices. Regarding that in Europe there are no more factories producing new screens with cathode tubes, most often the CRT waste is exported to the countries where CRT screen factories still exist. The open loop recycling uses old CRT screens for production of new and different products [3]. A large number of scientific papers studies the potential of application of CRT glass in production of: ceramic tiles, artificial marble, glass jewelry, decorative crystals, etc.

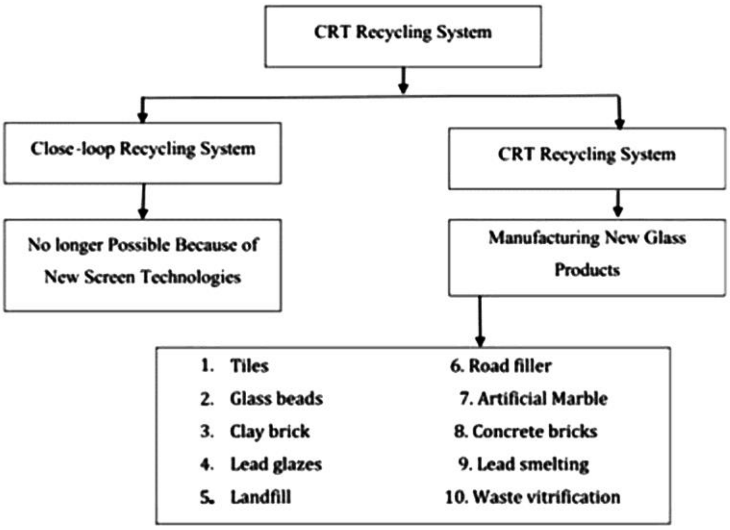

Fig. 1 The appearance of open and close loop of CRT glass recycling [3]

One of the possible directions of cathode glass usage considers the civil engineering industry, whereby glass would be used as substitution for a share of the aggregate or for a portion of filler in self-compacting concrete (SCC).

Emam Ali and Sherif Tersawy [4] examined properties of fresh and hardened SCC whereby the fine aggregate fraction was partially replaced by glass container cullet. Fine aggregate mass was replaced with 0%, 10%, 20%, 30%, 40% and 50% of CRT glass. The test results indicated that Slump Flow increased with the increase of glass share in the concrete mixture. On the other hand, the increase of glass admixture caused certain reduction of compressive strength, splitting tensile strength and static modulus of elasticity.

Kou and Poon [5] also examined properties of SCC where a portion of the river aggregate and crushed granite of grain size up to 10 mm was replaced by recycled glass containers. The river aggregate was replaced in the range between 0 and 30% with an increment of 10%, while granite was varied in the range between 5% and 15% with an increment of 5%. The results of their research indicate that the increase of the glass share in concrete mixture results in reduction of shrinkage and increase of concrete resistance to chloride action.

Miao Liu [6] in his paper used white and green glass container glass cullet as replacement for portions of both cement and fine aggregate in SCC. The glass admixture resulted in an increase of water/powder ratio and in decrease of required quantity of superplasticizer. The presence of glass was not reflected on the passing ability (L-box test), but it caused reduction of mechanical characteristics of concrete. The final conclusion of the study is that SCC with good physical-mechanical properties can be made if cement and fine aggregate are replaced with recycled glass in the quantity of up to 10%.

Ana Mafalda Matos et al [7] substituted 50% of limestone filler with recycled glass and monitored its effects on mechanical properties and durability of SCC made in this way. It was established that recycled glass increases concrete resistance to penetration of chlorides, reduces water absorption and has mechanical characteristics similar to the reference batch where filler was not substituted by recycled glass.

2. Materials Used in the Experiment

For making of SCC three fractions of river aggregate were used (0/4 mm, 4/8 mm and 8/16 mm) originating from the South Morava river screening plant “Šilo Prom” d.o.o. Belotinac which conforms to all the quality standards prescribed by SRPS EN 206-1:2011[10] and EN 12620:2010 [11] standards. Also, pure Portland cement CEM I 42,5R manufactured by “CRH” Novi Popovac was used, which meets all the quality requirements prescribe by the SRPS EN 197-1:2013 standard [12]. Sika Viscocrete 5380 was used as the chemical admixtures in the mixture as superplasticizer.

Fig. 2 System for lining out and separation of integral parts of a monitor using hot wire.

The “Jugo - Impex” E.E.R. d.o.o. company deals with collection and recycling of cathode ray tubes of old TV sets and computer monitors. The cathode ray tubes in this company are dismantled to component elements using the state-of-the-art automatic high speed CTR separator. The mentioned separator consists of the lining out device (Figure 2, left), hot wire for separation of components (Figure 2, right) and the vacuum system for collection of fluorescence and dust [8]. The recycling center, for the needs of this research donated a certain amount of cathode ray glass which was further pulverized in the Laboratory of building materials using laboratory mill. After milling, the glass was passed through the 0,125 mm sieve. The composition of oxides in the clear glass is as usual, the ratio being N_2O : CaO : SiO_2 = 1 : 1 : 6, which was confirmed by a chemical analysis (SiO_2 – 72,61%, Na_2O – 13,12%). There is a minor presence of other oxides (Al_2O_3, MgO, K_2O, SO_3).

3. Experimental Section

3.1. Concrete mixture composition

Concrete mixture composition is presented in table 1. The self-compacting concrete was made with: 400 kg cement, 1616 kg of the river aggregate with three fractions and 156 kg of recycled CRT glass, having fineness of 0,125 mm which served as a powder mineral admixture. Water/cement ratio was 0,45. The cathode ray tube glass had a share of 5,5% in volume of 1 m^3 of concrete.

Table 1 Concrete mixture composition

Type of material	Aggregate 0/4 mm	Aggregate 4/8 mm	Aggregate 8/16 mm	Filer	Cement	Water	Superplasticizer
Volume Percentage in1m^3[%]	29,62	11,58	20,11	5,5	12,70	18,15	0,45
Specific density [kg/m^3]	2620	2650	2650	2840	3150	1000	1100
Mass 1 m^3 [kg]	776	307	533	156	400	181,5	4,95

3.2. Fresh concrete tests results

The test results of fresh concrete are presented in table 2. Density of fresh concrete was tested according to SRPS EN 12350-6:2010 standard [13]. Entrained air content was tested according to SRPS EN 12350-7:2010 standard [14]. A concrete mixture can be considered SCC if it has flowability, viscosity, passing ability and segregation resistance. [9]. In order to verify the previously mentioned properties, the following fresh concrete tests were performed: slump and T_{500} spreading tests (SRPS EN 12350-8:2012 [15]), L – box test (SRPS EN 12350-10:2012 [16]) and test of stability on the sieve (SRPS EN 12350-11:2012 [17]).

Table 2 Fresh concrete tests results

Concrete characteristics	Measurement unit	Test result
Density	kg/m^3	2390
Air content	%	0,8
Spreading T_{500}	s	4,5
Slump test	mm	660
L-box test H1/H2	(mm/mm)	0,95
Segregation	%	12,8

After lifting of the filled cone, the time required for the concrete to spread over the diameter of 500 mm is measured, as well as the final diameter of the circle after the concrete has finished spreading (Figure 3, left). The L-box aims at checking the concrete tendency to flow between the rebars during placing (Figure 3, right). SCC resistance to segregation is checked by measuring the time of concrete mass passage through the 5 mm sieve for the duration of 120 seconds.

Fig. 3 Slump flow test and L – box test

3.3. Hardened concrete test results

Water saturated concrete density test was performed on the hardened concrete cubes (SRPS EN 12390-7:2010 [18]) having sides of 15 cm at the age of 2, 7, 28 and 90 days. Compressive strength testing was performed according to SRPS EN 12390-3:2010 standard [19], while simultaneously the ultrasound velocity through concrete was monitored (SRPS EN 12504-4:2008 [20]) as well as the rebound number (SRPS EN 12504-2:2008 [21]). Flexural tensile strength was tested on the prisms having dimensions 10x10x40 cm at the age of 28 and 90 days according to SRPS EN 12390-5:2010 standard. [22]. According to SRPS EN 12390-6:2012 standard [23] tensile splitting test was performed on the specimens having cylindrical form, having diameter of ∅15 cm and height of 30 cm. „Pull – off" bond strength test was performed on the cubes having sides of 15 cm at the age of 28 and 90 days, in all according to SRPS EN 1542:2010 standard [24]. Static modulus of elasticity was tested on the cylindrically shaped specimens according to SRPS IS0 6784:2000 standard [25]. The Boehme abrasion resistance was tested on the sample cubes having sides of 7.07 cm according to SRPS B.B8.015:1984 standard [29].

The test of resistance to simultaneous action of frost and salt was performed according to SRPS U.M1.055:1984 standard [26]. According to SRPS U.M1.016:1992 standard [27] was performed M-200 test of resistance to frost action. In figure 4 (left) is presented the appearance of the samples after 25 cycles of successive freezing and de-freezing. Determination of pressurized water penetration was tested on the cubes having 15 cm sides according to SRPS U.M1.015:1998 standard [28]. The review of test results of hardened concrete is provided in table 3. In figure 4 (right) is presented the specimen after the penetration test using water under pressure of 7 bars.

Table 3 Review of the hardened concrete test results

Property:	Age:	Test results:
Water saturated density [kg/m^3]	2 days	2390
	7 days	2388
	28 days	2385
	90 days	2370
Compressive strength [MPa]	2 days	38,7
	7 days	47,7
	28 days	59,0
	90 days	72,2
Static modulus of elasticity [GPa]	28 days	29,9
	90 days	33,3
Flexural strength [MPa]	28 days	6,4
	90 days	7,7
Tensile strength [MPa]	28 days	4,2
	90 days	5,5
Tensile– Pull-off strength [MPa]	28 days	4,2
	90 days	5,1
Ultrasound impulse velocity [m/s]	28 days	4691
	90 days	4748
Rebound number	28 days	51,3
	90 days	56,5
Bohme abrasion resistance [cm^3/50 cm^2]	90 days	9,5
Pressurized water penetration [mm]	-	0
Resistance to simultaneous action of frost and defrosting salt [mg/mm^2]	-	0,11
Frost resistance (reduction of compressive strength M200) [%]	-	15,62

Fig. 4 Appearance of the specimens after the tests of resistance to simultaneous action of frost and salt (left) and the appearance of the specimen after water permeability test

3.4. Production and fitting of curbs made of SCC with recycled CRT glass admixture

In the period when the laboratory tests of SCC with recycled CRT glass admixture were being conducted, there was ongoing reconstruction of Dragiše Cvetkovića street in Niš. In cooperation with the company “Put Inženjering d.o.o.” several curbs were made of the experimental concrete B 120/180-200, suitable for the reconstructed street. (Figure 5).

Fig. 5 Production of curbs made of SCC with CRT glass admixture

After the conducted appropriate curing of concrete, the curbs were fitted in the mentioned street (Figure 6). Since then, active monitoring of experimental curbs has been performed, for the purpose of observing their durability in real conditions.

Fig. 6 Fitting of curbs in Dragiše Cvetkovića street

4. Discussion of Results

Based on the measured spreading of 660 mm, concluded that SCC with recycled cathode ray tube glass admixture belongs to the spreading class SF2 (of 660mm to 750 mm). The time measured for T_{500} test is 4,5s, so it can be concluded that SCC has satisfactory flowability. The percentage of passage through the 5 mm sieve (sieve stability test) amounted to 12,8% which indicates that experimental concrete has satisfactory resistance to segregation. The L-box test, determined that the concrete belongs to the PA2 class (≥0,80).

The obtained early compressive strength values at the age of 2 and 7 days were very high. The compressive strength at the age of 28 days was 59 MPa, while after 90 days the increase of the strength was 22%. This increase can be partially attributed to the puzzolanic activity of the milled CRT glass. The values of tensile splitting strength and tensile flexural strength were at the satisfactory level. The average value of penetration of water under pressure of 7 bars was 0 mm, which proved that SCC is water impermeable. After 25 cycles of simultaneous action of frost and defrosting salt, it was determined that there occurred the flaking of the surface layer of concrete, but that it was less than 0,2 mg/mm^2. On the basis of SRPS U.M1.055:1984 standard [26] it can be concluded that SCC has the damage degree MS1 and that it is resistant to this action. Reduction of compressive strength after 150 cycles of alternating freezing and de-freezing amounted to 10,20% in comparison to the reference batch, i.e. 15,62% after 200 cycles which proved that concrete had M-200 frost action resistance. Boehme abrasion resistance was 9,5 cm^3/50 cm^2 which is a satisfactory result.

4. Conclusion

Waste glass of cathode ray tubes of TV sets' screens and computer monitors represents an environmental issue, because waste disposal sites of such waste may pollute the environment. The paper investigates various properties of fresh and hardened SCC with the admixture of recycled cathode ray tube glass. It was determined that experimental SCC has excellent fresh concrete properties in terms of flowability, filling ability and segregation resistance.

The obtained values of compressive and tensile strength were high which is in agreement with the results in the paper [7]. On the basis of the obtained results of water permeability testing, resistance to frost action and simultaneous resistance to frost and defrosting salt action, and to abrasion resistance it can be concluded that SCC with CRT has satisfactory durability. For this reason it can be considered suitable for making of precast concrete elements such as interlocking paving elements and concrete curbs whose cross section does not exceed 300 cm^2. The monitoring of the experimentally fitted curbs in Dragiše Cvetkovića street in Niš, made with the experimental concrete, exhibited no deficiency regarding durability in comparison with the classical curbs fitted in the same street.

Based on the previous assertions, it can be generally concluded that the SCC concrete made with recycled cathode ray glass, as powder mineral admixture, can be successfully used for production of precast concrete elements.

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MOGUĆNOST PRIMENE SAMOUGRAĐUJUĆEG BETONA SA DODATKOM RECIKLIRANOG CRT STAKLA ZA IZRADU BETONSKIH PREFABRIKATA

Količine elektronskog i električnog otpada (e-otpad) su u značajnom porastu od početka 21. veka. Nezanemarljivu količinu e-otpada čini staklo od katodnih cevi televizijskih ekrana i kompjuterskih monitora (CRT staklo) koje zbog složenosti procesa reciklaže i svog hemijskog sastava ugrožava životnu sredinu i predstavlja veliki ekološki problem. Jedan od vidova primene recikliranog CRT stakla jeste njegova upotreba za spravljanje samougrađujućeg betona (SCC). U radu su ispitana različita svojstva svežeg i očvrslog SCC betona kod koga je katodno staklo imalo ulogu praškastog mineralnog dodatka. Ovako spravljen SCC beton sa zadovoljavajućim fizičko – mehaničkim karakteristikama pogodan je za izradu različitih betonskih prefabrikata. U cilju praćenja trajnosti eksperimentalnog betona u realnim uslovima ogledno je postavljena nekolicina betonskih ivičnjaka od predmetnog betona tokom renoviranja jedne ulice u Nišu.

Ključne reči: *E-otpad, životna sredina, CRT staklo, SCC beton, betonski prefabrikati*