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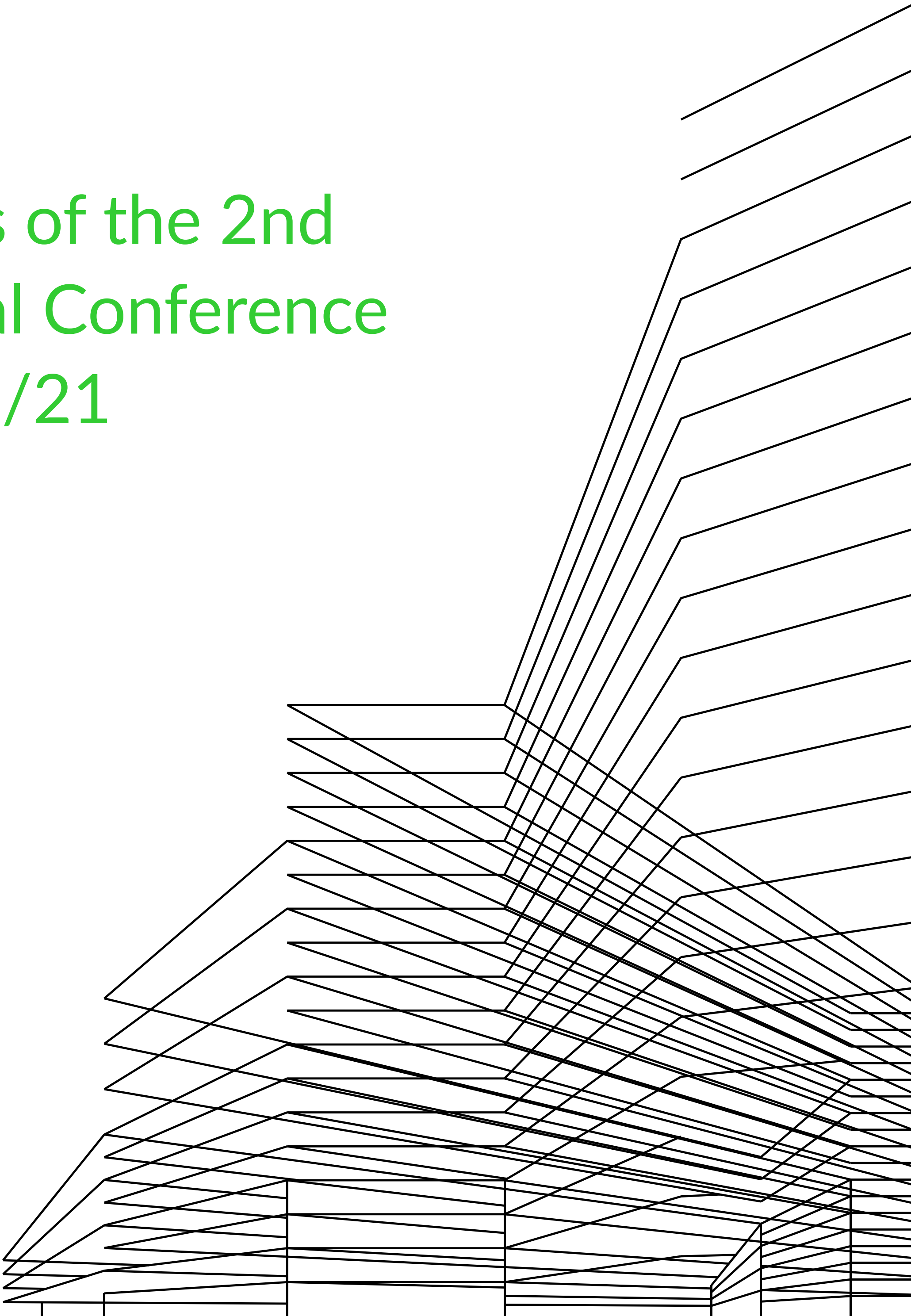

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UP

RESISTANCE OF CONCRETE MADE WITH FINELY MILLED CATHODE RAY TUBE GLASS AS A SUPPLEMENTARY CEMENTITIOUS MATERIALS TO SULPHATE ATTACK

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SUMMARY: Sustainable building is one of the key requirements in contemporary civil engineering aimed at reducing the harmful impact on the environment. Since the turn of the twenty first century, it has been insisted on usage of recycled materials which could, at least in part, substitute traditional materials. Even though the TV sets with cathode ray tubes are no longer being produced, the amount of cathode ray tube glass (CRT) on the waste disposal sites has still been increasing. The goal of experimental research was determining potential for usage of finely milled CRT glass as a supplementary cementitious material and checking resistance of such concretes on the sulphate action. Six experimental batches of concrete were made. The replacement percentage of cement with CRT was: 5%,10%, 15%, 20% and 35%, by cement mass. Each batch consisted of 18 cylindrical specimens with a diameter of 100 mm and height of 100 mm. A half of specimens was cured in saturated solution of calcium-hydroxide until the test. The second half of specimens was kept for the first 28 days in the saturated solution of calcium-hydroxide, after which they were exposed to action of 5% solution of sodium-sulphate. Assessment of durability of concrete to sulphate action was performed by the visual evaluation of concrete appearance and by testing the variation of compressive strength of treated concrete specimens at the age of 3, 6 and 12 months.

KEY WORDS: cathode ray tube glass; sustainable building, recycling; environment, sulphate action, durability.

1 INTRODUCTION

1.1 Cathode ray tube glass disposal and recycling problem

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. 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 50.000 tons and 150.000 tons of obsolete CRT screens. It is anticipated that the quantity of collected CRT glass at the annual level will not be reduced in the future period (Andreola F. et al. 2007). 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. 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 (Singh N. et al. 2016). There is a large number of scientific papers studying the potential of application of CRT glass in production of: ceramic tiles, artificial marble, glass jewelry, decorative crystals, etc.

One of the possible directions of cathode glass usage considers the civil engineering industry, whereby glass would be used for making of cement composites in two ways. The first option is to use it as a fine aggregate, which would replace a certain amount of natural aggregate. The other option is to use finely milled waste glass as a replacement for a share of cement when making mortar and concrete. One of the problems which can occur when using recycled glass aggregate for making of cement composites is the emergence of alkali-silicate reaction (ASR). Recycled glass has a high percentage of amorphous silicon dioxide (a glass bottle has around 70%) which has a potential of reacting with alkali from cement, creating an ASR gel (Rajabipour F. et al. 2010). This gel in the presence of moisture during a prolonged period of time has a tendency to expand, which can initially cause cracks, and later on, a complete destruction of hardened concrete. The research indicated that glass grain size has a considerable impact on the ASR reactivity of glass (Idir R et al. 2011; Shayan A et al. 2006). It was found that the size of cracks inside glass grains, occurring due to crushing and pulverization processes, determines the ASR reactivity (Maraghechi H et al. 2014; Rajabipour F et al. 2010, Matos A. et al. 2012). Where the internal cracks are larger, ASR occurs more readily. On the other hand, very finely milled powder does not cause the alkali – silicate reaction considering the presence of a small number of micro-cracks. The experimental research is focused on testing the impact of finely milled glass as a replacement for a portion of cement when making concrete, and on the concretes modified in this way resistance to the sulphate effects.

1.2 Sulphate action mechanism

The sulphate salts dissolved in water can have extremely adverse effects on concrete. Most common sulphates are those of calcium, magnesium, potassium and sodium. Sulphates are present both in soil and in ground waters. Also, acidic rain and seawater contain dissolved sulphates which is an aggressive environment for concrete structures exposed to their action. Industrial waste disposal is recognized as locations with potentially very high sulphate concentration. Sulphate corrosion can most often be first detected on the edges and periphery of concrete elements, and after a long lasting exposure there occur cracks and decline of strength. This type of corrosion is a very complex process in chemical terms.

The basic products of sulphate ions reaction with the products of cement hydration are: ettringite, gypsum and thaumasite (Bjegović D. et al. 2015; Bulatović V. 2017; Grdić Z. 2011; Neville A. M. 2001). Numerous researches of the sulphate attack development mechanism showed that there is a correlation between the content of celita mineral ·Al_2O_3 (tricalcium aluminate) content in Portland cement and onset of sulphate attack. Cement, and by this, concrete, with high content of celita will cause emergence of sulphate reaction whose product will be ettringite, which can be described by the chemical equation:

$$3CaO \cdot Al_2O_3 \cdot 12H_2O + 3CaSO_4 + 20H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 20H_2O \qquad (1)$$

Occurrence of ettringite increases the volume of solid matter up to 55% which gives rise to occurrence of considerable stresses in cement rock which causes onset of cracks. Ettringite is capable of absorbing water when found in microcrystalline form, and solid matter volume can be increased as much as 120%. Sulphates can also react with calcium hydroxide ($Ca(OH)_2$), which also causes increase of volume and decline in bearing capacity of a structure. The following relation describes the action of sodium sulphate:

$$Na_2SO_4 + Ca(OH)_2 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O + 2NaOH \qquad (2)$$

The mentioned reaction is also called the gypsum corrosion, considering that the reaction product is gypsum ($CaSO_4 \cdot 2H_2O$). In the case of concrete exposed to a long-lasting action of sulphate, during the first ten years, the sulphate corrosion is caused by the reaction (1), while after the mentioned period, the primary role in concrete deterioration is caused the by the reaction (2). The onset of cracks due to the increase of solid matter volume is not always the only manifestation of sulphate corrosion. Actually, in a large number of cases, the cement rock "softens" and disintegrates. There is also decalcification of C-S-H gel whereby the cement rock is softened and exhibits properties like putty (Grdić Z. 2011; Neville A. M. 2001).

Thaumasite is a very rare mineral which can occur in nature in some basic types of rocks, such as limestone. Thaumasite consists of calcium silicates, carbonates and sulphates $CaSiO_3 \cdot CaCO_3 \cdot CaSO_4 \cdot 15H_2O$. It is necessary that several conditions are met to cause occurrence of thaumasite in concrete. Damp environment, temperature below 15 °C, source of sulphate ions, most commonly from ground waters or soil, presence of carbonates in the aggregate used from making concrete and of calcium silicate which is present in hydrated PC. Similar to other products of suphate corrosion, thaumasite can cause concrete devastation after a protracted period, too. Thaumasite can occur in the existing cracks and voids in concrete, however it needs not cause concrete degradation. Devastation occurs when thaumasite replaces a portion of or entire hardened cement matrix (Bjegović D. et al. 2015).

1.3 Testing of sulphate resistance of cement composites modified with waste glass

In the previous period, various sulfate resistance tests were performed on mortars and concretes wherein a portion of cement or fine aggregate was replaced with different varieties of waste glass. For instance, comprehensive testing of concretes properties containing various waste E-glass particle contents was conducted (Chen H. et al. 2006). The size distribution of cylindrical E-glass particles was from 38 to 300 μm and about 40% of particles was less than 150 μm. Sulphate-immersion test was performed with reference to ASTM C 267. The volume expansion of chemical reaction induces internal stresses, which may generate internal cracks and ultimately lead to failure. After five cyclic wet-and-dry exposures, significant weight loss and strength reduction were recorded, which exhibited strong sulphate attack on specimens. An increase in E-glass content significantly decreases weight and strength loss, particularly of the specimens with lower water/binder ratio. Based on the properties of hardened concrete, optimum E-glass content is found to be 40–50 wt.% in this study. The surface defects of tested specimens also show a qualitative evidence of sulphate attack.

Crushed waste glass from windshields and commercial glass containers were also the subject of research (Matos A. et al. 2012). Researches tested mechanical strength and durability of mortar using glass powder as a partial cement replacement (0%, 10% and 20%) material to ascertain applicability in concrete. Resistance to external sulphate attack was evaluated according to the Portuguese standard E – 462. Blended Portland cement with 10% replacement with WGP showed an impressive resistance to sulphate attack, far higher than SF marginally within the limit of 0.10%. The pozzolanic activity of WGP and SF binds portlandite (CH) released in the hydration of calcium silicates (C_3S and C_2S) so CH is no longer available for reaction with sulphates. This prevents the formation of gypsum. Pozzolanic reaction produces a secondary C–S–H that also decreases the capillary porosity of mortar and enhances significantly the paste - aggregate interface.

The features, compressive strength, sulphate and chloride resistance and expansions related to alkali – silica reaction (ASR) were examined on cement - based mortars produced with cement containing waste glass (WG) and industrial by-products (Ozkan O. et al. 2007). Resistance to sulphates was tested by comparing compressive strength of specimens exposed to 4% Na_2SO_4 with the strength of reference specimens. These results show that replacement of cement by waste glass alone increased the durability of mortars to sulphate attack. If waste glass is used combined with granulated blast-furnace slag or fly ash then sulphate resistance is more increased. Especially the waste glass and blast-furnace slag combination provides the best results.

The comparative analysis of waste glass powders behaviour of different fineness with that of natural pozzolana, coal fly ash and silica fume was also studied (Carsana M. et al. 2014). Seven mortars mixtures were made with glass powders and other mineral additions in which the share of replacement of cement was 30%, except for silica fume used at 10%. One of durability tests was expansion due to sulphate attack in according to ASTM C1012 standard. Mortars with ground glass showed a negligible expansion (0.04%) even after more than 1 year of immersion in the sulphate solution (when tests were interrupted). Only the mortar with silica fume showed lower values. On the other hand, mortars with ground quartz sand reached an expansion of 0.1% just after two months of tests and the reference mortar (OPC) after about eight months.

The methodology of mentioned research was used as a basis for the choice of fineness of the waste CRT glass so that its pozzolanic activity could be activated. Two criteria used by the cited authors were used for the evaluation of own experimental research, those being: visual inspection of the sample surface and variation of compressive strength.

2 MATERIALS AND METHODES

2.1 Used materials

Ordinary Portland cement CEM I 52.5R manufactured by "CRH" Novi Popovac, satisfying all the quality requirements stipulated by the standards SRPS EN 196-1:2018, SRPS EN 196-3:2017, SRPS EN 196-6:2011 and SRPS EN 197-1:2013 was used for making of concrete mixtures. Three fractions (0/4 mm, 4/8 mm i 8/16 mm) of the river aggregate from the South Morava river were used. The CRT glass came from the recycling center "Jugo - Impex E.E.R." d.o.o. from Niš. Large shards of CRT glass granted by the recycling center were milled using a laboratory ball mill so that glass could pass the sieve opening of 0.063 mm with no residue. For making of concrete mixes, tap water from the municipal water supply system was used, as well as the chemical superplasticizer admixture Sika® ViscoCrete® 4000 BP.

2.2 Concrete mixtures composition

Reference concrete (E) is produced with 400 kg of pure PC and 1800 kg of three-fraction aggregate. Water/cement ratio was constant in all experimental batches, and amounted to 0,438. The share of replacement of cement with CRT glass was: 5%, 10%, 15%, 20% and 35%, in respect to the mass of cement. Designations of concrete mixes were made according to the share of replacement, whereby WG is an abbreviation of - waste glass. For instance, in the case of 20% of replacement of cement with CRT glass, the batch mark is WG20. The complete composition of concrete mixes is presented in table 1.

Table 1: Compositions of the concrete mixtures used in the experiment

Concrete	**Aggregate**			**Cement**	**CRT glass**	**Water**	**water - binder ratio**	**Admixture**
	0/4mm	**4/8 mm**	**8/16 mm**	**CEM I 52,5R**	**<0,063 mm**	**water supply**	m_v / (m_c+m_{wg})	**Sika Viscocrete 4000 BP**
	kg/m^3	**kg/m^3**	**kg/m^3**	**kg/m^3**	**kg/m^3**	**kg/m^3**	**-**	**kg/m^3**
E	774	414	612	400	0	175.3	0.438	2.40
WG5	774	414	612	380	20	175.3	0.438	2.40
WG10	774	414	612	360	40	175.3	0.438	2.40
WG15	774	414	612	340	60	175.3	0.438	2.40
WG20	774	414	612	320	80	175.3	0.438	2.40
WG35	774	414	612	260	140	175.3	0.438	2.40

2.3 Testing program and procedure of concrete samples production

2.3.1 Program of testing

Program of testing can be divided in two phases. In the first phase, physical characteristics of component materials were tested. In the experimental part of the paper are presented the most important characteristics of powdered CRT glass, chemical composition and particle size distribution. In this phase, the glass pozzolanic activity was tested (SRPS B.C1.018:2015) as well as the FTIR spectrum and XRD diffractogram of CRT glass. Alkali - silicate reactivity was tested according to the ASTM C227-10 standard on mortar series.

In the second phase, numerous tests of physical and mechanical characteristics were performed on the hardened concrete. This paper features only the results of the sulphate resistance test in accordance with the procedure described in the following text.

2.3.2 Concrete samples production

Prior to making each concrete batch, special attention was paid to the homogenization of cement with an appropriate quantity of milled CRT glass. For that purpose, an adequately sized vessel with a lid was used, and a mixer fitted with a special attachment. During the mixing process, which lasted 5 minutes, the special attachment revolved at 850 rev/min. Three precisely measured fractions of dried aggregate, from the coarsest to the finest, were added into the wetted mixing drum. After that, a half of the planned amount of water was added into the mixer, and it was mixed for 30 seconds in order to wet the aggregate grains evenly. Then, cement mixed with milled CRT glass and the remaining water were poured into the mixer. From that moment, a calibrated stop-watch measured the mixing time of these component materials. After 60 seconds from the start of mixing, the superplasticizer was added, with the total mixing time amounting to 5 minutes.

Currently, there is no standard in Serbia which defines the procedure of testing of concrete resistance to sulphate attack but a very thorough and comprehensive testing of sulphate resistance of concrete based on the recycled aggregate was conducted (Bulatović V. 2017).

In this paper, each experimental concrete batch was composed of 18 cylinder shaped specimens, having diameter 100 mm and height of 100 mm (a total of 108 specimens). Concrete is cast into metal moulds, and placed using a vibrating table. Half of all specimens comprised of “reference” specimens which were cured in saturated lime water up to the testing. The other half of specimens, after the necessary preparations, at the age of 28 days was immersed and cured in a 5% solution of $NaSO_4$ up to the testing. The procedure of preparation and curing of experimental samples looked like this:

- Making of concrete and keeping in hermetically closed moulds for 7 days at the temperature 20 ± 2 °C;
- Demoulding, reduction the basis of the cylinder to be parallel by cutting and curing for 14 days in saturated lime water (solution of 1,8 g $Ca(OH)_2$ to 1 dm^3 of water). "Reference" specimens of all batches (half of specimens) remained in lime water up to the moment of testing;
- 21 days after making, half of the samples intended for exposure to sodium sulphate were taken out of the lime water. Considering the expected degradation of samples after the long term presence of sulphate solution, bases of the extracted specimens were coated with Sikadur - 31 CF epoxy to prevent occurrence of stress concentration on the occasion of compressive strength testing;
- Half of the extracted specimens, after coating with epoxy was cured in the air in laboratory for 7 days; (Figure 1,a)
- At the age of 28 days, the specimens coated with epoxy were immersed in 5% solution of Na_2SO_4 (solution of 50 g of sodium sulphate to 1 dm^3 of water);
- Replacement of total 5% solution of Na_2SO_4 in specimen curing vessels after 3, 6 and 12 months with regular checks of pH value (Figure 1, b);
- Comparative testing of compressive strength of samples cured in $Ca(OH)_2$ and Na_2SO_4 solutions at 3, 6 and 12 months.

Figure 1: Curing of specimens in air, in the laboratory for 7 days (a) and Na_2SO_4 solution pH value checks (b)

Anhydrous sodium sulfate by the distributer DOO "Top Star" Zrenjanin was used. Dissolving of calcium hydroxide and sodium sulfate was done in warm water at temperature 28 - 32 °C. Only after cooling of the solution the specimens were immersed and kept in suitable containers. Solution pH value and lime water value in containers were performed using pH meter PH-220 with a range from 0 to 14 pH and measuring resolution of 0,01 pH. The pH solution value of Na_2SO_4 was ~7,5, i.e. ~12,5 u in the case of saturated lime water.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Phase I

Finely milled CRT glass had a density of 2.84 g/cm^3 and specific surface area by Blaine of 2450 cm^2/g. Chemical composition of glass is presented in Table 2. Figure 2a shows particle size distribution of CEM I 52.5R, while in Figure 2b particle size distribution of the examined glass is displayed. More than 63% of glass grains were finer than 36 μm, while 42% were finer than 20 μm. Around 25% of cathode glass particles were finer than 10 μm.

Table 2: Chemical composition of CTR glass

Chemical compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O
Share [%]	60.61	2.88	0.58	1.31	0.53	6.45	7.61

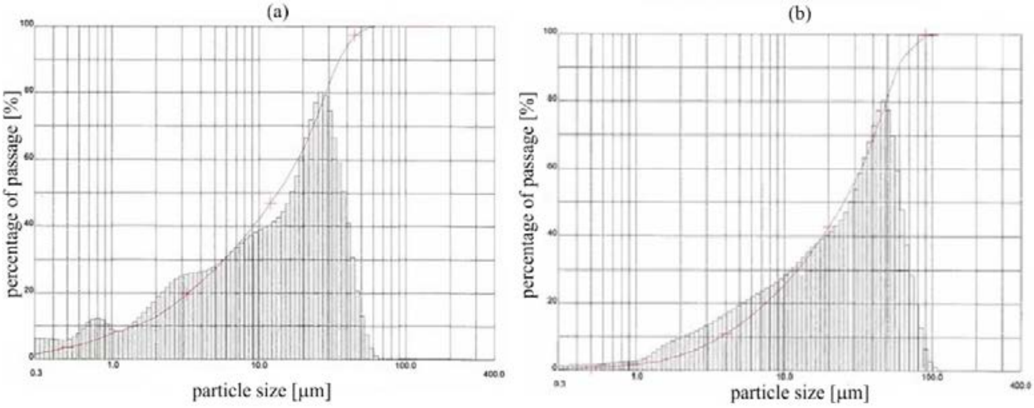

Figure 2: Particle size distribution of CEM I 52.5R (a) and CRT glass (b)

Pozzolanic activity of the glass was tested according to the standard SRPS B.C1.018:2001. The used standard classifies the pozzolanic material in three ways: according to the content of reactive silica (SiO_2), according to the particle size distribution and according to the mechanical properties. Glass pozzolanic activity was examined on the basis of the tested mechanical properties of mortar. The glass must have grains finer than 0,063 mm and be dried at the temperature of 98 °C. For preparation of mortar were used, 1350 g standard sand composed of three fractions, 300 g of fine CRT glass, 150 g of standard hydrated lime and 270 cm^3 of water. Mechanical strengths are tested on the test specimens having dimensions 40 mm x 40 mm x 160 mm. The test specimens are hermetically enclosed in tin boxes, where after the first 24 h spent in laboratory conditions they continue to be cured at the temperature of 55 °C for additional six days. The results of the obtained mechanical properties of mortar are presented in table 3.

Table 3: Results of mechanical properties of mortar

Test specimen	**Flexural strength [MPa]**	**Compressive strength [MPa]**
1	2.36	5.76
		5.82
2	2.28	5.76
		5.82
3	2.43	5.95
		5.82

The material is considered to be pozzolanically active and it is ranked to have no less than class 5, if at the age of seven days the minimum flexural strength is 2 MPa and compressive strength 5 MPa, which was proved with this test (Grdić D et al. 2015).

The FTIR analysis of the samples was made in the areas 4000 to 400 cm^{-1}, at a resolution of 2 cm^{-1}, on the BOMEM Michelson Hartman & Braun Series MB spectrometer. The absorption band at about 3400 cm^{-1} and 1650 cm^{-1}, showing that only a small amount of water is present in the glass, can be attributed to the stretching and bending vibration of either free OH groups or free H_2O molecules. The water has no substantial effect on the structure of the glass. It is also often reported that bands within the range from 900 to 1100 cm^{-1} are composite features of Si-OH species. The strong band at the frequency of ~800 cm^{-1}, therefore, is assigned to stretching vibration of Si-OH. The peak near 450 cm^{-1} and a low frequency peak near 700 cm^{-1} is assigned to Si-O-Si out of plane bending and Si-O-Si stretching modes respectively

(Figure 3a).

The XRD method was used for determination of mineral composition of investigated samples by the apparatus GNR Explorer, with scintillating counter at a voltage of 40 kV and electric current of 30 mA. Peak 2θ degree positions at about 19.0496, 29.6040, 40.7237 and 50.1789, with the maximum relative intensity at 29.6040 clearly show the presence of SiO_2 (quartz) in samples. Peaks from the XRD diffractogram indicate the presence of amorphous SiO_2, whereby the prominent peak at 40 indicates the presence of SiO_2 in the crystal form, too (Figure 3b).

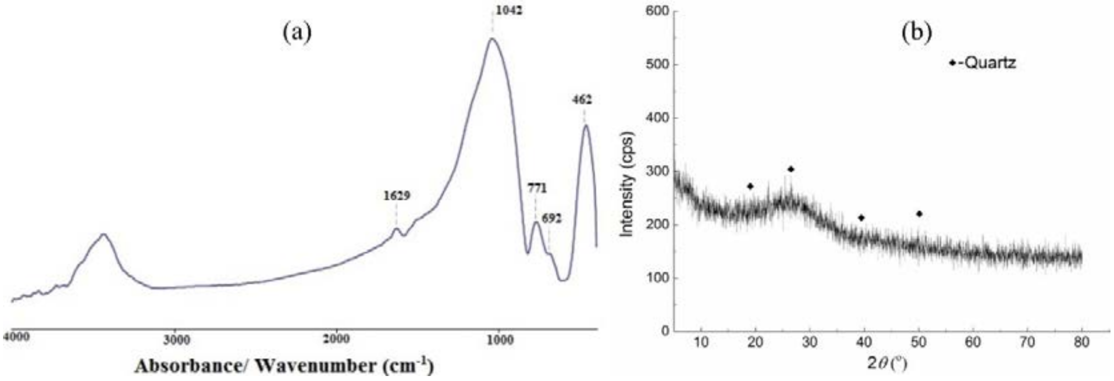

Figure 3: FTIR spectra of the CRT glass (a) and XRD diffractogram of CRT glass (b)

3.2 Phase II - Resistance of concrete made with CRT glass on sulphate attack

The level of sulfate resistance of concrete batches with CRT glass added was determined by comparing the compressive strength of reference specimens for each batch and of the specimens exposed to sulphate attack, table 4. Comparative testing of mechanical strengths was performed after exposing concrete to sulphate solution for 3, 6 and 12 months. Testing of compressive strength was conducted according to the standard ASTM C1231. In addition to strength variation, a visual inspection of potential damage of the specimens kept in the sulphate solution was performed.

Concrete	**Reference specimens cured in solution of $Ca(OH)_2$**			**Specimens cured in 5% solution of Na_2SO_4**			***Strength variation*** $\Delta f_{p,n}[\%]$		
	f_{E3} [MPa]	**f_{E6} [MPa]**	**f_{E12} [MPa]**	**f_{NS3} [MPa]**	**f_{NS6} [MPa]**	**f_{NS12} [MPa]**	$\Delta f_{p,3}$ ***[%]***	$\Delta f_{p,6}$ ***[%]***	$\Delta f_{p,12}$ ***[%]***
E	67.76	71.14	72.71	66.33	69.07	71.27	2.16	2.92	1.98
WG5	63.83	67.02	71.54	58.95	62.64	67.22	7.64	6.54	6.04
WG10	62.30	69.27	73.51	61.57	63.72	66.15	1.17	8.01	10.01
WG15	65.08	71.83	74.70	60.71	64.96	68.59	6.72	9.56	8.18
WG20	58.37	62.96	68.26	57.54	60.33	64.38	1.42	4.18	5.69
WG35	46.81	52.98	58.58	44.75	50.02	56.60	4.39	5.59	3.39

Strength variation was calculated according to the following formula:

$$\Delta f_{p,i} = \frac{f_{E,i} - f_{NS,i}}{f_{E,i}} \cdot 100 = [\%] \tag{3}$$

Where:

f_{Ei}- compressive strength of reference specimens after 3, 6 and 12 months of curing in $Ca(OH)_2$ solution in MPa;

f_{NSi} - compressive strength of specimens in 5% Na_2SO_4 solution after 3, 6 and 12 months in MPa;

$\Delta f_{p,i}$ – concrete compressive strength variation in %;

If the results of compressive tests of reference specimens cured in calcium hydroxide solution at the tests after 3 months ($f_{E,3}$) are firstly observed, it can be concluded that with the increase of share of finely milled CRT glass, compressive strength declines. Concrete mixes WG20 and WG35 have 13,9% and 30,9% lower strength than the reference batch E, respectively. At the tests after 6 months ($f_{E,6}$), the initial difference in compressive strength of the reference batch and sample up t the level of replacement of 15% of glass is reduced, while at the test after 12 months ($f_{E,12}$) the concrete mixture WG15 has 2,7% higher strength than E concrete. At the final test of concrete reference mixes after one year, WG20 and WG35 still have lower strengths than the reference batch, but this difference is now lower - 6,1% and 19,7%, respectively. Explanation for such increase of strength of concrete mixes with addition of CRT glass can be found in the process of pozzolanic reaction of glass. The nature of pozzolanic reaction of CRT glass is such that it occurs later than the process of cement hydration and that it is most intensive after 28 days which can explain the reduction of difference in the measured values of compressive strengths of the reference batch and batches with added glass.

After the impact of the presence of CRT glass on the compressive strength of concrete has been defined, one can observe sulphate resistance of experimental concretes. After curing the specimens in 5% solution of Na_2SO_4 for 12 months, no decline of compressive strength higher than 10% was found in comparison to the samples cured in calcium hydroxide. More important, the visual inspection of these specimens did not find any damage such as cracks or flaking. i.e. loss of mass. The tests are still underway, so after the curing period of 2 and 3 years in the presented conditions, the resistance to sulphate attack will be assessed. Generally speaking, it can be concluded that all the experimental mixes are resistant to action of sodium sulphate. At this moment, after one year of testing, it cannot be stated, with any degree of certainty, what the impact of present CRT glass on this kind of concrete resistance is.

4 CONCLUSIONS

After the impact of the presence of CRT glass on the compressive strength of concrete has been defined, one can observe sulphate resistance of experimental concretes. After curing the specimens in 5% solution of Na_2SO_4 for 12 months, no decline of compressive strength higher than 10% was found in comparison to the samples cured in calcium

Based on the obtained experimental results, a number of conclusions can be drawn:

- Based on the results of testing of pozzolanic activity of finely milled glass on lime mortar according to the SRPS B.C1.018:2015, the average value of compressive strength of 5,82 MPa was obtained. It can be concluded that the experimental glass is pozzolanically active, and it is class 5.

- The peak near 450 cm^{-1} and a low frequency peak near 700 cm^{-1} of FTIR analysis are assigned to Si-O-Si out of plane bending and Si-O-Si stretching modes, respectively.

- Peaks from an XRD diffractogram indicate the presence of amorphous SiO_2, whereby a prominent peak at 40 2θ indicates the presence of SiO_2 in the crystal form.

- Replacement of cement with CRT glass finer than 63 μm the amount of 35% by mass does not cause occurrence of alkali - silicate reaction. Free silicon in glass powder, which is amorphous material, will be quickly consumed during the pozzolanic reaction, and it will react with other compounds to form a mineral phase. In this way, the dissolved silicon dioxide will be included in the crystal grid of cement gel and it will not be available for the process of alkali-silicate reaction which would normally occur quite later than the pozzolanic reaction.

- By measuring the compressive strength of concrete specimens where a portion of cement was replaced with CRT glass, cured in calcium hydroxide, it was found in time, the difference of compressive strengths in comparison to the reference batch E declines. At the tests after 12 months, the batches where cement was replaced with up to 15% of CRT glass have the same or higher compressive strengths than the reference batch.

- After curing the specimens in 5% solution of Na_2SO_4 for 12 months, no decline of compressive strength higher than 10% was found in comparison to the samples cured in calcium hydroxide. Generally speaking, it can be concluded that all the experimental mixes are resistant to action of sodium sulphate.

- The visual inspection of these specimens did not reveal any damage such as cracks or flaking. i.e. loss of mass after exposing the samples to sulphate attack.

- The testing is underway, so after the curing period of 2 and 3 the resistance to sulphate attack will be reassessed.

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