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UNIVERSITY OF NOVI SAD
FACULTY OF TECHNICAL SCIENCES
DEPARTMENT OF CIVIL ENGINEERING
AND GEODESY
DEPARTMENT OF ARCHITECTURE AND URBAN
PLANNING
IN COOPERATION WITH
ASSOCIATION OF STRUCTURAL ENGINEERS OF
SERBIA

13

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PLANNING, DESIGN, CONSTRUCTION AND RENEWAL IN THE CIVIL ENGINEERING

International Scientific Conference

PROCEEDINGS
Novi Sad, Serbia 25 - 27 November 2015

EDITORS
V. Radonjanin, Đ. Lađinović, R. Folić

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iNDiS 2015

This year, Department of Civil Engineering and Geodesy, Faculty of Technical Sciences - Novi Sad, organizes 13th International Scientific Conference "iNDiS 2015".

The first conference took place in the 1976 with main topic „Industrial construction of apartments“ as current. In the following years, conference topics were extended to “Industrialization in civil engineering“, and soon, papers form all areas of construction have appeared, from urbanism planning and designing buildings to maintenance and major interventions on engineering structures. It has caused the expansion of the area covered by this conference and, besides civil engineers in various fields, urban planners, architects, engineers in other fields who work in construction, sociologists, economists and others took a part.

The present moment is characterized by, among other things, a crisis in investment sector, especially in new construction, but, as in the world, more and more resources must be directed to building management. This requires a transformation of our activities in construction and adaptation to these trends. This conference, as well as several previous ones, includes problems of planning, design, construction and renewal in civil engineering, disaster risk management and fire safety, which led to an adequate response of foreign and domestic participants. This wide area includes a wide circle of researchers and engineers, ie. all professions whose activities are related to architecture, civil engineering, geodesy and disaster risk management and fire safety in the field of construction.

Members of the International Scientific Committee actively participated in the preparation of the Conference, as well as in reviewing submitted papers, and wrote papers published in this Proceeding. These, as well as other papers, contain a variety of ideas and results of experimental and theoretical research that became the basis for formulating adequate calculation models of structures and models used in other areas of civil engineering and environmental protection.

It is expected that, using experience from abroad, adjustment to the legislation already adopted in Europe will be easier. In addition, it is expected to point out the main directions of the development of civil engineering in order to meet modern conditions and needs.

Two Proceedings were published for this conference “iNDiS 2015“, one in the Serbian and the other in the English language, which allows better communication and exchange of experiences with colleagues from foreign countries as well as establishing new and strengthening of existing professional and collegial relationship.

The editors would like to express sincere gratitude to all authors for the effort invested in writing papers and for the contribution to this event.

Novi Sad, November 2015 — Editors

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EFFECTS OF ADDITION OF FINELY MILLED CATHODE TUBE GLASS POWDER ON CONCRETE PROPERTIES

Abstract: The paper presents the results of testing of physical and mechanical properties of concrete which was made with addition of 0 to 10 %, at 2.5% increments, of finely milled recycled glass obtained from cathode tubes. The glass was milled to the fineness allowing it to completely pass through the sieve opening of 0,063 mm. Apart from the usual tests of the properties of fresh concrete, the hardened concrete underwent the bending tensile strength, splitting tensile strength and pull off strength tests at the age of 28 days. Based on the statistical processing of the obtained result, the effects of the addition of finely milled glass on the concrete properties were determined.

Key words: concrete, recycled glass, compressive strength, tensile strength, pull off

UTICAJ DODATKA RECIKLIRANOG STAKLA OD KATODNIH CEVI VELIKE FINOĆE MLIVA NA SVOJSTVA BETONA

Rezime: U radu su prikazani rezultati ispitivanja fizičkih i mehaničkih svojstava betona koji je spravljen sa dodatkom 0 do 10%, sa korakom od 2,5%, fino samlevenog recikliranog stakla koje potiče od katodnih cevi. Staklo je samleveno do finoće mliva koja omogućava da bez ostatka može da prođe kroz sito otvora 0,063 mm. Pored uobičajenih osobina svežeg betona, na očvrslom betonu utvđene su vrednosti čvrstoće pri pritisku pri starosti od 2, 7, 28 i 90 dana. Takođe, utvrđene su vrednosti čvrstoće pri zatezanju savijanjem, čvrstoće pri zatezanju cepanjem i pull off čvrstoća pri starosti od 28 dana. Na osnovu statističke obrade dobijenih rezultata utvrđen je uticaj dodatka fino samlevenog stakla na svojstva betona.

Ključne reči: beton, reciklirano staklo, čvrstoća pri pritisku, čvrstoća pri zatezanju, pull off

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1. INTRODUCTION

Ferdinand Braun was a scientist who designed the first cathode-ray tube in 1897. Until 1920, cathode-ray tubes (CRT) were used for reception and emission image of the first TV sets [1]. By the mid 20th century the first CRTs displaying image in color were introduced. One of the basic raw materials used for fabrication of CRT glass is silica (silicon dioxide), whose share is 50-60% [2]. In addition, the tubes are coated by metal oxides of barium and iron which serve as a protection from dangerous radiation when using the electronic devices. The European catalogue of waste materials of 2002 classified the waste glass made from recycled CRTs as dangerous was which must undergo certain treatment prior to being disposed at the landfills in order to remove all the matter potentially dangerous for humans and nature (lead, barium and strontium) [3].

Production of CRT glass increases every year. The mentioned catalogue of waste estimated in 2002 that he production of CRT glass reached 83.300.000 of units. Given the such extensive production it is logical that after a certain time, due to the development of electronics and obsolescence of many devices, proportionally huge waste will be generated. Data coming from many countries indicate the increase of the waste glass at the annual level. In California only, one of the most developed states of the USA, every year three million TV sets and almost as many computer monitors are disposed to landfills. Certain projections indicate that till 20150, the annual production of CRT glass in the world will be increased for almost six times [4]. Therefore, it can be concluded that waste CRT glass is a huge environmental problem for the entire world, and that it must be seriously addressed. One of the possible solutions is using the recycled glass to produce concrete.

Emam Ali and Sherif Tersawy tested the properties of fresh and hardened SCC, where they partially replaced the fine aggregate grade with recycled glass. The fine aggregate replacement share ranged between 0% and 50% by mass, with 10% increments. The testing results showed that the slump flow increased with the increase of replacement glass share in concrete. On the other hand, a certain decrease of compressive strengths and tensile splitting strength were recorded, as the share of replacement glass was increased [5].

Kou and Poon, researchers from the Faculty of Civil Engineering of Hong Kong, in addition to the previously mentioned experiments of SCC with added glass, also tested concrete shrinkage and resistance to chloride penetration. The results showed that with the increase of share of the added glass, shrinkage decreases, while the resistance of concretes to chloride penetration increases [6]. However, one of the most important conclusions in the papers [5] and [6], is that it is possible to successfully make a SCC with addition of recycled glass.

One of the potential usages of recycled CRT glass is replacement of a part of cement constituting mortars and concretes. In order to justify usage of glass as a partial replacement for cement, it is necessary to previously prove the puzzolanic activity of the glass.

The main problem when using recycled glass as concrete aggregate is potential for the rise of alkali-silica reaction (ASR). Recycled glass has a high content of amorphous silicon (e.g. glass bottles around 70%) which has a potential of reacting with the alkali in cement and ASR gel can be generated in the process [7]. ASR gel in humid conditions would expand in time, which would lead to the onset of cracks and later to the total destruction of hardened concrete. The size of the glass grains has a significant impact on the AS reactivity of glass. [7-10]. Some of the latest researches indicate that the size of the cracks inside the glass grains, which are grained in the grounding process, determine AS reactivity [7,8]. In cases of large internal cracks, it is easier for ASR to set in. On the other hand, a very finely ground glass powder does not cause ASR since less micro-cracks are present in it [8].

2. MATERIALS USED IN THE EXPERIMENT

Pure Portland cement CEM I 52,5R was used for making concrete mixes, as it meets all the quality requirements of the standard SRPS EN 197-1. Also, three fractions of the South Morava river aggregate were used, whereby 0-4 mm fraction had a share of 45%, 4-8 mm fraction had a share of 25%, while the third 8-16 mm fraction had a share of 30% in the mixture.

Experimental glass was provided to the Laboratory of building materials by the company "Jugo - Impex" E.E.R. d.o.o. It is a CRT glass which the company processes in the procedure of recycling of old TV sets and other electronic devices. Large shards of glass (figure 1, left) were ground to the fineness of 0-4mm in the asphalt plant of the company "Vodogradnja" Pukovac. The glass was milled to the desired fineness of 0,063 mm in the Laboratory of building materials (figure 1, right).

Figure 1 – Glass shards after recycling (left) and milled glass, finer than 0,063 mm (right)

The oxide composition of clear glass is common, and corresponds to the ratio N_2O : CaO : SiO_2 = 1 : 1 : 6, as confirmed by a chemical analysis (SiO_2 – 72,61%, Na_2O – 13,12%). The share of other oxides (Al_2O_3, MgO, K_2O, SO_3) is minor. No chemical admixtures were used in the experiment.

3. EXPERIMENTAL RESEARCH RESULTS

3.1. Glass puzzolanic activity tests

Puzzolanic activity of the glass was tested according to the standard SRPS B.C1.018:2001. The used standard classifies the puzzolanic material in three ways:

- According to the content of reactive silica (SiO_2)
- According to the particle size distribution
- According to the mechanical properties

Glass puzzolanic 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 24h 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 1.

Table 1 – Results of mechanical properties of mortar

Test specimen:	Flexural strength [N/mm^2]	Compressive strength [N/mm^2]
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 puzzolanically 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. The proved puzzolanic activity is in agreement with the research [7,8,10].

3.2. Concrete mixes composition

A total of five concrete mixes was made in the experiment (table 2). The goal was to make a classic concrete, without any chemical admixtures such as superplasticizers and air-entraining agents. The reference concrete was made with 400 kg of cement and 1720 kg of aggregate having three fractions. Water/cement ratio was kept constant at 0,50. The remaining four concrete batches were made by replacing a portion of cement with CRT glass. A protion of the cement mass was replaced with the recycled glass, the mass portions being 2,5% (the concrete marked C2,5), 5% (C5,0), 7,5% (C7,5) and 10% (C10,0).

Table 2 – Composition of the concrete mixes used in the experiment

Concrete	Aggregate						Glass	Cement	Water
	0/4 mm		4/8 mm		8/16 mm		<0,063mm		
	%	kg/m^3	%	kg/m^3	%	kg/m^3	kg/m^3	kg/m^3	kg/m^3
E	45	774	25	430	30	516	0	400	200
C2,5	45	774	25	430	30	516	10	390	200
C5,0	45	774	25	430	30	516	20	380	200
C7,5	45	774	25	430	30	516	30	370	200
C10,0	45	774	25	430	30	516	40	360	200

3.3. Test results and result discussion

The results of fresh concrete tests are presented in table 3. Slump test was conducted according to the standard SRPS ISO 4109:1997, and the content of entrained air was tested according to the standard SRPS ISO 4848:1997.

Table 3 – Fresh concrete test results

Concrete	Density [kg/m^3]	Slump class	Entrained air content [%]
E	2351	S2 (80 mm)	2,3
C2,5	2348	S2 (85 mm)	2,2
C5,0	2367	S2 (70 mm)	2,4
C7,5	2345	S2 (80 mm)	2,5
C10,0	2332	S3 (100 mm)	2,5

With the increase of glass content, there was no notable variation of density which averaged at 2350 kg/m^3. Slump class was S2, except in the case where 10% of glass was added and where slump was slightly higher – S3. A similar conclusion can be drawn about the content of entrained air since the results were fairly uniform, too.

Tabela 4 – Compressive strength values at the ages of 2,7, 28 and 90 days

Concrete	Age [days]			
	2	7	28	90
	f_p [N/mm^2]	f_p [N/mm^2]	f_p [N/mm^2]	f_p [N/mm^2]
E	29,1	36,4	44,2	50,9
C2,5	28,0	35,6	41,2	48,5
C5,0	27,1	34,6	40,0	47,1
C7,5	27,4	34,1	38,7	45,2
C10,0	26,1	32,6	38,2	40,7

The following parameters were tested on the hardened concrete: compressive strength (SRPS ISO 4012:2000), tensile splitting strength (SRPS ISO 4108:2000), flexural strength (SRPS ISO 4013:2000) and Pull off strength (SRPS EN 1542). The values of compressive strength at the age of 2,7, 28 and 90 days were presented in table 4.

The values of compressive strengths of all concrete mixes increase in the course of time, which was expected. It can be concluded that with the uniform increase of added glass content there is a uniform decrease of compressive strengths in comparison with the reference concrete, figure 2. Yet, there is no notable difference in compressive strengths of the reference concrete and C2,5, C5,0 concretes, nor even of C7,5 concrete. At the age of 28 days, the decrease of compressive strengths ranged from 6,79% for C2,5 concrete up to 12,44% for C7,5 concrete. At the age of 90 the decrease of strength in comparison with the reference concrete ranges between 10% for C2,5 concrete up to 16,14% for C7,5 concrete batch. The most prominent decrease of compressive strengths was measured in the case of concrete with 10% of recycled glass added. At the age of 28 days, this decrease in strengths was 13,57%, while at the age of 90 days the strength of C10 concrete batch was as much as 20,04% lower than the reference concrete.

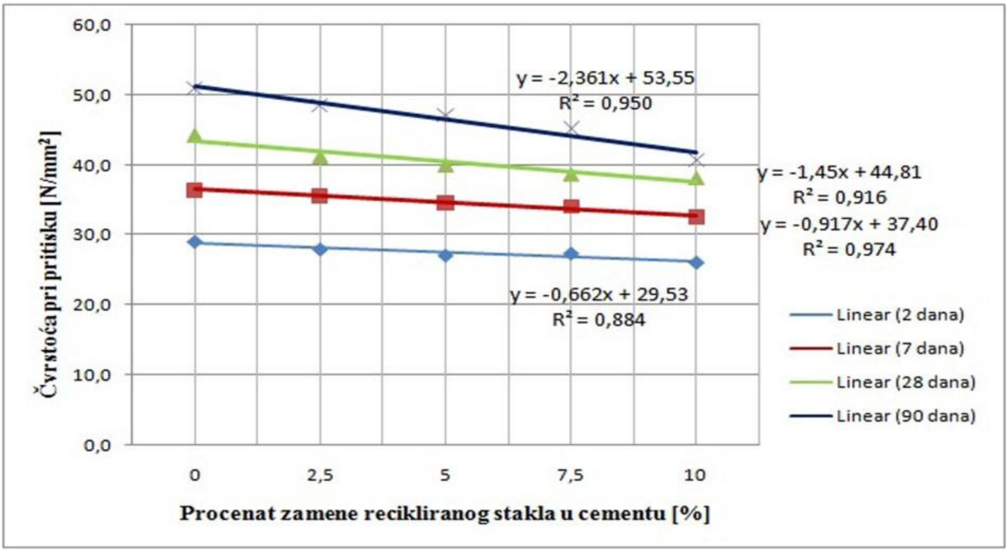

Figure 2 – Variation of compressive strength at the ages of 2, 7, 28 and 90 days in the function of quantity of added glass

The results of tensile splitting strength and tensile flexural strength were presented in figure 3. Through the statistic processing of data, it was concluded that the decrease of tensile strength is a polynomial function of the second degree with a high degree of correlation.

The highest decrease of tensile splitting strength of 28% was measured at C10 concrete. The decrease of flexural strength is lower in comparison to splitting strength so in the case of the highest content of added glass it amounts to only 12,5%.

Average values of bonding strength are presented in figure 4. The results were, to a great extent uniform, so in this occasion it cannot be assessed how replacement of one portion of cement with the recycled glass affects the bonding strength.

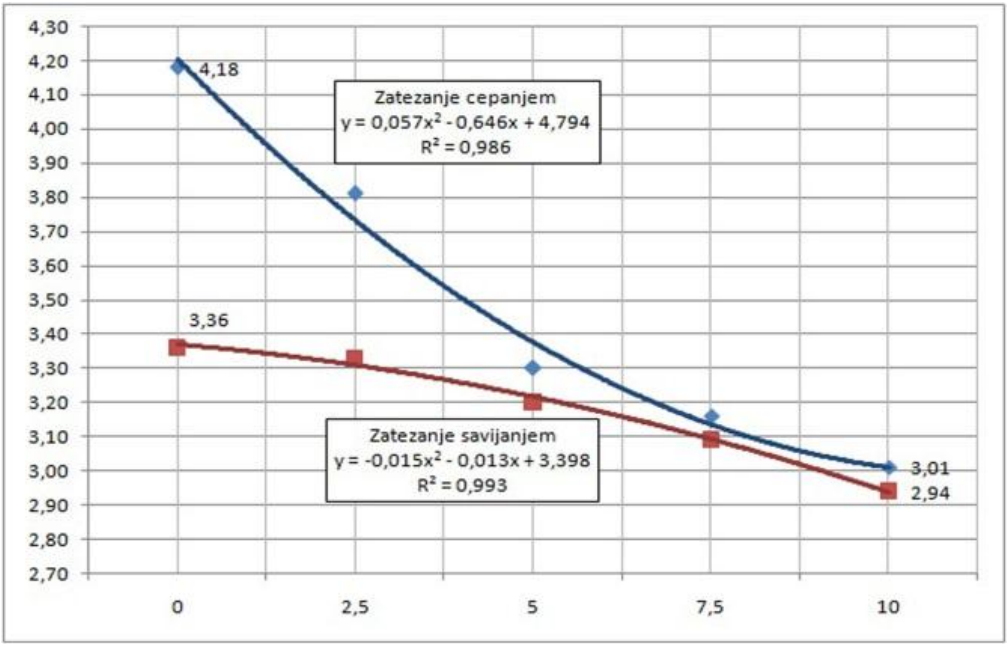

Figure 3 – Impact of addition of glass on the variation of tensile splitting and tensile flexural strengths

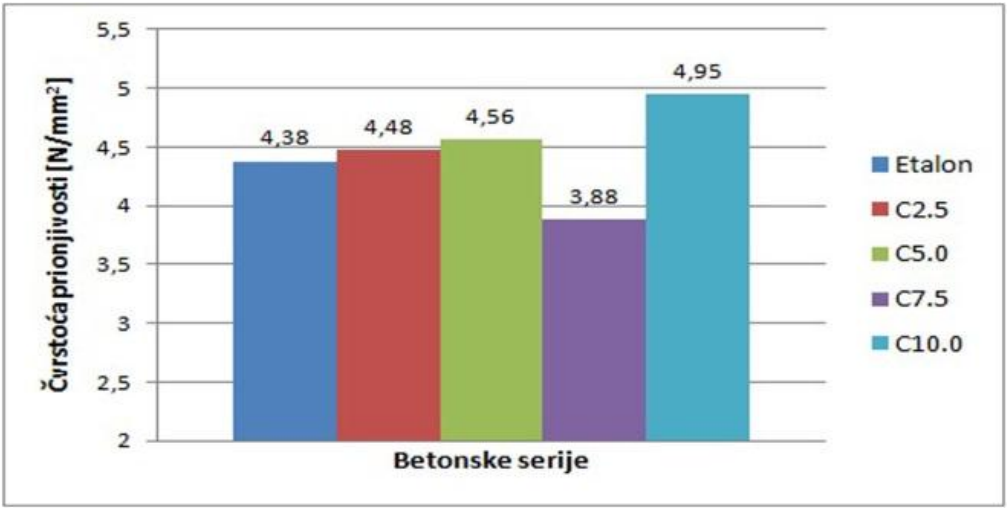

Figure 4 – Impact of addition of glass on the variation of bonding strength

4. CONCLUSION

Based on the obtained experimental results, the following conclusions can be made:

- Recycled glass is puzzolanically active, and on the basis of the tested mechanical properties it can be concluded that it belongs to class 5.
- Replacement of a portion of cement with the recycled glass in the 0 to 10% range does not have a notable impact on the change of density.
- There is no change in consistency, up to 7,5% of added glass. in case of C10 concrete batch the consistency is changed, in terms of increased slump.
- Increase of added glass content produces a negligible difference of entrained air content.
- With the increase of the recycled glass content, there is a decrease of compressive strength. The highest decrease is recorded for the C10 concrete batch an it is 13,57% at the age of 28 days, i.e. 20,04% at the age of 90 days.
- Tensile splitting strength and tensile flexural strength decrease as the share of glass in concrete increases. The decrease of tensile flexural strength is considerable lower than the decrease of tensile splitting strength. For the C10 concrete the decrease of tensile splitting strength is 28%, i.e. only 12,5% for the tensile flexural strength.
- The results of bonding strength are uniform for all the concrete batches. Additional tests are necessary to make a definitive decision about the impact of addition of CRT glass on this type of strength.

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