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DRUŠTVO ZA ISPITIVANJE I ISTRAŽIVANJE
MATERIJALA I KONSTRUKCIJA SRBIJE

SOCIETY FOR MATERIALS AND
STRUCTURES TESTING OF SERBIA

MEĐUNARODNI SIMPOZIJUM

O ISTRAŽIVANJIMA I PRIMENI SAVREMENIH DOSTIGNUĆA U GRAĐEVINARSTVU U OBLASTI MATERIJALA I KONSTRUKCIJA

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CIP- Каталогизација у публикацији
Народна библиотека Србије

624/628(082)
69(082)
666.7/.9(082)

МЕЂУНАРОДНИ симпозијум о истраживањима и примени савремених достигнућа у грађевинарству у области материјала и конструкција (2017 ; Вршац)
Zbornik radova = Proceedings / Međunarodni simpozijum o istraživanjima i primeni savremenih dostignuća u građevinarstvu u oblasti materijala i konstrukcija, [u okviru] XXVII kongres[a Društva za ispitivanje i istraživanje materijala i konstrukcija (DIMK) Srbije] - Vrsac, 18-20. oktobar 2017. = International Symposium on Researching and Application of Contemporary Achievements in Civil Engineering in the Field of Materials and Structures, [within] XXVII Congress [of Society for Materials and Structures Testing of Serbia] - Vrsac, October 18-20, 2017. ; [editor Dragica Jevtić, Radomir Folić]. - Beograd : Društvo za ispitivanje i istraživanje materijala i konstrukcija Srbije, 2017 (Beograd : Razvojno istraživački centar grafičkog inženjerstva TMF). - 563 str. : ilustr. ; 30 cm

Radovi na srp. i engl. jeziku. - Tiraž 100. - Napomene uz radove. - Bibliografija uz većinu radova. - Summaries.

ISBN 978-86-87615-08-3

1. Друштво за испитивање и истраживање материјала и конструкција Србије (Београд). Конгрес (27 ; 2017 ; Вршац)

а) Грађевински материјали - Зборници

b) Грађевинске конструкције - Зборници

c) Грађевински објекти - Зборници

COBISS.SR-ID 247427852

Izdavač: **Društvo za ispitivanje i istraživanje materijala i konstrukcija Srbije**
Beograd, Kneza Miloša 9/I

Editor: **Prof. dr Dragica Jevtić, dipl.inž.tehn.**
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Štampa: Razvojno istraživački centar grafičkog inženjerstva, Karnegijeva 4, Beograd

Tiraž: 100 primeraka

"Simpozijum o istraživanjima i primeni savremenih dostignuća u građevinarstvu u oblasti materijala i konstrukcija", koji je upriličen u okviru **XXVII Kongresa Društva za ispitivanje i istraživanje materijala i konstrukcija (DIMK) Srbije**, Vršac 18.-20. oktobra 2017. godine, održan je u saradnji sa **Institutom za ispitivanje materijala IMS Beograd**, a pod pokroviteljstvom **MINISTARSTVA PROSVETE, NAUKE I TEHNOLOŠKOG RAZVOJA REPUBLIKE SRBIJE.**

Vršac, oktobar 2017. godine

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DRUŠTVO ZA ISPITIVANJE I ISTRAŽIVANJE MATERIJALA I KONSTRUKCIJA SRBIJE
SOCIETY FOR MATERIALS AND STRUCTURES TESTING OF SERBIA

XXVII KONGRES – Vršac 18-20. oktobar 2017.
XXVII CONGRESS – Vrsac October 18-20, 2017.

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ISPITIVANJE ALKALNO-SILIKATNE REAKCIJE MALTERA SA DODATKOM STAKLA OD KATODNIH CEVI

Rezime: *Elektronski otpad iz domaćinstva često nastaje usled modernizacije i urbanizacije životnog i radnog prostora, ali i usled dotrajalosti uređaja, najčešće televizora i monitora. Iako retko reciklirane i vraćene u ponovnu upotrebu, katodne cevi od televizora i monitora (CRT) mogu se upotrebiti u vidu komponente za spravljanje kompozitnih mešavina. Malter i beton, kao neke od najprimenjivijih kompozitnih mešavina, pogodni su za primenu otpadnih materijala koji se mogu upotrebiti kao komponente u njihovom sastavu.*

U ovom radu prikazan je deo istraživanja uticaja usitnjenog CRT stakla na pojavu alkalno-silikatne reakcije (ASR) u malterskim mešavinama, kao i pri ispitivanju čvrstoće na savijanje i čvrstoće pri pritisku maltera sa zamenom drobljenog agregata usitnjenim CRT staklom. ASR ispitivanje je prema standardu RILEM RC 106-2 AAR.

Ključne reči: *Staklo od katodnih cevi, malter, alkalno-silikatna reakcija, savijanje, pritisak*

ALKALI-SILICA REACTION TESTING OF MORTAR WITH ADDED WASTE CRT GLASS

Summary: *Household electronic waste is often generated due to modernization and urbanization of workspace and living space, as well as due to wear-and-tear of devices such as TV sets and computer monitors. Although seldom recycled and reused, TV and monitor cathode-ray tubes (CRTs) can be used as ingredients in composite mixtures used in construction industry. As some of the most widely used composite mixtures, mortar and concrete are suitable for application of such recycled material ingredients.*

This paper presents part of the research study into impact of ground CRT glass on the alkali-silica reaction (ASR) in mortar mixtures, as well as impact of replacing crushed construction aggregate with ground CRT glass on tensile and pressure stress qualities of mortar.
ASR testing was done according to the RILEM RC 106-2 AAR guidelines.

Key words: *Waste CRT glass, mortar, alkali-silica reaction (ASR), tensile stress, pressure stress.*

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1. INTRODUCTION

Rapid advancements in electronics industry brought increased usage of liquid crystal displays (LCD) and almost completely replaced cathode ray tube (CRT) displays in devices like televisions, computer monitors and others. Modernization and urban city life together with industrialization and technological advancements lead people to think more about comfort and convenience, but less about their impact on the environment. It is reported that amount of CRT waste in Western Europe area is about 300,000 tons annually and rising [9]. Re-using waste CRT glass contributes to resource and energy savings. From an environmental point of view, waste glass recycling may become an important and sustainable approach to environmental protection [10].

Extensive research has shown that quality of new glass materials produced from recycled glass is acceptable only if the level of contamination from other categories and colors of glass (plastic, metal, ceramic, organic material etc.) is within acceptable limits. Possible uses of waste glass in civil engineering are in back-filling, roadway constructions, pipe bedding, drainage applications, landfill gas, architectural and decorative applications, etc. [11]. When researchers discovered that glass can be used as a building material, they also found glass to be unstable in alkali concrete.

Deterioration and even failure of concrete structures due to alkali-silica reaction (ASR) results from reactivity within the fabric of concrete sufficient to produce and propagate microstructures [6]. ASR is a concrete durability problem. In most cases, aggregates are chemically inert.

2. ALKALI-SILICA REACTION IN MORTAR

The main concern of using waste glass in concrete or mortar (as a partial substitute of cement or aggregate) is the possible ASR between cement paste and glass aggregate (or glass cement). That effect may produce excessive expansion, as well as internal and surface cracking. Previous research showed that using low alkali cements, cement with pozzolanic materials or reducing particle size of waste glass can reduce or even eliminate this effect [12]. Some of the aggregates react with alkali hydroxides in concrete which then leads to expansion and cracking of concrete in exploitation time. Alkali aggregate reaction has two forms: alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR) [7]. ASR as phenomenon in glass concrete/mortar is still hard to diagnose before using appropriate tests [1]. ASR is actually a reaction between the hydroxyl ions (OH^-) in the pore solution and reactive silica in the aggregate. The alkalis initially contribute to high concentration of hydroxyl ions in solution and forming of expansive alkali-silica gel. When poorly-crystalline hydrous silica is exposed to a strong alkaline solution, there is an acid-base reaction between the hydroxyl ions in solution and the acidic silanol (Si–OH) groups [8]. In general, ASR is critical factor limiting the incorporation of alkali reactive aggregate and cement. The amorphous silica in glass is susceptible to attack by alkaline environment and depolymerize to form a monomer $S_i(OH)_4$ which could further react with alkalis such as K^+, Na^+ and Ca^+ to form ASR gel [1]. Nowadays, more technologically advanced countries have in place national regulations for prevention of ASR in concrete structures and it's based on various principles that have to take into account material properties and local experiences [3].

2.1. Rapid test methods

Today there is a real need to immediately detect alkali reactivity of concrete made of alkali reactive aggregate. The testing is tasked to quickly determine a potential alkali-reactivity of aggregates through the evaluation of the expansion of mortar-bars. Procedures of some of the most often used rapid tests for alkali reactivity detection of aggregate are in Table 1.

Name of the test	Procedure of using
ASTM C227Mortar bar test	Bars in these tests were placed in heat-sealted, polyethylene bags with 10ml of water. Expansion are limited to 0.05% at 3 months, to 0.10% to 6 months. Some late expansions of alkali-silicate reactive aggregates should not be higher of 0.10% at 18-24 months
NBRI method	This method is planned by Oberholster and Davies. Mortar bars, as bars dimensions according to ASTM C227 test, are exposed to 1M NaOH solution at 80°C for 14 days. Expansion should be measured in a hot bar condition. Expansion are limited to 0.10% for innocuous, 0.10% to 0.25% to slowly expansive and greater than 0.25% for rapidly expansive aggregates
Duncan method	Mortar bars, as bars dimensions according to ASTM C227 samples are exposed to 100% relative humidity and to the temperature of 64°C for 16 days. Expansion is limited to 0.05%
Danish salt method	ASTM mortar bars are exposed to saturated NaCl solution at 50°C. Expansion is limited to 0.10% in a salt solution. Report must be given at 8 and 20 weeks.
Japanese rapid test	ASTM mortar bars are made with adding NaOH to raise Na_2O to 3%, than at 24hours they are exposed to saturated stream at 125°C (0.15MPa) for 4 hours.
Chinese autoclave test	Mortar bars are cured at 125°C in stream prior to autoclaving in 10% of KOH solution for 6 hours at 150°C.
Rilem TC 106-2 AAR Ultra-accelerated mortar-bar test (UAMBT)	Prisms are moulded from mortar prepared with aggregate to be tested. The specimen are placed in the containers with 1M NaOH solution already heated to 80°C. Expansion of the specimens must take periodically to 14days.

Table 1. Procedure of using rapid ASR mortar bar tests[6][4]

2.2. Detection of alkali-reactivity of aggregates – Ultra-accelerated mortar-bar test (UAMBT)

In accordance to ASTM C 227 standard, mortar bars 25 mm x 25 mm x 285 mm or 40 mm x 40 mm x 160 mm in size should be prepared. Principle of the method is that the prisms should be demodulated after 24 hours and their initial length measured. The specimens are then placed in the water and heated in the oven to 80°C for the next 24 hours. After specimens are removed from the water, zero expansion reading must be taken before cooling. The specimens then should be placed in the containers with 1M NaOH solution already heated to 80°C. Expansion of the specimens must be recorded periodically for 14days. A set of sieves according to ISO 6274, having square apertures of 4 mm, 2 mm, 1 mm, 500 µm, 250 µm and 125 µm. A balance capable of weighing 1000 g must be with accuracy 1g. Modules providing for prisms with a 285 mm length, and cross section 25 mm x 25 mm (lengths in range 250 mm to 300 mm are also acceptable), also according to Note 1, moulds for prisms 40 mm x 40 mm x 160 mm can also be considered. An ordinary Portland cement CEM I or ASTM type I with minimum Na_2O could be used. The specific surface of cement, when measured according to the air permeability method shall be greater than 450 m^2/kg.

Proportion of the dry materials for the test mortar using 1 part of cement to 2.25 part of the aggregates by mass. Recommended water/cement ratio is 0.47 by mass.

Grading requirements		
Sieve Size		Mass %
Passing	Retained	
4 mm	2 mm	10
2 mm	1 mm	25
1 mm	500 µm	25
500 µm	250 µm	25
250 µm	125 µm	15

Table 2. Grading requirements

3. EXPERIMENTAL DETAILS AND TEXTING PROGRAMME

According to D. Grdić et al. [2] further research should be continued on influence of ASR on mortar properties, shrinking due to drying, modulus of elasticity. This paper is a continuation based on recommended research of ASR on mortar.

3.1. Materials

The test specimens were manufactured using the CRH cement CEM I 52,5R, conforming to SRPS EN 197-1 [5] with alkali content of 1.03%.

Crushed limestone aggregate Dolac was used as aggregate with maximum nominal size 4 mm. Recycled washed glass aggregate was taken from „E-reciklaža“ Niš company and crushed by laboratory mill.

Standard tap water was used during the concrete production in all mixtures. Crushed glass aggregate was crushed to the granulation 2/4 mm, 1/2 mm, 0.50/1 mm, 0.25/0.50 mm, 0.125/0.50 mm. The oxide composition of clear glass is usual, and corresponds to the ratio N_2O : CaO : SiO_2 = 1 : 1 : 6, which was confirmed on this occasion as well: (SiO_2 – 72,61%, CaO – 11,70%, Na_2O – 13,12%). Presence of other oxides (Al_2O_3, MgO, K_2O, SO_3) is negligible. No chemical admixtures were used in the experiment [2].

3.2. Mixture proportions

The portion of dry materials used for the test mortar was 1 part of the cement to 2.25 parts of aggregate by mass. Used free water/cement ratio of 0.47 by mass, where the free water was available for cement hydration. For testing five different mixtures were prepared. The referenced mortar (E) comprised of cement and natural crushed limestone aggregate.

	w/c	cem	Mass retained between sieves (g)									
			0.125 – 0.25 mm		0.25 – 0.5 mm		0.5 – 1 mm		1 – 2 mm		2 – 4 mm	
	G	g	A	G	A	G	A	G	A	G	A	G
E	282	600	202.50	0	337.50	0	337.50	0	337.50	0	135.00	0
25 G	282	600	151.87	50.63	253.12	84.38	253.12	84.38	253.12	84.38	101.25	33.75
50 G	282	600	101.25	101.25	168.75	168.75	168.75	168.75	168.75	168.75	67.50	67.50
75 G	282	600	50.63	151.87	84.38	25.12	84.38	253.12	84.38	253.12	33.75	101.2
100 G	282	600	0	202.50	0	337.50	0	337.50	0	337.50	0	135.0

Table 3. Mixture proportion of mortars A-crushed limestone aggregate; G-recycled glass aggregate

Other mixtures with natural valley gravel aggregate were replaced by recycled glass aggregate, waste CTS glass aggregate at 25% (25G), 50% (50G), 75% (75G) and 100% (100G) (Figure 1.). The mixture proportions of mortar are in Table 3.

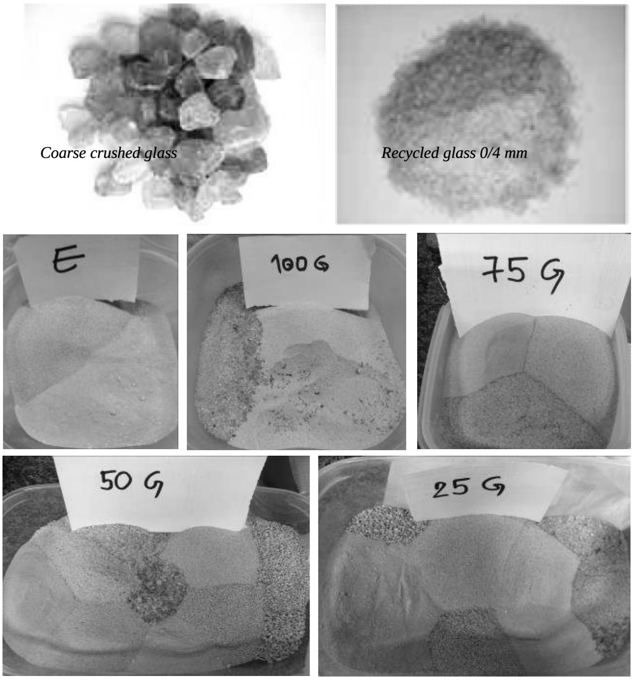

Figure 1. Dry materials used in the test

3.3. Test results

The test research of ASR in mortar, according to RILEM TC 106-2 AAR standard recommendations, has been carried out for a period of 14 days. The observed period is a period in which the most turbulent reactions have been expected in the form of chemical reactions between cement, aggregate and water. Results of expansion tests are given in Diagram 1.

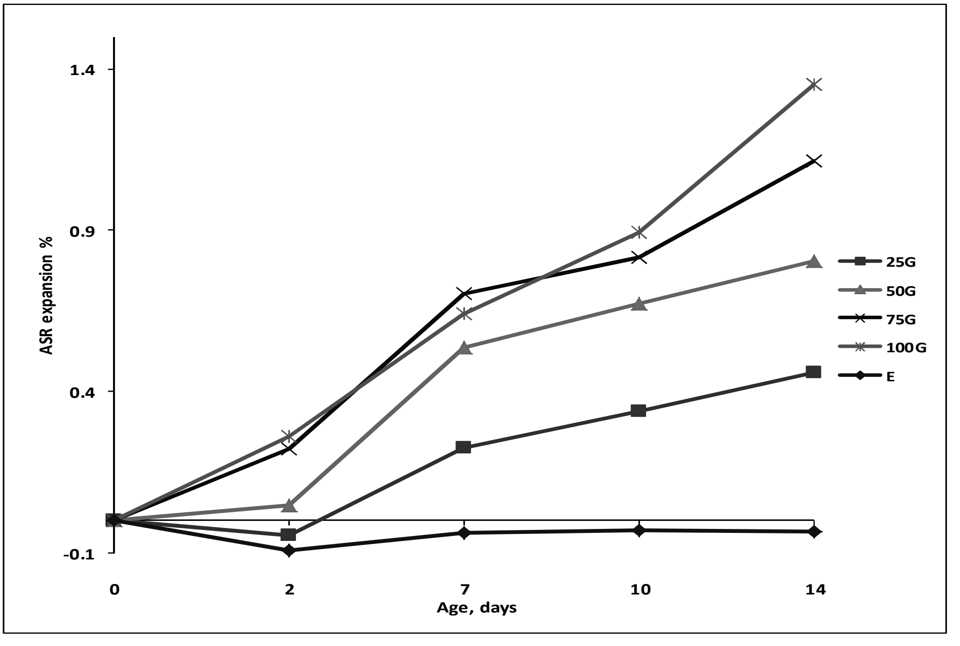

Diagram 1. Expansion of mortar bars including CRT recycled glass

Diagram curves show shrinkage and expansion processes in the observed specimens in various percentages used crushed CRT glass replacing crushed limestone aggregate. The observation period, shrinking is characteristic for etalon (E) specimens, and specimens where the crushed limestone aggregate has been replaced by crushed CRT aggregate in an amount of 25% (25G) for a measurement on 2 days. Other curves that represent the behavior of samples during the observed period show only expansion. For the observed period of 2 days, mixtures named 50G, 75G and 100G, lowest percentage of expansion are for the mixture group 50G (0.045%), while the highest percentage of expansion has been found in specimens from the group 100G (0.26%). When observing period was 7 days, all observed specimens, except from group E, show the expansion process. The highest percentage of expansion has been found in samples of group 75G (0.70%), while the smallest percentage of expansion has been found from the specimens of group 25G (0.22%). In this period, expansion of samples from group 100G was 0.64%. When observation period was 14 days, the highest percentage expansion belongs to the samples of 100G group (1.35%), while the smallest percentage of expansion belongs to the samples of 25G group (0.46%). In Figure 2, samples of 75G and 100G were shown. Crack on surface visible on the 100G specimens

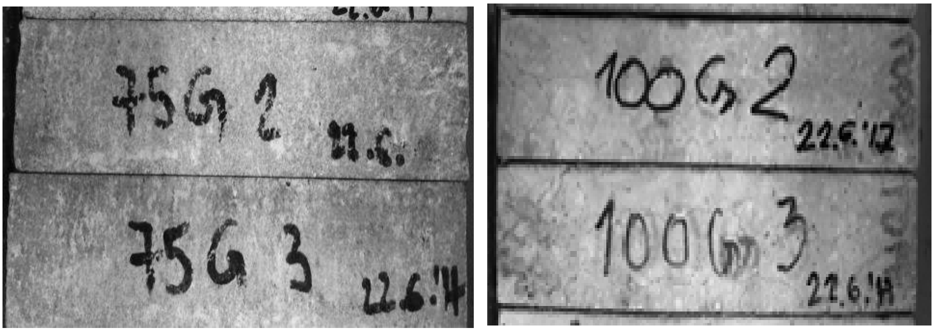

Figure 2. Surface of specimens 75G and 100G

The pressure and tensile strength, as the most important characteristics of the mortar, are similar for mortar at the observed age, Table 4. At the age of 14 days, the highest strength at pressing and tensile stress showed the mixture of etalon – mixture named E. The smallest compressive and tensile strength showed mixture where 100% of crushed limestone aggregate was replaced – mixture named 100G.

Mortar type	fs N/mm^2	fp N/mm^2
E	9.98	60.04
25G	9.48	56.99
50G	9.08	55.53
75G	7.15	49.31
100G	6.88	42.23

Table 4. Tensile and compressive strengths of mortar after 14 days

4. CONCLUSION

Observation of mortar shrinkage and expansion processes, conducted in accordance with test duration standard, lead to the conclusion that during the observation period ASR had an impact on the expansion of mortar with ground CRT glass used in place of crushed limestone aggregate. The impact of ASR on expansion increased with higher percentage of recycled CRT glass replacing crushed limestone aggregate. Reduced compressive and tensile strength values are attributed to significantly smoother surface of the CRT glass aggregates, as well as the fact that recycled glass aggregate has a harmful coating that prevents proper adhesion of the recycled glass aggregate's grains and cement matrix. Aside from being prescribed by the RILEM TC 106-2 AAR guidelines used in this research, 14 day testing period is significant for the fact that the most important chemical reactions in the mixture occur during that time period.

Specimen monitoring continued for 90 days to see through completion of hydration process between cement and mortar. Further research should be conducted using same testing methodology and guidelines using cements that contain mineral additives, as well as using mineral supplements to partially substitute cement or aggregate in order to further reduce adverse effects of ASR.

ACKNOWLEDGEMENTS

Authors of this paper would like to thank Professor Goran Radenković, Faculty of Civil Engineering and Architecture, University of Niš and Laboratory for Building Materials, who provided equipment and materials for the conduct of this test.

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