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

MEĐUNARODNI SIMPOZIJUM

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IMPACT OF REPLACEMENT OF NATURAL AGGREGATE WITH THE RECYCLED GLASS OBTAINED FROM CATHODE TUBES ON THE CHANGE OF CEMENT MORTAR PROPERTIES

Abstract: *The contemporary trend in the construction industry in the world is usage of alternative sources of building materials which can, at least to some extent, replace the traditional material, primarily for the purpose of reduction of the harmful effects on the living environment. The paper presents the results of experimental research of the change of properties of fresh and hardened cement mortar which occurred due to replacement of the natural aggregate with the recycled glass obtained by crushing of the cathode tubes. The natural aggregate was replaced by the recycled glass in the following percentage: 25%, 50%, 75% and 100%. It was found that the recycled glass affects the consistency and density of the mortar, compressive strength, bending strength and frost resistance. No considerable impact on the compressive strength and entrapped air was found.*

Key words*: cement mortar, recycled glass, consistency, air content, strength, frost resistance*

UTICAJ ZAMENE PRIRODNOG AGREGATA RECIKLIRANIM STAKLOM OD KATODNIH CEVI NA PROMENU SVOJSTAVA CEMENTNOG MALTERA

Rezime: *Savremeni trend u industriji građevinarstva u svetu je upotreba alternativnih izvora građevinskih materijala koji makar jednim delom mogu zameniti tradicionalne materijale, pre svega u cilju smanjenja štetnog uticaja na životnu sredinu. U radu su prikazani rezultati eksperimentalnog istraživanja promene svojstava svežeg i očvrslog cementnog maltera koje su nastale usled zamene prirodnog agregata recikliranim staklom dobijenim drobljenjem katodnih cevi. Zamena prirodnog agregata recikliranim staklom je rađena u količini od 25%, 50%, 75% i 100%. Utvrđeno je da reciklirano staklo utiče na konzistenciju i zapreminsku masu maltera, promenu čvrstoće pri savijanju i otpornost na delovanje mraza. Značajniji uticaj na promenu čvrstoće pri pritisku i sadržaj uvučenog vazduha nije utvrđen.*

Ključne reči: *cementni malter, reciklirano staklo, konzistencija, sadržaj vazduha, čvrstoća, otpornost na mraz*

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1. INTRODUCTION

The contemporary trend in the construction industry in the world is usage of alternative sources of building materials which can, at least to some extent, replace the traditional materials. The primary purpose is reduction of the harmful effects on the living environment, in terms of energy consumption, pollution, waste disposal and global warming. The disposed and recycled materials, as well as industrial by-products are used for making of contemporary mortars and concretes for several decades. Application of industrial by-products which have certain puzzolanic activity (fly ash, grounded granulated slag, etc.) is well known in the cement industry. In the latest period, starting from 80s, these materials were implemented in making of self-compacting concretes. The research in this field was conducted in our country as well, [2-4]. Even though the research on this topic and others conducted in our country yielded results which are applicable in practice, usage of SCC is still very limited.

Potential for application of different waste and recyclable material for concrete making is also a global object of research for several decades. During this period a large number of papers was published where the research results were presented. Granulated recycled rubber which is available in Serbia is very frequently tested. Extensive research regarding the concrete with the addition of rubber were performed in the Laboratory for Building Materials of the Faculty of Civil Engineering of Niš. The authors concluded that the replacement of up to 10% of fine river aggregate with rubber granules contributes to slightly better hydro-abrasion resistance of concrete [5]. D. Jevtić et al. also dealt with the research of the cement-based composite made with recycled rubber aggregate [10].

Nabajyoti and de Brito researched the properties of fresh and hardened concrete in which 5%, 10% and 15% of volume of the natural aggregate is replaced by shredded PET packaging material [15]. The authors concluded that addition of PET aggregates improves abrasion resistance of concrete, even though there is a certain reduction of concrete strength. In our area, usage of rice husk is completely exotic, but in the countries where rice is grown on an industrial scale, numerous researches were conducted investigating potential of application of the rice husk ash as an addition in concrete making. Gastaldini et al [1] researched total shrinking, chloride penetration and compressive strength of the concretes which had 5%, 10%, 20% and 30% of Portland cement was replaced by the rice husk ash. The authors, apart from other affirmative results, also concluded that substitution of only 5% of pure Portland cement with the rice husk ash reduces the concrete cost.. Hesami et al. [14] who studied the impact of cement replacement in the range between 0% and 12% of rice husk ash in cavernous concretes concluded that the optimum replacement quantity is 8% to 10% of cement whereby the desired properties of concrete are achieved.

Crushed and ground waste from the fired brick products can be used for making of concretes and concrete prefab materials. The colleagues from the IMS [9] Institute who researched potential for replacement of natural aggregates in the percentage between 25% to 100% by the crushed brick, and application of the concretes for production of the pedestrian pavement blocks. Disfani et al. [12] researched the potential of application of aggregate obtained by crushing the bricks for cement stabilization in road building.

Based on the number of published papers, it can be concluded that he aggregate of recycled concrete, as a component of new concretes, perhaps was the most frequent research subjects. Research, scientific projects and doctoral dissertations in this field were successfully done in Serbia as well [2, 13].

2. RECYCLED GLASS AS AGGREGATE FOR MORTARS AND CONCRETES

Glass is being produced in various forms: bottles, jars and other containers for the food processing industry, flat glass for windows, shop windows and similar purposes, light bulbs, cathode tubes, LCDs in various electronic devices, etc. The glass recycling process (though it refers to other materials, as well) consists of collection, separation, processing and manufacturing of a new product. The waste glass must be separated according to the type, either on its original site or in the recycling facility. It is particularly important in the case of glass, since mixing of glass of different colors is not allowed, not only for the purpose of addition to concrete, but also when used for other purposes. Glass, and especially that which is created as a waste of food processing industry, can be recycled unlimited number of times. In effect, 90% of recycled glass is used for production of new food storage containers [19]. As for the clear glass, great care must also be taken, since considerable quantities originate from CRT and LCD screens, which are extremely toxic because of the coatings on their interior sides. These types of glass should be treated separately from other clear glasses. Separation of the mentioned coatings and their safe storage presents a special problem. The company „Jugo-Impex“ E.E.R. d.o.o. „E-Reciklaža“ from Niš, in their state-of-the-art facility manages to recycle up to 97% of the waste. However, the remaining 3% of hazardous matter must be exported to Germany and Holland in the specialized facilities for treatment of this matter. This export is different from the usual sense of the term, since no money is earned from it, but on the contrary, it must be paid for. It was the second reason for the conducted research. The mentioned company cleaned a certain amount of CRT glass (cathode tubes) from the hazardous coatings, so the remaining clear glass was used in the experimental work. Irrespective, in the work with it, all protective equipment for eye, skin and respiratory system was used.

Research of potential for application of recycled glass in concrete making is very numerous, which is witnessed by a large number of papers published in the world. The research was conducted both on fresh and hardened concrete, whereby, the object of interest were practically all the concrete properties. A special attention was paid to research of alkali-silicate reaction of glass – $Ca(OH)_2$ in presence of moisture, since this form of corrosion is most damaging from the aspect of concrete durability. It has been stated long ago that glass is instable in the alkali environment, so the solution of this issue was approached from two directions: crushed glass was rendered inert and potential puzzolanic properties of the glass were activated. For example rendering glass inert and ASR were researched by Shi-Cong and Chi-Sun [18] by using the polymer – epoxy resin as binder and fine crushed glass (< 10 mm) with addition of fly ash and metakaolin. The obtained concretes have excellent properties but are also very expensive, at the same time.

The other, much more present direction in research is activation of potential puzzolanic properties of the glass. In order to achieve this goal, glass must be ground in a very fine powder (< 10 μm). Experimental research showed that with such powder, it is possible to replace up to 30% of cement in concrete without detrimental effects [17].

The authors of this paper have knowledge of only two small scale researches done in our country [6, 11]. It was another reason to engage in research of the subject matter.

3. EXPERIMENTAL RESEARCH

3.1. Materials used in the experiment

Experimental research was conducted on the samples made from cement mortar. For making of the mortar, Holcim cement CEM I 52,5R was used, which meets all the quality conditions according to the standard SRPS EN 197-1. For making of the reference mortar was used fine aggregate (0/4 mm) from the South Morava river, from the screening plant „Vodogradnja“ d.o.o. Pukovac which meets all the quality conditions according to the standard SRPS B.B2.010.

Coarse crushed glass (figure 1, left) was additionally crushed to the granulation 0/4 mm (figure 1, right) from which, in the further procedure, almost all particles smaller than 0,125 mm were removed in order to make the particle size distribution as similar as the natural river aggregate as possible. The particle size distribution of the river aggregate and of the recycled glass aggregate were presented in figure 2.

Figure 1. Coarse crushed glass (left) and recycled glass 0/4 mm (right)

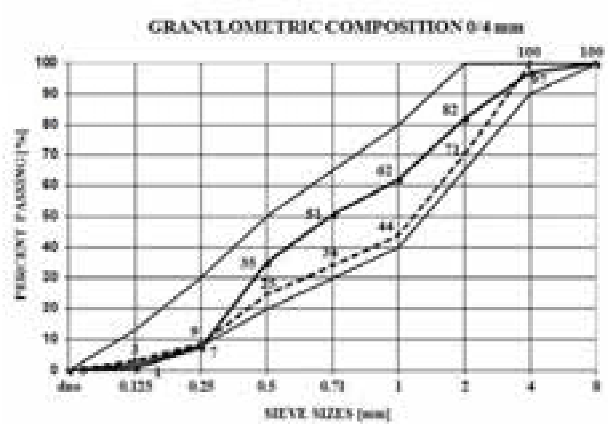

Figure 2. Particle size distributions of the river aggregate and recycled glass aggregate

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.

3.2. Composition of mortar mixtures and test results

For the purpose of testing of the influence of fine river aggregate replacement with the appropriate recycled glass aggregate, five different mortar mixtures were made. The ratio of cement (m_c) and sand (m_p) was kept constant and it was $m_c : m_p = 1 : 3$. Water cement ratio was also constant, and amounted to 0,5. The reference mortar (E) was made with fine river aggregate only, while in other four mortars, it was replaced by the aggregate of recycled glass, in the amount of 25%, 50%, 75% and 100%. The replacement of the river aggregate by the recycled glass was performed in terms of volume. According to the substitution quantity, the following designations were assigned to the mortar mixtures: WG25, WG50, WG75 and WG100. Compositions of all mortar mixtures are given in table 1. In the same table are given the results of consistency tests (mortar flow test according to SRPS B.C8.042), air content (according to SRPS B.C8.050) and density of fresh compacted mortar (according to SRPS ISO 6276).

Fresh mortar	Mortar designation				
	E	WG25	WG50	WG75	WG100
Cement mass [g]	450	450	450	450	450
River aggregate mass [g]	1350	1012	675	338	-
Recycled glass mass [g]	-	351	701	1052	1402
Water mass [g]	225	225	225	225	225
Consistency [mm]	130	145	160	170	175
Air content [%]	5	5,4	4,8	4,6	5,0
Density [kg/m^3]	2265	2305	2345	2383	2396

Table 1. Composition of mortar mixtures, and fresh mortar test results

Compressive strength is tested at the ages of 2, 7, 28 and 90 days according to SRPS EN 196-1. The testing results are presented in table 2.

Mortar type	Age [days]							
	2		7		28		90	
	f_s [N/mm^2]	f_p [N/mm^2]	f_s [N/mm^2]	f_p [N/mm^2]	f_s [N/mm^2]	f_p [N/mm^2]	f_s [N/mm^2]	f_p [N/mm^2]
E	5,6	27,5	7,9	46,3	8,4	55,3	9,3	62,8
WG25	6,0	29,8	7,3	43,6	8,1	57,2	8,1	62,5
WG50	5,9	30,6	7,5	44,9	7,6	57,1	6,8	64,7
WG75	5,8	29,6	6,4	45,7	7,0	51,8	6,0	62,8
WG100	5,9	29,6	5,9	41,6	6,0	49,2	5,9	59,3

Table 2. Bending and compressive strengths of mortar after 2, 7, 28 and 90 days

Mortar frost resistance tests was performed in a generally known way (SRPS U.M8.002, item 14), by freezing the saturated samples at the temperature of -20˚C for a duration of 4 hours and defrosting in the water having temperature 20˚C, for a total of 25 times (one cycle a day). The flexural and compressive strength test results after 25 cycles of frost action are graphically displayed in figures 3 and 4.

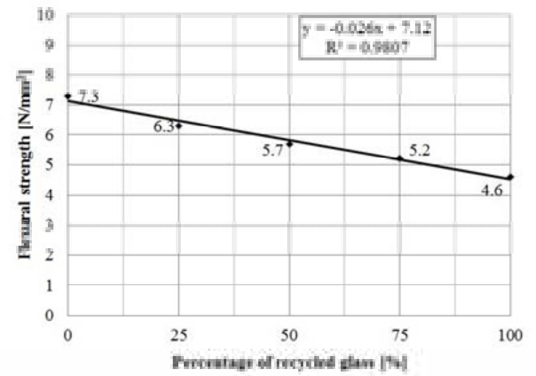

Figure 3. Variation of flexural strength after 25 cycles of frost action, as a function of the content of recycled glass in mortar

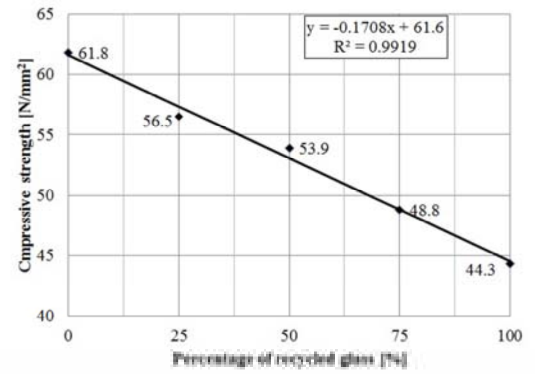

Figure 4. Variation of compressive strength after 25 cycles of frost action, as a function of the content of recycled glass in mortar

4. RESULTS DISCUSSION

Based on the consistency test results obtained by measuring the mortar flow (table 1) it was determined that with the increase of the glass content, the spreading increases. At first sight, having in mind the form of the grains, one may expect the opposite behavior of mortar in terms of consistency change. However, it is known that glass does not absorb water as opposed to the natural aggregate, so the increase of the content of glass in mortar causes increased quantity of water in the cement paste. Such, increasingly liquid paste contributes to the reduction of friction inside mortar, which results in increased spreading. Such testing results are in agreement with the results of other researches, as mentioned in the literature [8].

By reviewing the results available in the literature, for instance [8, 16], it was supposed that replacement of the natural aggregate by the recycled glass leads to the increase of air content. It must be noted that the analyzed results were obtained by testing the concrete with the recycled glass aggregate having grain size up to 25 mm. In this research the air content in all mortars is around 5% (table 1). There are small differences in the measured values, but they can be considered relevant, and in part can be ascribed to technical characteristics of porosimeter equipment.

Density of fresh compacted mortar (table 1) increases with the increase of the natural aggregate with recycled glass. These results are in agreement with the data which are in agreement with the data mentioned in the literature, for example [7]. The increase of density ranges between cca. 2% for mortar with 25% of recycled glass to cca. 6% for mortar with 100% of natural aggregate replacement.

The values of compressive strength, as expected, increase in time, whereby they are considerably regular for the appropriate age, table 2. At the age of 2 days, compressive strength moves from 27,5 N/mm^2 to 30,6 N/mm^2, at the age of 7 days from 41,6 N/mm^2 to 46,3 N/mm^2, at the age of 28 days from 49,2 N/mm^2 to 57,1 N/mm^2 and at the age of 90 days from 59,3 N/mm^2 to 64,7 N/mm^2. The relative differences of the lowest and highest values of compressive strength for the same age are fairly regular and amount to 11%.

As opposed to the compressive strength, the flexural strength, except at the age of 2 days, reduce with the increase of content of glass in mortar, table 2. Explanation for such trend should be sought in the microstructure of mortar, more accurately in the quality of the bond between the aggregate grains and hardened cement paste – transition zone. By analyzing the microscopic imaging of the broken mortar prism samples after the test, it was determined that the surface of the glass grains is completely clean, figure 5 left. This indicates that the bond with the hardened cement paste is considerably weaker than in the case of river aggregate case, figure 5 right. It was also seen that he breaking line of mortar with recycled glass mostly went around the glass grains, while in the case of mortar with the river aggregate the breaking line passed through a certain number of grains as well.

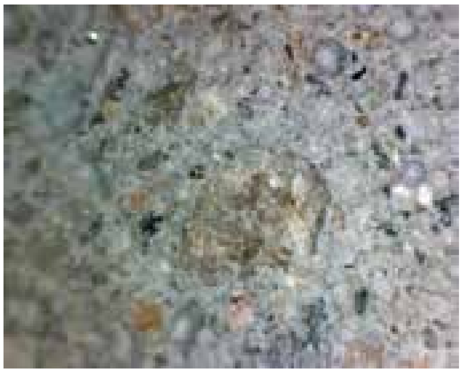

Figure 5. Appearance of the surface of broken mortar samples with 100% of recycled glass – left and reference sample – right

Flexural and compressive strengths of recycled glass mortars after the frost action are reduced in comparison to the reference one. This reduction grows with the increase of glass content, figures 3 and 4. Reduction of compressive strength of WG25 mortar is 8,6%, of WG50 mortar is 12,8%, of WG75 mortar the reduction is 21,0% and of WG100 mortar it is as much as 28,3%. Probable reason for such behavior of mortar with recycled glass should be sought in the quality of transit zone.

5. CONCLUSION

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

- with the increase of content of recycled glass instead of fine natural aggregate, the consistency of mortar becomes more plastic, that is, the spreading is higher,
- density of the fresh compacted mortar is increased with the increase of content of recycled glass can amount to up to 6% in mortars where complete fine natural aggregate was replaced by glass one,
- compressive strength increases with the age of mortar,
- replacement of natural sand with recycled glass does not affect significantly the change of compressive strength,
- bending strength reduces with the increase of recycled glass content which is ascribed to the poor characteristics of the transit zone at the contact of glass grains and hardened cement paste,
- compressive strength, after the frost action is considerably reduced with the increase of content of recycled glass. The resistance to frost action is problematic above 50%, and especially above 75% of recycled glass substituting the natural sand.

Further research of mortar, some of which are currently underway, should be directed in towards research of: influence of ASR on mortar properties, shrinking due to drying, modulus of elasticity. The research on concrete where the use of finely ground glass as a replacement for a part of cement is planned in particular.

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