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USAGE OF CATHODE RAY TUBE WASTE GLASS FOR THE PARTIAL SUBSTITUTION OF AGGREGATE IN CEMENT MORTAR

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ABSTRACT

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 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 have still been increasing. Regarding the specific chemical composition of the CRT glass, the recycling process is not simple. This paper presents the potential for usage of waste cathode ray tube glass as a partial substitution of aggregate in cement mortar.

Key words: environment, recycling, CRT glass, cement mortar.

INTRODUCTION

Electronic waste increases at a much higher rate than other solid wastes in the world. According to the assessment of the United Nations University, electronic waste will be increased and it will reach almost 50 million tons until 2018 [1]. For instance, out of 45.7 million tons of accumulated electronic waste in 2016, 6.3 million tons is the glass from TV sets and computer monitor screens. Although the production of TV sets with cathode tubes is discontinued, the amounts of cathode ray tube glass are still increasing. The production of c*athode* r*ay tube* glass increased, along with the rising demand of TV sets and Computer screens until the end of the previous century. However, scientific progress brought about new technologies of TV and computer screens manufacturing known as TFT (*Thin Film Transistor*) and LCD (*Liquid Crystal Displays*) which since the turn of 21st century entirely extinguished further production of cathode ray tubes. Table 1 presents the statistical data of Maria Socolof et al. [2] where one can see the number of globally produced screens. From the table one can clearly find out how much the new types of screens affected the reduction of the CRT screen production.

Table 1. Number of produced screens in the world, in millions of units [2]

Screen type	1998	2002	2010	2011	2012	2013	2014	2015	2016
CRT	80,7	83,3	36	21	18	12	7	5	5
LCD	1,3	32,2	178	197	205	222	238	250	261
Total:	82,0	115,5	214	218	223	234	245	255	266

CRT devices make up as much as 43% of electronic waste in the USA. It is estimated that there are around 232 million CRT devices still in use, so considerable amounts of these devices end up on the waste disposal sites each year, despite the fact that they almost cannot be found in the market. It is considered that around 85% of these devices will be collected in the following ten years. The existing recycling centers do not have sufficient capacity to stockpile and recycle the estimated quantities of CRT devices. There is a large problem occurring in the process of CRT glass recycling: it is almost twice as costly to recycle the cathode ray tubes as other electronic waste. In the USA the cost of transport and total recycling of 1 kg of glass costs among 0.14 and 0.24 dollar [3].

China is the world's largest producer, consumer and exporter of electronic equipment. At the same time, it faces big problems caused by accumulation of electronic waste, and illegal import of the waste from other countries *[4]*. In response to the considerable increase of electronic waste and potential deleterious effects on the environment, the Chinese government enacted a set of measures and laws regulating collection of the waste, its storing and its recycling process. It is estimated that the amount of waste CRT glass will be considerably increasing in China until the end of the current year.

A record number of 20 million units of CRT devices was sold in Europe in 1996. Since then, there was a gradual decline of selling, and ten years after this date, the selling was halved. Since 2011, the CRT devices have practically not been sold in Europe, but at the same time the amount of CRT waste on waste disposal sites started to increase *[5]*. Nowadays, it is not possible to find any CRT monitor or TV set in the electronic appliance shops. However, these devices survived in the households, and it is estimated that around 50-150 thousand tons of CRT screens end up annually on the waste disposal sites in Europe. The predictions of Fernando Andreola et al. is that the amount of collected CRT will not decline in the future period *[6]*.

CRT GLASS AS A PARTIAL REPLACEMENT OF FINE AGGREGATE IN CEMENT MORTARS

There are two types of cathode ray tubes: black-white and color cathode ray tubes. Three fundamental glass elements of CRT screen are *neck glass*, *funnel glass* and panel (*panel glass*). Their share in the total mass differs and it is: 1%, 33% and 66%, respectively. Neck glass, even though its mass share in the screen is small, contains around 25% of lead, which is far more than other parts. The funnel is the largest part of the cathode ray tube and it contains around 20% of lead. The panel is the front, visible part of the cathode ray tube and it almost contains no lead (0-3%).

Waste glass can be used for production of cement mortars in two ways. One possibility to use it as a filler, substituting a portion of natural aggregate. The other possibility is to use finely milled waste glass as a substitution for a part of cement when making the mortar. Further in the text will be presented the test results of the mortar where a part of aggregate was replaced either by panel glass or by funnel glass of CRT screens.

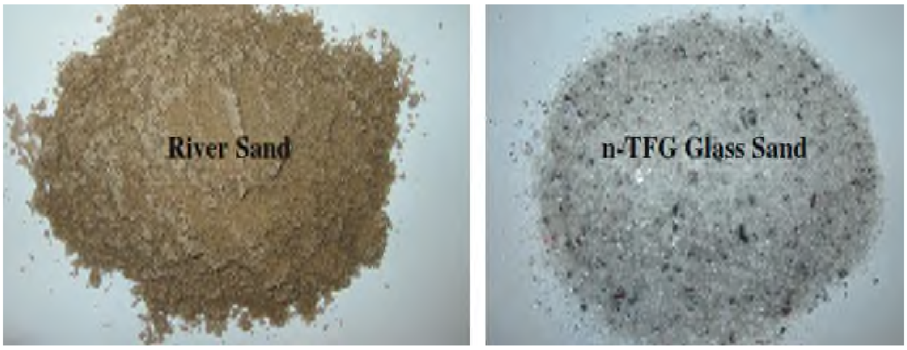

Figure 1. appearance of natural aggregate (left) and milled CRT glass (right)

Hui Zhao et al. [7] tested the properties of a mortar where a portion of natural river aggregate was replaced by CRT funnel glass. The funnel glass was not treated by nitrous acid to remove the present lead, but it was used in its original form. Fine river aggregate was replaced by CRT glass in the amount of 0%, 25%, 50% and 75% of its mass. On the same occasion, 25% of standard Portland cement was replaced by mineral admixtures – fly ash (4 mortar admixtures – FA series) and granulated slag (4 mortar admixtures GGBFS series), so a total of eight mortar mixtures were made. In figure 1 is displayed the appearance of natural aggregate (left) and recycled funnel glass, with particle fineness lower than 4 mm (right).

By testing the mortar consistency using Slump flow test, it was found that increasing the share of CRT aggregate in the mixture causes an increase of the spread diameter. Such trend can be explained by the fact that the grain of the glass aggregate has a smoother edge in comparison to the natural river aggregate, and that it "absorbs" incomparably less water than the river aggregate. The increase of the cathode glass replacement share (instead of sand) causes an increase of fresh mortar density in comparison to the control mixture without CRT (Figure 2) [7].

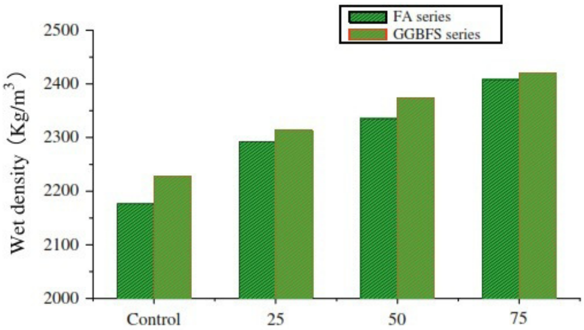

Figure 2. Density of fresh mortar depending on the replacement share of glass instead of aggregate *[7]*

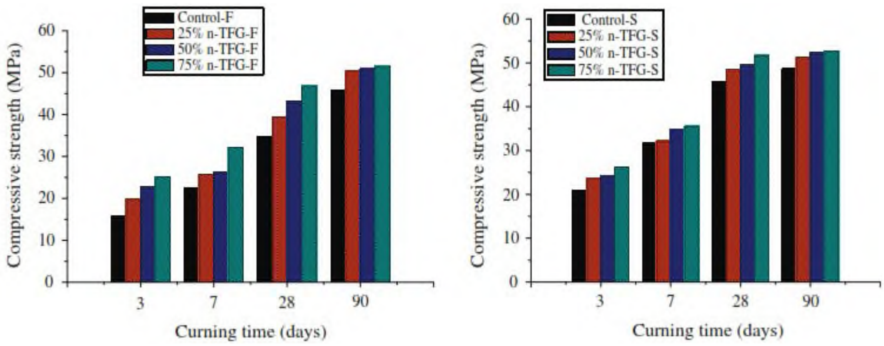

Figure 3. Effects of replacement of natural aggregate by CRT glass on the compressive strength of mortar at the age of 2, 7, 28 and 90 days *[7]*

Compressive strength was tested at the mortar age of 3, 7, 28 and 90 days. The test results bay Hui Zhao et al [7] are displayed in figure 3. It can be concluded that he mortars with the glass admixture had a higher compressive strength than the reference mortar at all the ages.

Hui Zhao et al. in the paper [8] researched the effects of replacement of complete natural aggregate by two types of CRT glass on the cement mortar properties. The first type was the CRT funnel glass which contained a certain amount of lead (*marked in the paper as MG*), while the other type of the glass underwent the lead separation treatment (*marked in the paper as G*). In this paper as well, 25% of the standard Portland cement was replaced by mineral admixtures – fly ash (*3 mortar mixtures*) and granulated slag (*3 mortar mixtures*). One of the conclusions is that on the occasion of replacement of the total river aggregate using the recycled glass, there occurs an increase of spread diameter on the test table [8]. In the table 2 are presented the results of compressive strengths of mortars with various aggregates and mineral admixtures at the age of 28 and 90 days. Firstly, it can be concluded that the batches of mortar with granulated slag have higher values of strengths and higher values of static modulus of elasticity in comparison to the batches of mortar with fly ash, with the same type of aggregate. Also, the mortar batches made with the CRT glass which contains lead have higher values of mechanical strengths in comparison with the batches of mortar made with two other types of aggregates, at the same age. .

Table 2. Compressive strength, flexural strength and static modulus of elasticity with various aggregates and mineral admixtures at the age of 28 and 90 days [8]

Mortar batch:	Compressive strength [MPa]		Flexural strength [MPa]		Static modulus of elasticity [GPa]	
	28 days	90 days	28 days	90 days	28 days	90 days
R-F	28,42	44,23	5,23	6,38	7,89	11,61
MG-F	40,21	49,25	5,63	6,72	12,47	13,75
G-F	38,75	47,29	5,56	6,68	10,26	13,64
R-S	29,04	42,92	5,46	6,10	8,23	10,48
MG-S	44,91	45,95	5,86	6,64	13,25	13,37
G-S	39,93	44,86	5,58	6,58	10,32	11,68

** R – river aggregate; F- fly ash; S – granulated slag*

In the Laboratory of building materials of the Faculty of Civil Engineering and Architecture of Niš the tests of the effects of replacement of natural aggregate by panel CRT glass on the properties of mortar in fresh and hardened states were also conducted. For making of the mortar, cement CRH CEM I 52,5R was used. For making of reference mortar, fine aggregate from the South Morava river from the screening plant „Vodogradnja" d.o.o. Pukovac was used. The company "Jugo - Impex" E.E.R. d.o.o. from Niš deals with collection and recycling of cathode ray tubes of scrapped TV sets and computer monitors. The recycling center granted a certain amount of cathode ray tube glass for the purposes of this research, and the glass was further processed and milled in the Laboratory of building materials *[9]*.

Table 3. Fresh mortar test results *[9]*

Fresh mortar	Mortar mark				
	E	WG25	WG50	WG75	WG100
Consistency [mm]	130	145	160	170	175
Entrained air [%]	5	5,4	4,8	4,6	5,0
Density [kg/m^3]	2265	2305	2345	2383	2396

Table 4. Flexural and compressive strengths of the mortar at the age of 2, 7, 28 and 90 days [9]

Type of mortar	Age [days]							
	2		7		28		90	
	f_s [MPa]	f_p [MPa]	f_s [MPa]	f_p [MPa]	f_s [MPa]	f_p [MPa]	f_s [MPa]	f_p [MPa]
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

For the purpose of testing the effects of replacement of river fine aggregate by a corresponding aggregate made of recycled glass, five different mortar mixtures were made. The ratio of cement (m_c) and sand (m_p) was constant and it was $m_c : m_p = 1 : 3$. Water/cement ration was also constant and amounted to 0,5. The reference mortar (E) was made with fine river aggregate only, while the other four mortars contained a varying 25%, 50%, 75% and 100% share of replacement glass. The replacement of river aggregate by recycled glass was performed by volume. The mortar mixtures obtained their marks according to their replacement share: WG25, WG50, WG75 and WG100. Table 3 provides the results of consistency testing (slump flow test according to SRPS B.C8.042), entrained air content (according to SRPS B.C8.050) and the density of fresh compacted mortar (according to SRPS ISO 6276) *[9]*. Compressive and flexural strengths were tested at the ages of 2, 7, 28 and 90 days according to SRPS EN 196-1. The test results are displayed in table 4.

DISCUSSION OF THE RESULTS

On the basis of the results presented in the papers [7-9] it was determined that glass has effects on the consistency of the mortar; the higher the share of the glass the higher the spread diameter in the slump flow test. Regarding the well known fact that glass does not absorb water, as opposed to natural aggregate, the increase of the share of glass in past gives rise to an increased amount of water in cement mortar. Entrained air content did not noticeably change with the increase of the glass share [9]. Testing of the fresh mortar density in the papers [7] and [9] established that the increase of glass replacement share causes the increase of density. CRT glass has a higher density than fine natural aggregate, which can explain such effect of CRT glass on the mortar density. On the basis of the results presented in the paper [9] it was determined that the increase of density in comparison with the reference batch is 2% for the batch WG25 and up to 6% for the batch WG100.

The results of the compressive and flexural strengths are slightly different in the presented researches. According to the results presented in the paper [7] it was determined that with the increase of the replacement share of recycled CRT glass causes an increase of compressive and flexural strengths. The authors provided two possible explanations for such a phenomenon. The first explanation would be that the replacement of the aggregate with the recycled glass improved the aggregate packing. The other explanation is that the presence of CRT aggregate in mortar accelerates cement hydration. Also, in figure 3, it can be seen that while retaining the same shares of replacement glass instead of aggregate in the mortar at the age of 7 and 28 days, those mortar mixtures containing 25% of granulated slag have higher strengths in comparison to the mixtures with 25% of fly ash. On the other hand, at the mortar age of 90 days, the compressive strengths of the batches with different mineral admixtures become practically equal. In the paper [9] as well, the values of compressive strength increase in time, as expected, and they are fairly uniform for the corresponding age, table 4. At the age of 2 days, compressive strength ranges between 27,5 N/mm^2 and 30,6 N/mm^2, at the age of 7 it ranges between 41,6 N/mm^2 and 46,3 N/mm^2, at the age of 28 days the range is between 49,2 N/mm^2 and 57,1 N/mm^2 and at the age of 90 days, between 59,3 N/mm^2

and 64,7 N/mm^2. The relative difference of the lowest and the highest value of compressive strength, flexural strength, except at the age of 2 days decrease as the glass share in the mortar increases, table 2. Such trend should be explained by the microstructure of the mortar, or, more precisely by the quality of the realized bond of the aggregate and hardened cement mortar – transit zone.

CONCLUSION

On the basis of the results presented in the papers [7-9] several conclusions can be made when it comes to the effects of CRT aggregate on the properties of fresh and hardened mortar. With the increase of the share of CRT glass aggregate instead of fine natural aggregate, the mortar spread diameter increases.

The density of fresh compacted mortar increases with the increase of the glass share in the mortar mixture.

Compressive strength increases with the increase of mortar age. At the age of 90 days, the paper [7] determined that the highest strengths were recorded in the mortar batches which had the highest percentage of glass replacement share, while in the paper [9] a slight decrease of strength at the same age for the highest share of replacement was determined. Certainly, mortar compressive strength has a considerable value and facilitates usage of mortars in practice.

Flexural strength in the paper [8] does not change considerably for the varying percentage of glass admixture, while in the paper [9] it was determined that this strength decreases as the glass share increases.

One of the most important conclusions is that the recycled glass of cathode screens can be successfully used as a replacement for a portion of natural aggregate in mortar. In this way, a huge global environmental problem can be mitigated, and perhaps fully resolved. In order to determine an optimum percentage of replacement of aggregate by using CRT glass instead, it is necessary to perform some tests of mortar durability, the most important being: investigation of potentially dangerous alkali-silicate reaction (ASR) and possible leaching of lead of the mortars which had the funnel glass added.

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