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The influence of addition of CRT Glass cullet on selected parameters of concrete composites

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Abstract. In recent years, with the abandonment of use of CRT television and computer screens the waste dumps observe systematic growth of amounts of CRT glass. This type of waste is non-biodegradable and unsafe for the environment. The best way to overcome this negative influence of glass waste on the nature surrounding us is to reuse it. The article investigates the influence of addition of CRT glass cullet on selected mechanical properties of concrete and mortar. Composition of two batches of concrete utilized 0-2 mm fraction of glass cullet, as replacement of sand, in amounts of 10 and 15%. The remaining 3 batches utilized CRT glass cullet as addition to dust fraction, calculated in relation to the mass of cement (5, 7.5 and 10% respectively) with volumetric deduction of aggregate. The following were measured for 6 resulting batches of concrete: compression strength after 2, 7 and 28 days of curing; frost resistance for 100 cycles of freezing and defrosting, water absorption and specific gravity. The CRT glass cullet was added to mortar in the following quantities: 5, 7.5 and 10% of cement mass, deducing cement. Research results indicate the validity of use of the previously unused CRT glass cullet in production of concretes.

1. Recycling of waste CRT glass

CRT (Cathode Ray Tube) waste glass is characterised by changing chemical composition that depends on type of receiver and its manufacture year. The monitors are usually made of two types of glass, i.e. the barium-strontium glass and led glass, bound together with led frit [1]. The high led oxide content (11-24%) of this material makes the CRT waste glass particularly dangerous for the environment and forms a significant ecological issue worldwide [2].

From 2003 in all member countries of European Union the EEC directives 2002/96/EC [3] and RoHs 2002/95/CE [4] came in force. The purpose of those document is to limit the threats connected with manufacture of electronic and electric devices and proper management of waste devices.

In Poland the regulation that aims at adjusting Polish law to standards and EU directive in the light of socio-economic needs for environmental protection within the discussed subject is the 29 July 2005 act on used electric and electronic equipment (Journal of Laws "Dz.U." of 20 September, 2005), as amended. Among others this act prohibits the design of devices in such a way, that specific technical solutions prevent it from reusing its used parts. It also sets the procedure for waste equipment that secures the protection of human health and life, and also the environmental protection, following the rules of sustainable development. It imposes, on manufacturers, importers and suppliers of electronic and electric devices, the duty to attain a set level of reuse and recycling of materials, parts and substances from used devices.

As it results from literature of the subject [5] till present date CRT glass cullet was only investigated for its use in production of glass-ceramic composites for traditional ceramics. This waste is used as an alternative filler when using glass-ceramic composites, added as a finely ground waste glass powder together with other industrial waste such as fly ash, mining waste, solid waste from aluminium casting or polymer waste [6, 7]. We find a broader description of use of CRT glass cullet for manufacture of glass-ceramic composites in position [8].

2. Research materials and methods

The present work utilises waste CRT glass cullet (Figure 1a) acquired from CRTs of both TV sets and computer monitors, both from screen and conical sections of the CRT. The following were used for concrete tests: CEM I 42.5R Portland cement, sand, 2-8 mm and 8-16 mm fractions basalt aggregates, plasticizing and aerating additions, CRT cullet milled to 0-2 mm fraction (A) (Figure 1b) and milled CRT glass culled that was additionally crushed twice in disintegrator.

Figure 1. Crushed CRT cullet a) initially crushed, b) milled, c) milled and crushed twice in disintegrator.

Six series of concretes were made. The control concrete with W/C ratio of 0.62 with addition of 0.5% of cement mass of plasticizer – series 1K. In the subsequent series the control concrete was modified in its composition as follows:

- series 1MSK utilizes CRT cullet (A) in the quantity of 10% of sand mass, adjusting the sand mass,
- series 2MSK – utilizes CRT cullet (A) in the quantity of 15% of sand mass, adjusting the sand mass,
- series 1DSK – utilizes CRT cullet (B) in the quantity of 5% of cement mass, adjusting the aggregate volume,
- series 2DSK – utilizes CRT cullet (B) in the quantity of 7.5% of cement mass, adjusting the aggregate volume,
- series 3DSK – utilizes CRT cullet (B) in the quantity of 10% of cement mass, adjusting the aggregate volume.

The flexural and compression strength tests were also conducted for 4 series of small beams made of mortar. The series of control beams (1K) was made of normalized mortar on the basis of Portland cement CEM I 42.5 R without the addition of glass cullet. There were also 3 series of beams made of normalized mortar on the basis of Portland cement CEM I 42.5 R modified with glass cullet:

- series 2 utilizes CRT glass cullet (B) in the quantity of 5% of cement mass, adjusting the mass of cement
- series 3 utilizes CRT glass cullet (B) in the quantity of 7.5% of cement mass, adjusting the mass of cement
- series 4 utilizes CRT glass cullet (B) in the quantity of 10% of cement mass, adjusting the mass of cement.

Composition of the respective cement mixes is presented in table 1, and the composition of the respective cement mortars in table 2.

Table 1. Composition of cement mixes with addition of A & B.

Concrete series	Ingredients (kg/m^3)					
	Cement	Water	Aggregate	Plasticiser	Additive	
					A	B
1K	295	184	2060	1.47	-	-
1MSK	295	184	1982.5	1.47	77.5	-
2MSK	295	184	1944.1	1.47	115.9	-
1DSK	295	184	2044.1	1.47	-	14.75
2DSK	295	184	2036.1	1.47	-	22.13
3DSK	295	184	2028.2	1.47	-	29.5

Table 2. Compositions of mortars with the addition of B.

Concrete series	Ingredients (g)			
	Cement	Water	Aggregate	B Additive
1BK	450	225	1350	-
2	427,5	225	1350	22.5
3	416	225	1350	33.75
4	405	225	1350	45.0

3. Research results and their discussion

Concrete compression strength tests were conducted pursuant to the PN-EN 206-1 [9] standard, and their results are presented in table 3.

With the assumed water/cement ratio we designed the test cement mix in such a way, as to achieve appropriate consistence and workability. For the control series cement mix we assumed the consistence of S3 (drop of cone in the range of 100-150 mm). The strength tests for each series of concrete were conducted after 2, 7 and 28 days of curing. The average compression strength of control (1K series) cement after 2 days was f_{cm}=10.5 MPa. Addition of (A) glass cullet as replacement of sand in the quantity of 10.0% of sand mass (1MSK series) and (B) in the quantities of 7.5 and 10.0 (1DSK & 3DSK series, respectively) caused the lowering of average compression strengths. After 2 days of curing there was an average drop in compression strength of 1.2% in comparison to control sample. The 2MSK series resulted in average compression strength increased by 15.3%. In the 2DSK series of concrete with the addition of 7.5% of the (B) additive and decrease in volume of aggregate we observed the increase of compression strength by 12.9% in comparison to control sample.

The average compression strength measured after 7 days of curing for 1K series of concrete was f_{cm}=20.6 MPa. Addition of CRT glass cullet caused a drop in compression strengths for 2DSK & 3DSK series in comparison to test sample, by 9.6 and 12.0% respectively. The remaining series of concrete, that is 1MSK, 2MSK, 1DSK, noted increase of strength in comparison to control sample, by 1.8, 10.8 and 13.2%, respectively.

The average compression strength measured after 7 days of curing for 1K series of concrete was f_{cm}=30,7 MPa. Only the 2MSK series demonstrated increase in average compression strength of 1.6% in comparison with control series. The remaining concrete series: 1MSK, 1DSK, 2DSK, 3DSK demonstrated a drop of in average compression strength in comparison with control concrete, by 13.2, 8.6, 3.1 and 17.5%, respectively.

Table 3. Test results for concrete from respective series.

Concrete series	Average compression strength f_{cm} (MPa)			Water absorption n_w (% of mass)	Specific gravity ρ (kg/m^3)
	after 2 days of curing	after 7 days of curing	after 28 days of curing		
1K	10.5	20.6	30.7	4.5	2151
1MSK	10.4	20.9	27.3	4.7	2133
2MSK	11.8	22.5	31.2	4.7	2186
1DSK	10.4	22.8	28.5	4.7	2137
2DSK	11.6	19.0	29.9	4.6	2139
3DSK	10.4	18.6	26.2	5.0	2141

On the basis of methods of the PN-88/B-06250 standard entitled Regular concrete [10] we conducted water absorption tests for concretes of respective series. Results are presented in table 5. According to the aforesaid standard the water absorption rate of concretes exposed to environmental factors should not exceed 5%, and 9% for concretes screened from direct action of atmospheric conditions. Both the control series concrete and the modified CRT cullet modified concretes met this condition, as water absorption ranges from 4.5 to 5%.

We also conducted frost resistance tests with direct method (PN-88/B-06250) for the F100 proteciton class, and their results are presented in table 4. The results is deemed positive, if after n cycles of freezing – thawing that are required for respective class of frost protection the average compression strength drop does not exceed 20% and the average mass loss does not exceed 5% and none of the tested samples is cracked or scratched. The drop in resistence to freezing/thawing was in case of concretes: 1MSK, 2MSK, 1DSK, 2DSK & 3DSK of: 2.7; 0.7; 0.7;5.8 & 1.2% respectively.

Table 4. Frost resistance test results for respective series of concrete.

Concrete series	Frost resistance	
	Average mass loss ΔG (%)	Average compression strength loss ΔR (%)
1K	0.46	10.31
1MSK	0.47	2.69
2MSK	0.48	0.73
1DSK	0.49	0.74
2DSK	1.6	5.8
3DSK	0.48	1.2

Table 5. Test results for respective series of cement mortars.

Mortar series	Properties					
	Flexural strength [MPa]			Compression strength [MPa]		
	after 2 days	after 7 days	after 28 days	after 2 days	after 7 days	after 28 days
1BK	3.17	6.38	8.47	16.84	35.00	57.67
2	3.22	6.31	8.70	16.33	35.83	51.67
3	3.22	6.20	8.07	15.83	34.83	47.83
4	2.86	5.77	7.70	15.00	32.83	43.67

The flexural strength tests after 2, 7 and 28 days demonstrated similar results for average flexural strength of normalized mortar and the glass cullet modified mortar. The flexural strength tested after 2 days of curing was in the range of 2.86 ÷ 3.22 MPa, when tested after 7 days it is in range of 5.77 ÷ 6.38, and after 28 days it ranges between 7.7 MPa and 8.7 MPa.

Compression strength tests after 2 and 7 days revealed comparable average compression strength results for all series of cement mortars. The average compression strength of beams made on the basis of CEM I 42.5 R cement that was not modified with CRT cullet was higher than that of remaining beam series, with a total of 57.67 MPa. For the remaining series of beams (2, 3 & 4) these values were lower with: 51.67, 47.83 & 43.67 MPa, respectively.

4. Conclusions

Tests conducted for the designed concrete confirmed the possibility of use of waste CRT cullet as replacement of fine aggregate that is sand, up to 15% of sand mass. The tested concrete with added CRT cullet had a 1.6% higher compression strength, with remaining parameters on level comparable with control series. Use of dust from crushing CRT cullet in quantities of 5 to 10% results in slight, up to 10%, decrease in compression strength of concrete, when compared with control sample. The drop in compression strength was also recorded in case of cement mortars that utilized the same dust of crushed CRT glass cullet that was milled and additionally crushed twice in disintegrator to be utilized as partial replacement of cement.

Taking the aforesaid into account we ascertained that use of CRT glass cullet from old, waste receivers, as a replacement of fine aggregate in concrete perfectly matches the concepts of sustainable development.

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