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Mechanical properties of concrete mortar based on mixture of CRT glass cullet and fluidized fly ash

Paweł Walczak^{a,*}, Jan Małolepszy^b, Manuela Reben^b, Karol Rzepa^b^a*H+H Polska Sp. z o.o., ul. Kupiecka 6, 03-046 Warsaw, Poland*^b*Faculty of Materials Science and Ceramics, AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Kraków, Poland*

Abstract

The problem with the waste from electric and electronic equipment (WEEE), consisting of about 80% of television sets and computers containing a cathode ray tube (CRT) have just begun to deal with. Cathode ray tubes (CRTs) are the video display components of televisions and computer monitors (EPA, 1995). Arising problem related with recovery and recycling of CRT glass stimulates examinations aimed at making cullet-based ceramic materials of reinforced mechanical strength. Glasses as cone and neck contain principally different lead contents another dangerous elements instead panel glass has other heavy metals (Ba, Sr, etc.) that forbid their recycling in the glass industry for the production of containers, domestic glassware and glass fiber. As it is well known concrete is an excellent material for immobilization of these metals, what was the reason to undertake this research. The use of CRT (Cathode Ray tube) waste glasses in concrete has attracted a lot of interest worldwide due to the increased disposal costs and environmental concerns. Because of silica large quantities CRT glass in the theory is a pozzolanic in nature, thus it can be used as a sand replacement in light concrete. The research was performed with use of concrete mortars. As a reference concrete mortar a mix of cement, sand, expanded clay aggregate and water was used. The purpose of this work was to investigate the influence of additives e.g. CRT glass cullet as an aggregate, and fluidized fly ash on concrete properties. Based on obtained results both CRT glass cullet and fluidize fly ash improved compressive and flexural strength in respect of standard concrete mortar without these additives. The use of CRT glass as a sand replacement caused the increased of compressive strength of concrete mortar of about 16% and its flexural strength of about 14%.

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* Corresponding author. Tel.: +48 698 818 243
E-mail address: pawel_walczak86@wp.pl

1. Introduction

The use of recycled waste glasses in Portland cement and concrete has attracted worldwide interest due to increasing disposal costs and environmental concerns. Large proportion of the post consumer glass is recycled into the packaging stream again, but some sub grain packaging glass cullet does not meet the strict criteria for packaging glass thus is sent to landfill. On the other hand Cathode Ray Tube (CRT) is classified as a hazardous glass waste and there are several issues surround CRTs which create barriers to increased recovery of the glass. Thus in the last decade the great attention has been paid on how to improve the construction industry methods and services by using glassy waste to sustain good product performance and meet recycling goals. The potential benefits and drawbacks of using glass as a partial replacement for cement or fine aggregates in concrete have been extensively studied and are well understood [1, 2]. The use of crushed or ground glass in concrete mixes as an entire or partial replacement for aggregate is of growing interest, because this operation reduces the demand on the natural resources construction materials and provides multiple alternatives to the traditional ingredients of concrete mixes. Attempts has been made in using crushed glass as fine aggregate in the replacement of river sand, and also as a coarse aggregate in concrete production. A major concern regarding the use of glass in concrete is the chemical reaction that takes place between the silica glass particle and the alkali in pore solution of concrete [3]. The glass used in cement-based materials can lead to two types of behaviours having antagonistic effects: alkali-silica reaction, which causes damage in concretes, and pozzolanic reaction, which is beneficial for concrete properties. The alkali-silica reaction (ASR) is usually associated with coarse particles containing amorphous silica [4]. A several papers have reported that most alkali-reactive aggregates can show pozzolanic activity when they are ground to a few tenths of a micrometer or smaller, supporting the idea that the pozzolanic reaction only concerns fine materials. Results of the literature showed that the pozzolanic activity of the glass depended on several parameters and that each type of glass should be studied to evaluate its activity [5, 6]. Since the European Directives constitute a specific legislation on WEEE: 2002/95/EC (ROHS), (2002/96/EC) on the restriction of the use of certain hazardous substances in electrical and electronic equipment, a special attention has been paid on the treatments of used television sets and computer monitors containing CRT (Cathode Ray Tube). European Waste Catalogue classifies CRTs as hazardous waste and makes landfill disposal of CRT materials costly. The great amount of CRT waste produced all over the world implies that its recycling is presently necessary not only due to the rising cost of landfill disposal, which is reflected on the cost of new CRTs produced, but also as a consequence of the “zero-waste” objective which must be the final goal of all future human activities [7]. The recycling of glass from CRT is quite problematic because a CRT is made up of four different chemical types of glass (screen or panel, cone or funnel, neck and frit junction) [8-10]. Glasses as cone and neck contain principally different lead contents another dangerous elements instead panel glass has other heavy metals (Ba, Sr, etc.) that forbid their recycling in the glass industry for the production of containers, domestic glassware and glass fiber [11, 12]. Small amount of contaminant may result in the contaminating of a large batch. May put production off for many hours. Difficult to really proceed with glass remanufacturing for two reasons:

- composition issue: difficult to know what is in the glass, including foreign materials as well as other forms of cullet.
- reliability issue: because of the inconsistent nature of CRT recycling, there is not yet a sure way of guaranteeing industries a constant supply of cullet year-round. There is an increasing urgency to develop new applications for CRT glass.

For a new environmental sustainable economy, wastes are to be considered as a real opportunity to produce clean a high-quality secondary raw material. Arising problem related with recovery and recycling of CRT glass stimulates examinations aimed at making cullet-based ceramic materials of reinforced mechanical strength [13]. The application areas for CRT utilization in ceramic and glass industry can hopefully be a starting point for wider research in this area. In ceramic and glass industry, there is a wide range of various production processes and end products ranging from bulk products, such as construction materials e.g. bricks and tiles, to high-technology applications, such as reactive glass materials. In order to propose a new option for waste CRT glass recycling, as independently as possible from glass composition, in the present research the production of concrete mortars was carried out using cement, a standard quartz, ground-waste-mixed CRT glass (funnel), fluidized fly ash. Mortars are expected to take advantage of ground glass; that the addition of silica fume as a component material in the

production of cement mortars can lead to the preparation of products, with high mechanical properties. Because of silica large quantities, CRT glass in the theory is a pozzolanic in nature, thus it can be used as a sand replacement in light concrete. Throughout this paper the term “concrete mortar” will be used to refer to these mixtures.

2. Materials and methods

2.1. Materials

In this study the following raw materials were used: cement CEM I 42.5 according to EN 197-1:2012, a standard quartz with a mean particle size of approximately 80 μm , expanded clay aggregate (grain size 0-4 mm), and CRT glass cullet with a mean particle size of approximately 80 μm and a Blaine fineness of 2000 cm^2/g . The particle size distribution (PSD) of the fine fraction of the aggregate, cement, and powdered mixed CRT glass were determined by a Horiba LA950 laser scattering PSD analyzer. The particle size of CRT glass cullet has been established due to the fact that the finest fraction of a component is most reactive. On the other hand it affects the w/c ratio as well as the alkali silica reaction in the presence of Na_2O and K_2O . Thus according to [14] the waste glass falls in the range of submicron sized particles and is overlapped to that of the smallest cement particles. In this study fluidized fly ash from electric plant Turów was used. The chemical composition of both, fluidized fly ash and CRT glass cullet were tested by XRF, (table 1).

Table 1. Chemical composition of CRT glass cullet and fluidized fly ash.

Chemical composition, %	CRT glass cullet	Fluidized fly ash
SiO_2	63.01	29.73
CaO	1.03	23.31
MgO	1.23	2.08
Al_2O_3	1.97	21.80
Fe_2O_3	0.065	5.86
TiO_2	0.07	1.54
Na_2O	7.50	1.25
K_2O	6.93	1.32
BaO	5.23	0.06
SrO	12.97	0.05
SO_3	-	7.88
LOI	-	4.73
Other	-	0.39
Σ	100	100

2.2. Samples preparation and tests methods

A total of three mortar mixes including a control mixture were prepared (Table 2). Crushed CRT glass was used to replace river sand at levels of 100% and 80% by weight. The raw materials composition is shown in the table 2.

Table 2. Mix proportions of concrete.

Samples	Cement	Sand quartz	CRT glass cullet	Fluidized fly ash	Expanded clay
S1	100	100	-	-	100
S2	100	-	100	-	100
S3	100	-	80	20	100

Sample S1 is a reference sample without CRT glass and fluidized fly ash. In the sample S2 sand quartz was entirely replaced by CRT glass cullet and in the sample S3 a part of sand quartz (20% wt.) has been replaced by fluidized fly ash which contains phases similar to metakaolin.

All samples were mixed in a standard laboratory concrete mixer at a water/cement ratio guaranteeing constant consistency. When the mixing process was completed the fresh mortar samples were placed into the steel mold 40 x 40 x 160 mm. After filling up each mold, compaction was achieved by placing the moulds on a mechanical vibrating table. Thereafter, the mortar specimens were covered with a plastic sheet and allowed to cure in the laboratory environment at $23 \pm 3^\circ\text{C}$ for 24 h. After 1 day, the prepared samples were removed from the mold and cured in water at a temperature of $23 \pm 3^\circ\text{C}$ until the date of the test. The flexural strength and compressive strength of samples were determined after 2 and 28 days with use of AUTOMAX 5 Controls.

The test program was divided into two parts. The first part dealt with the short term mechanical behavior tests and the second one with the long-term mechanical tests. These tests include compressive and flexural strengths.

3. Results

3.1. Flexural strength results

The flexural strength behaviour of the reference (S1) and modified concrete mixes (S2, S3) at various CRT content and test ages is presented in Fig.1.

Both, flexural and compressive strength were tested after 2 and 28 days curing. Fig. 1 shows the results of flexural strength after 2 and 28 days.

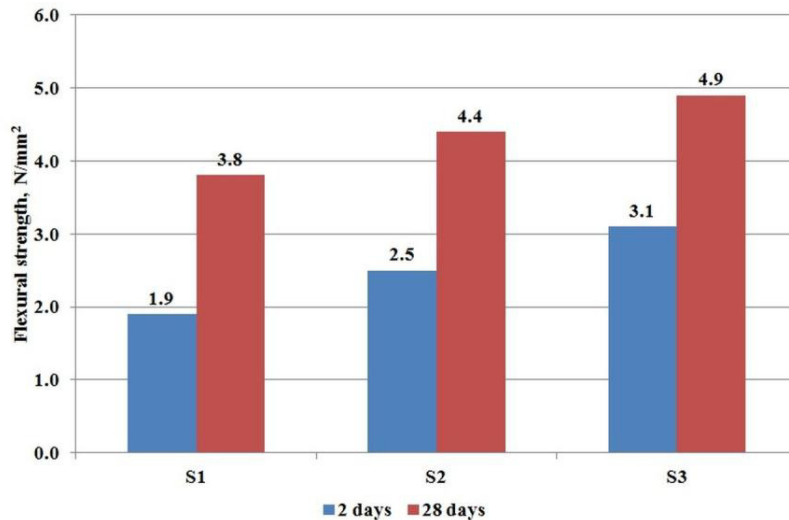


Fig. 1. Flexural strength results.

The results indicate that the modified concrete mixes (S2,S3) possessed higher flexural strength values than the reference mix S1. CRT glass and fluidized fly ash are more reactive than sand quartz and causes the incensement of flexural strength (Fig.1). Clear improvements in flexural strength for the modified concrete mixes compared to that of the reference mix were observed at all ages (2 and 28 days). Flexural strength of sample S2 was higher of about 30% in comparison to the reference sample S1. The highest increase of the flexural strength was observed for the mix S3 (63%). It is likely that these results are due to the role of the metakaolin phases of fluidized fly ash in the pozzolanic reaction, filler function and acceleration of the cement hydration process resulting in improved flexural strength. Due to the high silica content of the pozzolanic material it has the capability to react with the calcium hydroxide generated from the hydration process to produce a gel of calcium silicate hydrate (C-S-H). The C-S-H content has an important effect on the strength of concrete [15, 16].

3.2. Compressive strength results

Fig. 2 shows the compressive strength results of the mixes. Similar trends to that of flexural strength can be observed. However, the rate of compressive strength increase was greater than that for flexural strength.

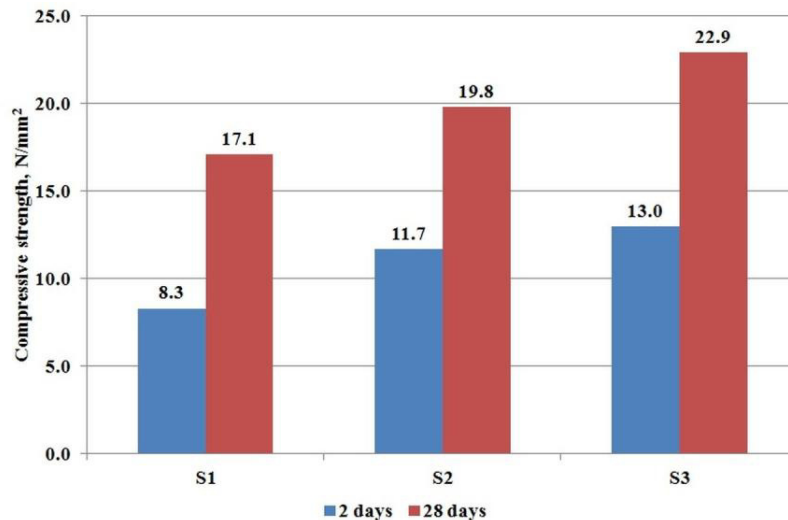


Fig. 2. Compressive strength result.

In these two test methods: flexural and compressive strength results show the same relationship. The use of CRT glass cullet instead of quartz sand caused an increase of compressive strength of about 41% after 2 days and of about 16% after 28 days. It means that the increase was the same for flexural and compressive strength (both by 16%). Addition of fluidized fly ash in the presence of CRT glass (mix S3) improved compressive strength: about 57% after 2 days and 34% after 28 days in comparison to the reference sample S1. The same trend was observed in the case of sample S2: compressive strength higher of about 11% after 2 days and of about 16% after 28 days.

4. Conclusions

In the present research, the production of concrete mortars was carried out using a cement, sand quartz, expanded clay, CRT glass cullet and the addition of fluidized fly ash was also investigated.

It has been demonstrated that the use of CRT waste glass may develop pozzolanic activity which is affected by glass finenesses and chemical composition.

The following important conclusions were derived from the study:

- using CRT glass in conjunction with fluidized fly ash additions and expanded clay, it is possible to produce a structural lightweight concrete with compressive strength up to 22.9 MPa at 28 days age.
- the use of CRT glass cullet as an aggregate improved flexural and compressive strength in comparison to the same mix where only the sand quartz aggregate was used,
- improvements in the value of the compressive strength in both the short- and long-term behaviors were achieved when CRT glass cullet and fluidized fly ash was used as a partial replacement for sand quartz
- improvements in flexural strength at all curing times were observed and these correlated with observed increases in compressive strength.
- concrete mortars can be a direct of utilization of CRT glass,
- it is necessary to continue investigations of the influence of CRT glass on concrete durability, microstructure and phase composition.

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