Possibility of recycling of waste LCD residues in concrete industry

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Introduction

Over the last years, technological advancement in electric and electronic equipment have boosted economic growth and improved people's lives in countless ways. However, the growing dependence on electronic products in households and workplaces has set a new environmental challenge, how to manage with the fastest growing waste stream (Charles *et al.*, 2017). Liquid crystal displays (LCDs) are nowadays widely used in TVs, laptops, desktops and any other device coupled with a screen. LCD panels belong to waste electronic and electric equipment (WEEE) that contain a wide range of compounds, some of which are toxic or hazardous, whereas others like base and precious metals are valuable and can be recovered. Recovery of scarce resources like the critical raw materials was pointed out in many European policies, especially antimony, beryllium, cobalt, fluorspar, gallium, germanium, graphite, indium, magnesium, niobium, PGMs, rare earths, tantalum, tungsten (Ferella *et al.*, 2017). Since that LCD contains an indium, a great efforts were made to find an appropriate treatment to extract indium as it was described in (Zhang *et al.*, 2015).

On the other hand, several research were conducted in order to examine a possibility of using a milled waste LCDs glass in concrete (Wang, 2011) and ceramic industry (Lin *et al.*, 2009). Those research were conducted before the highlighting of the possibility of indium extraction from waste LCDs. Since that waste LCD glass has been shown as a good substitute for aggregate in concrete prior to indium extraction treatment, the purpose of this paper was to examine the properties of fresh and hardened concrete when a treated milled LCD is used as a substitute for aggregate in concrete and compare the results with the results of concrete when an untreated milled LCD is used as a substitute for aggregate in concrete.

Material and methods

Properties of fresh concrete were tested according to standards described in HN EN 12350. Properties of hardened concrete were tested according to standards described in HRN EN 12390. Results for properties of hardened concrete are the average of three specimens dimensions 150*150*150 mm after curing 28 days.

Six experimental concrete mixtures with different percentage of aggregate replacement were made plus one reference concrete mixture. The concrete mixtures were made according to the recipe for concrete strength class C20/25. LCDs that was used as an aggregate substitute was milled on particles up to 10 mm in size and it was gained from authorized waste treatment facility for WEEE management. Milled LCDs, after quartering, were used as an aggregate substitute in 1%, 5% and 10% and three experimental concrete mixtures were tested.

For the purpose of testing the other three experimental concrete mixtures, milled LCDs, after quartering were treated with aqua regia in order to extract indium and other precious metals. After precipitation, the residues of treated LCDs were neutralized and dried up to constant weight. Afterwards, neutralized and dried LCD residues were quartered and used as an aggregate substitute in 1%, 5% and 10%.

Results and discussion

The testing of properties of fresh concrete are conducted due to theirs preventive character (Ukrainczyk, 1994). Regarding to the fresh properties of concrete the following properties were tested: density, air content and consistency.

According to the author Herak – Marović (2007), the density value of normal concrete is around 2000 to 2600 kg m^{-3}. Therefore, it is possible to conclude that regardless to the percentage of untreated or treated LCDs substitutes for aggregate in concrete, a significant change in density value of concrete was not noticed. A slight increase of concrete density value was noticeable in concrete mixtures where untreated LCDs samples were used, regard to the concrete mixtures were treated LCDs samples were used.

An increase in air content value was noticed in concrete mixtures where untreated LCDs samples were used as an aggregate substitute in regard to the concrete mixtures where treated LCDs samples were used. The air content in concrete has an impact on the concrete strength, but in this research air content did not change considerably with respect to the mean value (2.5%) so it didn't have an impact on the concrete strength. For example, if the granulometric curve of the aggregate deviates from the optimum grain packing, the air content value is higher, which is particularly noticeable for concrete with smaller amounts of cement paste (Ukrainczyk, 1994). Different values of air content in concrete mixtures in relative to the values of the reference concrete mixture result is consequence of a changed granulometric curve.

Based on the comparison of results for the consistency of concrete with untreated and treated LCDs samples used as an aggregate substitute in concrete, two opposite research results were noticeable. The slump value of concrete mixture with the higher percentage of untreated LCDs samples used as an aggregate substitute were decreased so the concrete was stronger. In relation to the slump value of reference concrete mixture it is noticeable decreased in slump value for the concrete mixture where 1% of treated LCDs samples were used as an aggregate substitute. With the higher percentage of

aggregate substitute (5% and 10%) with treated LCDs samples, a significant increase in slump value was noticeable, which lead to the fall of concrete strength. Respectively, if the treated LCDs samples are used as an aggregated substitute in concrete mixture, it should be up to 5% in order to preserve the concrete consistency.
The testing of properties of hardened concrete are conducted in order to the ability of concrete to resist the internal stresses which occur under the influence of external loads (Ukrainczyk, 1994). Regarding to the hardened properties of concrete, compressive strength and tensile strength were tested.

In regard to the reference mixture, the values of compressive strength of concrete had decreased when a percentage of an untreated LCDs samples that were used as an aggregated substitute was increasing. The concrete with the 1% and 5 % of replacement with the untreated LCDs samples are in accordance with the strength criteria, while the replacement of aggregate with 10% of untreated LCDs samples is not adequate. Furthermore, in accordance with the results of consistency, it is noticeable that a replacement of aggregate with 1% of treated LCDs samples shows the higher concrete compressive strength compared to the reference concrete mixture value. With the increasing of the replacement of aggregate with treated LCDs samples, the compressive strength is decreased. Nevertheless, the concrete with the 5% and 10 % of replacement with the treated LCDs samples are in accordance with the strength criteria.

The results indicates that with the higher percentage replacement of aggregate with the untreated LCDs samples in concrete tensile strength is decreased, but it is still inside the proscribed criteria. In accordance with the results of consistency and compressive strength values, a replacement of aggregate with 1% of treated LCDs samples shows the higher concrete tensile strength compared to the reference concrete mixture value, which is decreasing with the percentage increasing of replacement.

Conclusions

According to the discussed results, it is possible to conclude that up to 5% of aggregate replacement in concrete with the untreated and treated LCDs milled samples can be used. Since that tensile and compressive strength values of concrete were slightly better in concrete mixture where treated LCDs samples were used as an aggregate substitute, residues of LCDs after extraction of indium and treatment with acid solutions can be successfully used in concrete industry.

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