RHEOLOGICAL AND STRENGTH PERFORMANCE OF CEMENT PASTE WITH GROUND FLUORESCENT LAMP GLASS WASTE AND ASH

Patricija Kara
Riga Technical University, Institute of Materials and Structures
E-mail: patricija.kara@rtu.lv

ABSTRACT

The rheological behaviour of fresh mortars is a key characteristic since it determines the material's workability, having as well a great influence on the hardened product's final characteristics. Portland cement substitution with lamp glass waste (DRL – mercury vapour lamps and LB – fluorescent tubes) in concrete has a significant effect on strength performance and workability. In the present study an experimental program aiming to evaluate the effectiveness of lamp glass waste ground from 10min to 60min and used as a cement component in cement paste mix, has been completed. Viscosity, electrical conductivity and compressive strength of cement paste samples with Portland cement substitution at a level of 30% with ground lamp glass waste and bottom wood/coal ash were determined. The results showed a significant increase of the workability for cement paste mixes with LB and wood ash, and an increase of compressive strength for DRL and coal ash mixes.

Key words: viscosity, electrical conductivity, fineness, compressive strength, lamp glass waste, bottom ash.

INTRODUCTION

The production of Portland cement leads to the release of a significant amount of CO_2 and other greenhouse gases and the environmental issues associated with CO_2 will play a leading role in the sustainable development of the cement-based construction materials and concrete industry during the 21st century. One of the biggest threats to the sustainability of the cement industry is the dwindling amount of limestone in some geographical regions. As limestone becomes a limited resource, employment and construction associated with cement-based construction materials will decline; therefore, those involved with these industries must develop new technique for creating cement-based construction materials with a minimal use of limestone. We must use more blended cement produced by blending with clinker other pozzolanic materials, such as coal or bio-mass fly ash, slag, silica fume, and such other pozzolanic materials as finely ground waste glass (Naik, 2011). The use of glass waste as a coarse aggregate was not successful in the previous years because of the marked strength regression and excessive expansion. But in recent years research has shown that increasing the surface area to the volume ratio of glass will reduce the effects of the ASR reaction and this can be accomplished by using glass with smaller particles. Finer particles tend to accelerate the reaction, which may allow the gel to expand before the concrete hardens and no alkali-silica reaction had been detected with particle sizes up to 100 μm (Corinaldesi, 2005).

With the replacement of cement with other recyclable resources, worldwide CO_2 emissions would be reduced. A replacement of 50% of cement worldwide by other cementitious materials would reduce CO_2 emissions by more than one billion tones. And this is equivalent to removing approximately one-quarter of all automobiles in the world (Malhorta, 2004). Waste management is a very important issue both from the public health perspective and the industrial one. As an increasing amount of hazardous materials need to be disposed of in a safe and economical way, the wastes are to be considered a real opportunity to produce clean secondary raw materials reducing costs and conserving resources (Andreola, 2010). Glass waste corresponds to many types of after-use products and can be completely recycled. Since most of this glass waste is made with soda-lime material, its melting and working temperatures are relatively low, which makes it easy to reprocess. But in spite of this recycling advantage, a large amount of glass waste is still discarded in landfills or simply thrown into the environment, including fluorescent lamps (Morais, 2012). Fluorescent lamps are used widely all over the world due to their long life and energy saving capability. Fluorescent and high intensity discharge lamps contain mercury, lead, and other components of environmental concern. Of that 17,400 tonnes of lamp waste, there was an estimated 2,4 tonnes of mercury and 2,5 tonnes of lead. The fluorescent lamp recycling facility crushes the lamps, separates the metal caps and recovers mercury. The majority of the by-product from the processing is the lamp glass. For 55000 tubes recycled, approximately 30 m^3 of waste glass will be generated. Because of the mercury contamination, the lamp glasses are finally sent to landfill. Similar to the mixed color bottle glass, the waste lamp glass awaits for the assessment of re-use (Shao, 2001). According to the data, from the only one lamp recycling centre in the Baltic States located in Liepaja (Latvia), the accumulated amount of lamp glass waste in the period from 2004 to 2012 is 1.8 thousand tonnes from which 0.5 thousand tonnes were exported outside of Latvia. There have been several investigations conducted in recent years about the application of this glass waste as a partial cement substitution in concrete. (Shakhmenko, 2010; Kara, 2012; Kara, 2013).

In this paper viscosity, electrical conductivity and compression strength of cement paste substituted with finely ground fluorescent lamp glass waste and bottom coal/wood ash are investigated focusing on cement paste workability behaviour.

MATERIALS AND EXPERIMENTAL PROGRAM

The glass powder that was obtained from the fluorescent lamp chippings (named LB) and mercury vapour lamps (named DRL) were received from a local lamp recycling centre (Fig.1). The chippings were then washed and dried before being ground in a laboratory planetary ball mill Retsch PM400 (with rotation speed 300 min-1).

Figure 1. DRL (left) and LB (right) lamps

The DRL and LB chippings were ground for 10, 20, 30, 40, 50 and 60 minutes. The coal and bottom ashes were obtained from a local source and ground for 30 min. The fineness of powders was obtained by the Blaine apparatus Testing Bluhm&Feuerherdt GmbH (50ml) using a method with the prior need of measuring the density of the powder with a pyknometer in accordance with EN 196-6. The fineness of DRL and LB powders is shown in Figure 2. The fineness of coal bottom ash was 840 m^2/kg, wood coal ash was 660 m^2/kg. Ordinary Portland cement CEM I 42.5N was used as a binding agent and its fineness was 390 m^2/kg. Sikament 56 was applied as a polycarboxylates plasticizing agent at a dosage of 1% by weight of cement. The chemical analysis of powders was determined in conformity with EN 196-21 methodology and the results are summarized in Table 1.

In order to reveal the influence of waste glass and bottom ashes on the rheological properties of cement paste, cement paste mixes were prepared. The cement, glass powders and ashes, plasticizer were dosed by mass. Constant w/c ratio of 0.28 was maintained throughout all the tests. Plasticizer was mixed into the water used for the cement paste. In total, 22 cement paste mixes were prepared. *Six mixes* named LB10, LB20, LB30, LB40, LB50, LB60 were prepared with a cement substitution at a level of 30% with LB waste glass (grinding time from 10 to 60 minutes). *Six mixes* named DRL10, DRL20, DRL30, DRL40, DRL50, DRL60 were prepared with a cement substitution at a level of 30% with DRL waste glass (grinding time from 10 to 60 minutes). *Three mixes* named LBp20, LBp40, LBp60 were prepared with cement substitution at level of 30% with LB waste glass (grinding time from 20, 40 and 60 minutes), plasticizer. *Three mixes* named DRLp20, DRLp40, DRLp60 were prepared with a cement substitution at a level of 30% with DRL waste glass (grinding time from 20, 40 and 60 minutes), plasticizer and w/c=0,28. *Two control cement paste mixes* with and without plasticizer. *Two mixes* named CBA and WBA were prepared with a cement substitution at a level of 30% with coal/wood bottom ash ground for 30 minutes.

Table 1

Chemical composition of glass powders, bottom ashes and Portland cement used in the study

Bulk oxide, %mass	DRL	LB	Wood ash	Coal ash	PC
CaO	1.320	5.110	13.5	20.42	69.01
Al_2O_3	2.600	1.220	16.72	3.59	5.260
SiO_2	71.140	65.520	40.69	56.93	18.74
K_2O	1.702	1.881	1.592	5.636	0.727
Na_2O	3.301	12.354	0.431	1.274	0.382
Fe_2O_3	0.170	0.110	9.5	1.91	2.030
MnO	0.006	0.011	0.193	0.469	0.059
MgO	0.615	2.946	5.132	3.505	1.812
TiO_2	0.006	0.027	0.84	0.193	0.261
SO_3	0	0.143	0.552	0.024	3.004
P_2O_5	0.023	0.038	0.865	1.723	0.151

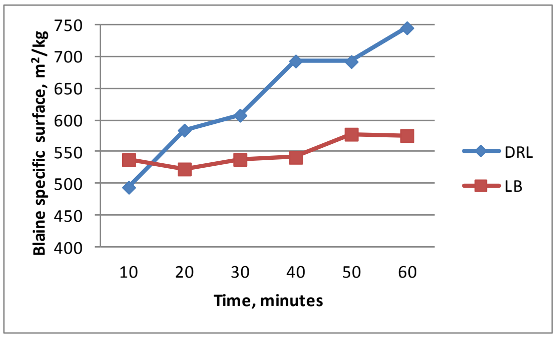

Figure 2. The fineness of DRL and LB powders vs grinding time

The rheological behaviour of the cement pastes was tested after the mix components were mixed for 25 minutes. Dynamic viscosity of cement pastes was tested by Malvern Instruments vibroviscometer SV-10 (Japan), the principle of its operation is based on an electromagnetic force driven vibration of two acoustic plates in a 13ml container. Two cement paste mixes were tested in parallel with a time interval for 5 minutes: A- first pair of two cement paste mixes, B – second pair, C- third pair. Each test had six levels: (i) first cement paste was prepared and tested at vibroviscometer for 5 minutes, in the meantime of running the experiment a second cement paste mix was prepared, (ii) the first cement paste mix was taken off from the vibroviscometer and left to harden, a second paste mix was placed for testing for 5 minutes; (iii) a second cement paste mix was taken off from the vibroviscometer and left to harden, then the first paste mix was slightly remixed in the test container by spoon and placed for testing for another 5 minutes; (iv) the first cement paste mix was taken off from the vibroviscometer and left to harden, the second paste mix was slightly remixed in the test container by spoon and placed for testing for another 5 minutes; (v) and (vi) – repeat of (iii) and (iv). The dependence of the cement paste's (w/c=0.28) viscosity on time when the grinding time of LB waste glass was increased from 10 to 60 minutes is shown in Figure 3. The dependence of the cement paste's viscosity on time when the grinding time of DRL waste glass was increased from 10 to 60 minutes is shown in Figure 4. The dependence of the cement paste's (w/c=0.28) viscosity with plasticizer on time when the grinding time of LB and DRL waste glass was 20, 40 and 60 minutes is shown in Figure 5. The dependence of the cement paste's viscosity on time of wood (WBA) and coal (CBA) bottom ashes is shown in Figure 6.

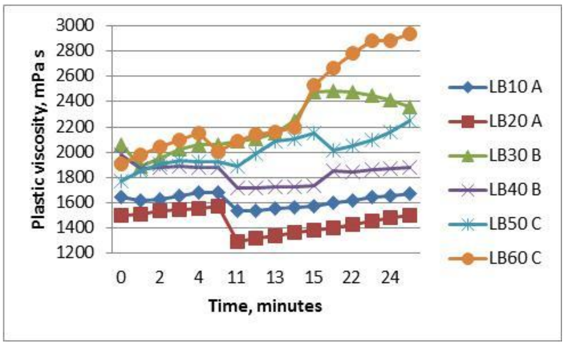

Figure 3. Time dependence of viscosity of Portland cement paste with the increase of LB waste glass powder grinding time

It can be seen in Figure 2 and 3 that the finer the LB glass waste is, the better the viscosity is of the cement paste. The optimal grinding time for LB glass waste is 30 minutes with Blaine specific surface area of 542 m^2/kg. In Figure 3 it is possible to observe the increase of the viscosity of cement paste with LB glass waste with increased time duration. The best result in this experiment set is for the mix LB60C. In comparison with Figure 6 where it is shown the viscosity of the cement paste, cement substitution with LB glass waste reasonably improves the workability and has an impact on the rheological properties of the cement paste. However, after first 10 minutes of the experiment it is observed that there is a slight decrease of viscosity for all cement paste samples with LB glass waste.

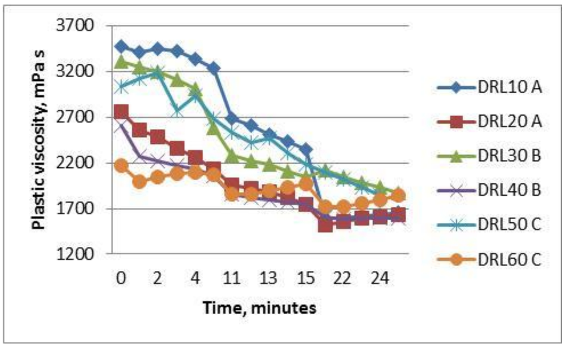

Figure 4. Time dependence of viscosity of Portland cement paste with the increase of DRL glass waste powder grinding time

It can be seen from Figures 2 and 4 that the finer is DRL glass waste the better viscosity of the cement paste in the first 5 minutes of the experiment. The Blaine specific surface area of DRL glass waste is much higher in comparison to LB glass waste with an increase of grinding time as it can be seen in Figure 2. The optimal grinding time for DRL glass waste is 20-30 minutes. In Figure 3 it is possible to observe a decrease of the viscosity of cement paste with DRL glass waste with an increased duration of time. The higher the grinding time of DRL glass waste the lower is the viscosity is of the cement paste. It can be described by the fact that - DRL particles are finer and more active than they are for pozzolanic reactions in the cement paste. The best result in this experiment set was the mix DRL10A from the workability's point of view. In comparison with the control mix, the cement paste with DRL glass waste also performed better.

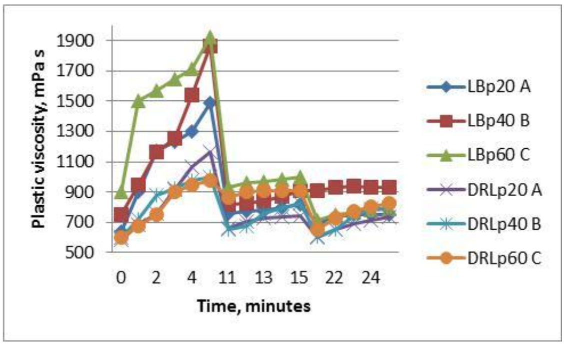

Figure 5. Time dependence of viscosity of Portland cement paste with plasticizer and LB and DRL glass waste powder ground for 20, 40 and 60 minutes

It can be seen in Figure 5 that the addition of plasticizer into cement paste mixes changes the character of viscosity of the mixes with DRL and

LB glass waste. It is observed that in the first 5 minutes the LB mixes have a significant increase of viscosity and in the second 5 minutes of the test – a significant decrease of viscosity with values equal to DRL mixes viscosity.

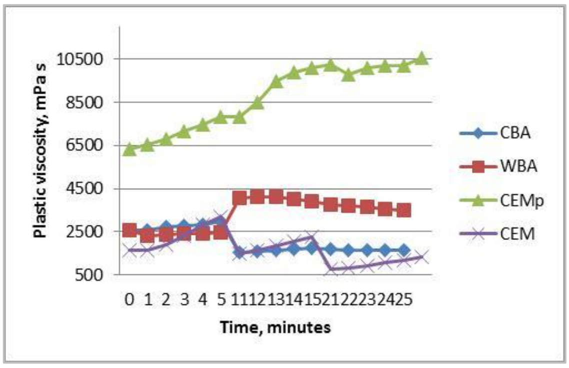

Figure 6. Time dependence of viscosity of Portland cement paste with/without plasticizer and coal and wood ashes

DRL mixes have almost a constant raising of viscosity in the duration of the experiment which is lower than is shown in Figure 4 but the workability of the mix is improved. The best results in this experiment set are for LBp40 and DRLp60. Plasticizer Sikament 56 improves the workability of DRL glass waste cement paste.

It can be seen in Figure 6 that the cement paste with WBA has increased viscosity and with CBA decreased viscosity. It was observed during the experiments that wood ash improves the workability of cement paste mixes, when coal ash absorbs more water. The cement paste mix electrical conductivity was studied immediately after mixing with water and at the 5th, 10th and 15th minute of the test with the device Metter-Toledo MPC 227 (electrical electrode in Lab 730, measuring interval (0-1000)μS/cm). The measurements were obtained at an ambient air temperature 21 ± 0.5°C.

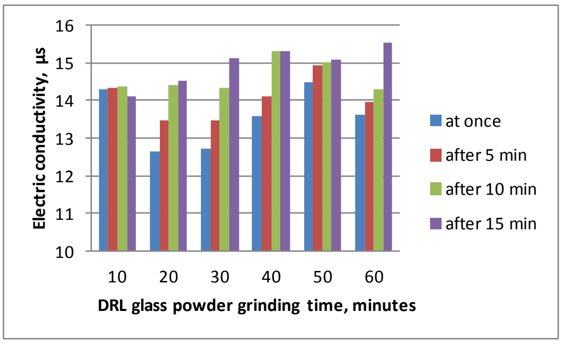

Figure 7. DRL glass and cement mix electrical conductivity

The results are shown in Figures 7, 8 and 9. It can be seen that electrical conductivity increases with time in the experiment for all mixes. In Figure 7 it is possible to see that mix DRL40 and DRL50 has better results and that DRL glass waste particle size influences the electrical conductivity of the cement mixes. In Figure 8 it is possible to observe that the electrical conductivity of LB glass waste cement paste mixes is decreased depending on the grinding time of LB glass waste: LB has finer particles and lower is electrical conductivity. Addition of plasticizer lowers the value of electrical conductivity in both DRL and LB cement paste mixes, but in comparison with Figure 7 and 8 results, in Figure 9 it is possible to observe that the finer the glass waste powder particles are, the better the electrical conductivity is in LB mixes in comparison with the DRL mixes.

In order to determine the compressive strength of cement paste mixes with glass waste and ashes, cement paste specimens were cast in 40x40x40mm steel moulds. The optimal grinding time for 30 minutes was chosen. The cement was substituted at a level of 30% with glass waste or ashes. The moulds were cleaned and lightly coated with form oil before the casting procedure. Samples were compacted on a vibrating table.

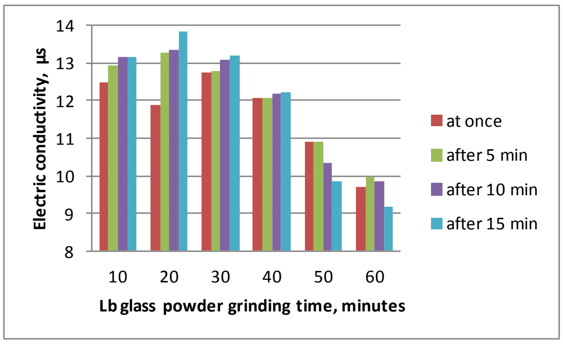

Figure 8. LB glass and cement mix electrical conductivity

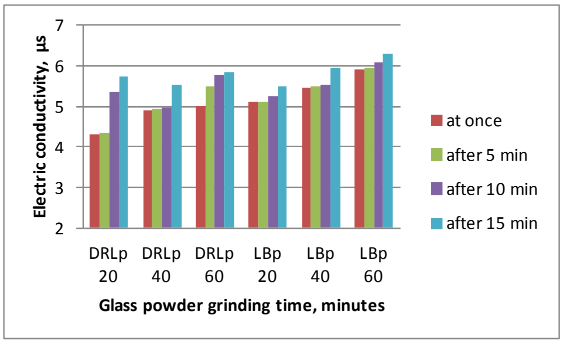

Figure 9. DRL or LB glass, cement and plasticizer mix electrical conductivity

After that the specimens were covered with polyethylene wrap and left to set for 24 hours. Then they were removed from the moulds and cured in water at a temperature of +20±2ºC for 28 days. Compression tests were performed at the age of 7, 28 and 56 days. The results are shown in Figure 10.

As it can be seen the best results were performed by the mixes with DRL glass waste powder with a maximum compressive strength for mixes DRL30 equal to 102 Mpa and DRLp30 equal to 117MPa at the age of 56 days.

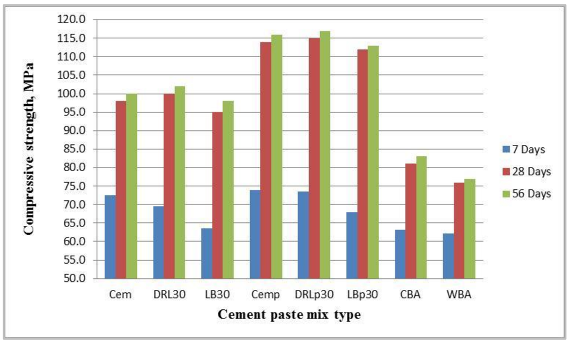

Figure 10. Influence of glass waste and bottom ash and curing time on the cement paste mix compressive strength

CONCLUSIONS

The rheological behavior of cement paste is improved by the application of fluorescent lamp glass waste in the mixes. However, the effectiveness of glass waste grinding time on rheological behavior and strength performance depends on the chemical composition of the glass waste and bottom ash used as a cement component in the cement paste mix. As it was observed, the finer the LB glass waste particles were the higher the value of viscosity was including lower electrical conductivity. The finer the DRL glass waste particles, the lower value of viscosity, and an almost constant electrical conductivity was observed.

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