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Recycled Aggregate Concrete with Fluorescent Waste Glass and Coal/ Wood Ash Concrete Wastes

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Consumption of natural aggregate as the largest concrete component is constantly and rapidly increasing with the increase in the production and utilization of concrete. Recycled aggregate is a valuable resource as replacement for virgin aggregate in concrete. In present study is investigated the approach of optimized utilization of concrete aggregate wastes (CAW) in concrete. The produced concrete cube specimens with fluorescent waste glass powder/suspension and fly/wood ash after determination of their mechanical properties are recycled and used as partial replacement of natural aggregates in recycled aggregate concrete (RAC). Therefore, it helps to convert waste product with determined properties into recourse and potentially to reduce the amount of waste disposed and preserve natural resources. The mechanical properties of recycled aggregate concrete are discussed from the point of the potential of its utilization in structural concrete.

Keywords: *fluorescent waste glass suspension, coal/wood ash, recycled concrete aggregate waste.*

1. Introduction

Concrete as a primary building construction material is the most consumed man-made material in the world. In 2007 the world concrete consumption was 11 billion tons or approximately 11.7 ton for each living human being (Mehta 2006, Naik 2005, Naik 2008). One of the most important parts of concrete is cement as hydraulic binder and production of cement itself is an energy-intensive and highly polluting process which contributes about 5-8% to global CO_2 emissions and accounts for 3% of total (5% of industrial) energy consumption worldwide. Production of each ton of cement results one ton of carbon dioxide (CO_2) (Gartner 2004) into the atmosphere. The aggregates constitute approximately 80% of concrete volume. According to Mehta (2006), the global concrete industry consumes about 10 billion tons of sand and rocks and taking into account today's industry development this number is even higher. Concrete being as a primary material in construction industry also is one of the most consuming landfills waste materials. The disposal of the construction and demolition (C&D) waste is becoming increasingly difficult and expensive and also environmental concerns are increasingly limiting the option of landfilling such waste. The scarcity of virgin aggregates and the increasing cost of landfilling the C&D waste are encouraging more value-added use of recycled aggregate (demolished concrete). Production and transport of virgin aggregates generate emissions representing 0.0046 million tons of carbon equivalent for each ton of virgin aggregate, compared to only 0.0024 million tons of carbon equivalent per ton of recycled aggregates (E.P.A. 2003). Planners, engineers and public authorities are looking for ways of making reuse of C&D waste and, therefore, there is important concern to find optimal approach of production of concrete with preferably reduced cement volume and equal/improved properties in comparison to conventional concrete, concrete waste utilization and its recycling. In 2002 the total volume of C&D waste was over 1 billion tons annually (Mehta, 2002). According to data in 2008, about 300 million tons of C&D waste were generated in the U.S. each year and about 50% of this waste was recovered for recycling and the rest was landfilled (Damtoft 2008).

Recycled aggregate is a valuable resource; value-added consumption of recycled aggregate, as replacement for virgin aggregate in concrete, can yield significant energy and environmental benefits. Concrete produced with coarse recycled aggregate and natural sand differs from normal concrete produced with virgin aggregates in terms of some mechanical properties and durability characteristics. Some of these differences depend upon the quality of the original concrete from which the recycled aggregate is obtained for use in recycled aggregate concrete (Tavakoli 1996, Hansen 1983, Shayan 2003). Original concrete of relatively low strength tends to produce lower-quality aggregates when compared with higher-strength original concrete as far as the effects on the strength and durability of recycled aggregate concrete are concerned. It has been reported that recycled aggregate concrete with properties in fresh and hardened states that are comparable to those of normal concrete can be produced using coarse recycled aggregate of desired quality and natural sand (Shayan 2003, Hansen 1992). The use of recycled aggregate in concrete is hindered by its higher water absorption (two to three times that of normal aggregate) and the increased shrinkage of the resulting recycled aggregate concrete. These drawbacks result largely from the cement hydrates (from old concrete) that adhere to the surface of recycled aggregates. It should be noted that most aggregates offer engineering properties that are superior to these of cement hydrates (Nassar and Soroushian 2012). Recycled aggregates constitute only 5% of the total aggregate used in concrete (Mehta 2006, Naik 2005, Naik, 2008).

Several researchers (Salem et al. 2003, Buyle-Bodin and Hadjieva-Zaharieva 2002, Ravindrarajah 1985) have found increased water absorption, drying shrinkage and particularly air permeability of the recycled aggregate concrete when compared with normal. An initial absorption that is nearly four times that of normal concrete has been measured with recycled aggregate concrete (Buyle-Bodin and Hadjieva-Zaharieva 2002). Increased moisture absorption and drying shrinkage of recycled aggregate concrete adversely influence its long-term performance and durability (Mehta 2006, Neville 2000, Basheer et al. 2001). Moisture movement in hydrated cement paste influences the drying shrinkage of concrete. Large-volume use of recycled aggregate concrete requires resolution of the problems with increased water absorption drying shrinkage resulting concrete.

Glass is also one of the most popular materials due to progressive growth of urbanization nowadays, but increased production of glass causes also simultaneously the growth of glass wastes. Disposal of this waste is a complex problem for many countries in the world. According to data of 2009 in Latvia have been imported 42.6 thousand tonnes of glass and the recycling of glass waste was 12.5 thousand tonnes (Kara et al. 2012). Recycling of post-consumer glass for use as raw material in production of new glass is very limited, mainly due to the mixed-color nature of waste glass. In the sixties, many studies have been devoted to use crushed glass waste as an aggregate for concrete production (Pike et al. 1960, Schmidt and Saia 1963, Jonhston 1974). This aggregate was also applied in road construction. The glass waste was also used for production of glass tiles and bricks, wall panels, glass fibre, agriculture fertiliser, landscaping reflective beads and tableware (Reindl 1998). The properties of glass seemed comparable to those of large aggregate in terms of constitution, strength and durability, and the larger size of the glass meant lower processing costs. These early attempts however, were unsuccessful due to the alkali–silica reaction (ASR) which takes place in the presence of the amorphous waste glass and concrete pore solution with marked strength reduction and simultaneous excessive expansion (Shao 2000). Due to high disposal costs of glass wastes, the use of glass as concrete aggregate again attracted the attention of researchers and it was found that if glass was ground to a particle size of 300μm or smaller, the ASR induced expansion could be reduced and in fact, data reported in the literature that if waste glass finely ground under 75μm, this effect does not occur and mortar durability is guaranteed (Shao 2000). The benefits of developing alternative or supplementary cementing materials as partial substitution for ordinary Portland cement (OPC) powder were described by Malhotra and Mehta (1996).

Non-recycled waste glass due to specific chemical composition (with heavy and toxic metals) constitutes a problem for solid waste disposal and therefore it has even more limited market in comparison to mixed-color nature of waste glass (cullet). Non-recycled waste glass like fluorescent lamp glass causes a problem for disposal because it is not biodegradable and landfill is not the best environment friendly solution for it. For example, yearly from 300 to 500 tonnes of fluorescent lamps are partially recycled in Latvia (Kara 2012). The used borosilicate (DRL) and leaden silicate (LB) waste glass powders obtained from fluorescent lamp chippings after recycling process which includes lamp classification, glass separation, cleaning from harmful components, crushing into chippings and grinding can be applicable as microfiller in concrete (Shakhmenko 2009, Kara 2012).

Waste glass as powder milled to certain surface specific area in order to accelerate beneficial chemical reactions in concrete offers desired chemical composition and reactivity for use it as a supplementary cementitious material (SCM) for enhancing the chemical stability, pore system characteristics, moisture resistance and durability of concrete. The beneficial effects of milled waste glass can enhance the residual cement occurring on the surface of recycled aggregates, thus improving the performance characteristics of recycled aggregate concrete (Nassar and Soroushian 2012). The old mortar / paste clinging to the surface of recycled aggregate are porous in nature due to the presence of large oriented crystals of calcium hydroxide (a product of cement hydration) at the aggregate-remnant interface. When milled waste glass is used in recycled aggregate concrete as partial replacement of cement, it interacts with calcium hydroxide to form calcium silicate hydrate (C-S-H) which is the key binder among cement hydrates. This reaction can enhance the quality of the remnant cement paste on recycled aggregates, thus benefiting the impermeability and dimensional stability of recycled aggregate concrete (Nassar and Soroushian 2012).

In present study is investigated the approach of optimized utilization of concrete aggregate wastes (CAW) in concrete. The produced concrete cube specimens with fluorescent waste glass and fly/wood ash after determination of their mechanical properties are recycled and used as partial replacement of natural aggregates in recycled aggregate concrete (RAC). Therefore, it helps to convert waste product with determined properties into recourse and potentially to reduce the amount of waste disposed and preserve natural resources.

2. Methods

An experimental study was carried out to investigate the effects on the mechanical properties of concrete with CAW obtained from crushed concrete specimens (from previous studies with cement substitution at level of 30% with waste borosilicate (DRL) glass chippings obtained from fluorescent lamps and ground into powder with specific surface area of 2310 cm^2/g and coal/wood ashes (Kara, 2012)) after they have been stored as concrete waste. Crushed concrete specimens grains from coal/wood ash concrete, DRL – fluorescent waste glass concrete, DRLS – fluorescent waste glass suspension concrete were separated into fractions (4/8mm, 8/11.2mm, 11.2/16mm) (see Fig. 1).

Ordinary Portland cement CEM I 42.5N from "Kunda Nordic" (Estonia) was applied as binding agent. Cement conforms to standard EVS EN 197-1:2002 "Cement – Part 1: Composition, specifications and conformity criteria for common cements". Natural local aggregates (gravel, crushed stone and sand) have been used for mix preparation.

Coal Ash   Wood Ash   DRL   DRLS

Fig. 1. *Concrete aggregate wastes*

Sikament 56 polycarboxylat plasticizing agent was added in several concrete mixes.

A total of 15 different concrete mixes were prepared. Three sets of experiments were hold. The first set of experiments included 7 mixes and was made with natural aggregate substitution by 100%: control mix with gravel 4-11.2mm (named CTRL), control mix with crashed stones 4-11.2mm (named CTRL1), 2 mixes with coal RAC 4-11.2mm but different w/c ratios – RC (w/c=0.49) and RC1(w/c=0.59) 4-11.2mm, 1 mix with wood RAC (named RW) 4-11.2mm, 1 mix with DRL fluorescent waste glass RAC 4-11.2mm (named RDRL) and 1 mix with DRL fluorescent waste glass suspension RAC 4-11.2mm (named RDRLS).

The second set of experiments included 4 mixes and was made with natural aggregate substitution by 50%: Control mix with gravel 4-11.2mm (50%) and crashed stones 4-11.2mm (50%) (named CTRL2), 1 mix with coal RAC (50%) 4-11.2mm and with gravel 4-11.2mm (50%) and crashed stones 4-11.2mm (50%) (named RC2), 1 mix with wood RAC (50%) 4-11.2mm and with gravel 4-11.2mm (50%) and crashed stones 4-11.2mm (50%) (named RW2), 1 mix with DRL fluorescent waste glass suspension RAC (50%) 4-11.2mm and with gravel 4-11.2mm (50%) and crashed stones 4-11.2mm (50%) (named RDRLS2).

The third set of experiments included 4 mixes and was made with natural aggregate substitution by 50% and plasticizer: Control mix with gravel 4-11.2mm (50%) and crashed stones 4-11.2mm (50%) (named CTRL3), 1 mix with coal RAC (50%) 4-11.2mm and with gravel 4-11.2mm (50%) and crashed stones 4-11.2mm (50%) (named RC3), 1 mix with wood RAC (50%) 4-11.2mm and with gravel 4-11.2mm (50%) and crashed stones 4-11.2mm (50%) (named RW3), 1 mix with DRL fluorescent waste glass RAC (50%) 4-11.2mm and with gravel 4-11.2mm (50%) and crashed stones 4-11.2mm (50%) (named RDRL3).

Table 1. *Concrete mix compositions, kg/m^3*

Mix type	W/C ratio	Portland cement CEM I 42,5 N	Gravel (4,0-11,2 mm)	Crashed stone (4,0-11,2 mm)	Natural sand (0,3-2,5 mm)	Quartz sand (0-1,0 mm)	CAW	Plasti-cizer	Water
CTRL	0.49	410	1000	-	650	119	-	-	200
CTRL1	0.49	410	-	1000	650	119	-	-	200
RC	0.49	410	-	-	650	119	1000	-	200
RC1	0.59	410	-	-	650	119	1000	-	242
RW	0.49	410	-	-	650	119	1000	-	200
RDRL	0.49	410	-	-	650	119	1000	-	200
RDRLS	0.49	410	-	-	650	119	1000	-	200
CTRL2	0.59	410	500	500	650	119	-	-	242
RC2	0.59	410	-	500	650	119	500	-	242
RW2	0.59	410	-	500	650	119	500	-	242
RDRLS2	0.59	410	-	500	650	119	500	-	242
CTRL3	0.49	410	845	155	650	119	-	7	200
RC3	0.49	410	423	77	650	119	500	7	200
RW3	0.49	410	423	77	650	119	500	7	200
RDRL3	0.49	410	423	77	650	119	500	7	200

Details for different mixes are shown in table 1.

All concrete mixes were made with capacity of 6.2 litres. The mixing procedure was following:

- Mixing of the dry ingredients for 120 s;
- Adding 70% of the total water for 60 s;
- Adding the rest of the water and mixing for 60 s.

As soon as the mixing finished, Abram slump test was carried out for each mix in accordance with LVS EN 12350-2:2009 "Testing fresh concrete – Part 2: Slump test".

Specimens were cast in 100x100x100 mm plastic or steel moulds, which conform to standard LVS EN 12390-1:2009 "Testing hardened concrete – Part 1: Shape, dimensions and other requirements for specimens and moulds". The moulds were cleaned and lightly coated with form oil before the casting procedure. Concrete was compacted on a vibrating table. After that the specimens were covered with polyethylene pellicle and left to set for 24 hours (w/t plasticizing agent) and for 48 hours (with plasticizing agent). Then they were removed from moulds and cured in water (with temperature +20±2°C) for 7 days and in curing chamber (with air temperature +20±2°C and relative humidity ≥95%, see Figure 1) for other 21 days or until testing, thus conforming to LVS EN 12390-2:2009 "Testing hardened concrete – Part 2: Making and curing specimens for strength tests". To evaluate hardened concrete properties compressive strength test was carried out. Before the test, the specimens were dried. The testing was done according to LVS EN 12390-3:2009 "Testing hardened concrete – Part 3: Compressive strength of test specimens". Compression testing machine with the accuracy of ±1% was used; the rate of loading was 0.7 MPa/s. Compressive strength was conducted up to 112 days. Three specimens per mix for each age were prepared and the mean compressive strength value was calculated. The concrete strength containing ground waste glass was compared to the concrete control mix.

3. Results and Discussion

The results for fresh concrete properties – slump test – are summarized in table 2.

The slump class for almost all mixes varied between S1 and S2, except for the control mix with plasticizer (CTRL3) and mix with DRL fluorescent waste glass suspension CAW (RDRLS2). Coal/wood CAW showed better workability on concrete in comparison to fluorescent waste glass CAW. That could be described by different water absorption levels of CAW in mixes. However, as it is evident from the experiment, additional water amount improved workability of RDRLS2 and also decreased the compressive strength value.

Concrete cubes' strength tests were carried out after 7, 28, 56, 84 and 112 days. After 7 days of hardening, the first part of samples was tested on compression strength. The specimens were dried before the test. Three tests per mix for each age were carried out – to measure the compressive strength. The testing was done according to LVS EN

Table 2. *Slump test results*

	CTRL	CTRL 1	RC	RC1	RW	RDRL	RDRLS	CTRL2	RC2	RW2	RDRLS2	CTRL3	RC3	RW3	RDRL3
Slump, mm	30	10	30	40	30	20	20	45	45	50	95	160	20	55	40
Slump, class	S1	S1	S1	S1	S1	S1	S1	S2	S2	S2	S2/S3	S4	S1	S2	S1

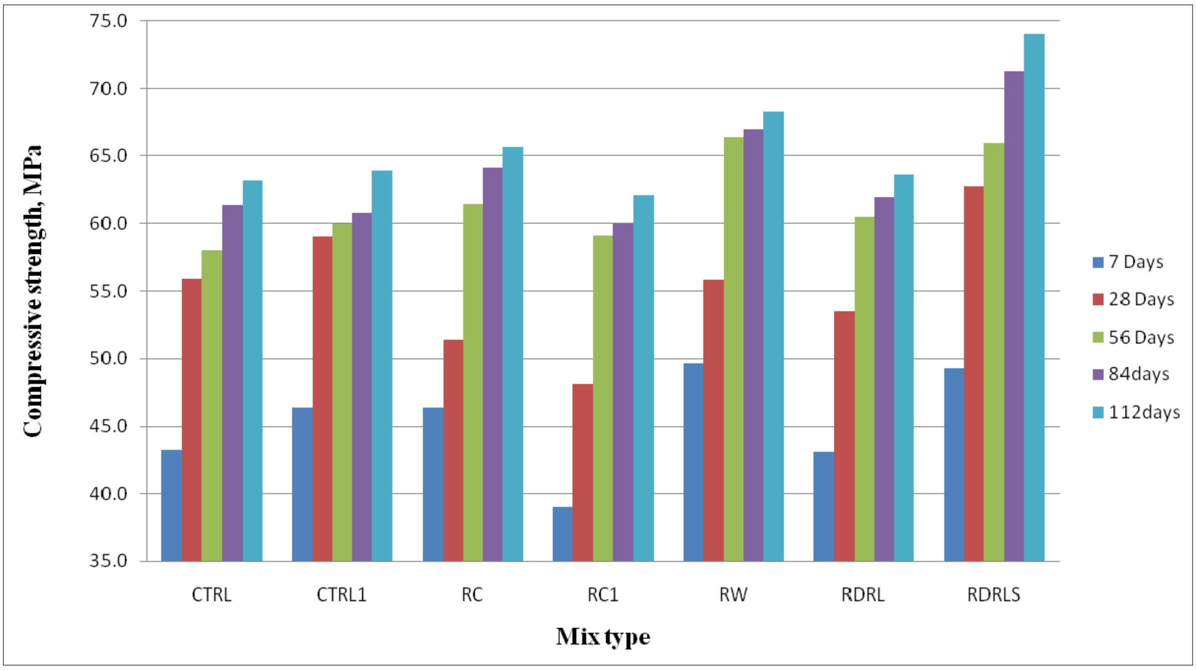

Fig. 2. *Influence of CAW (100%) content and curing time on the concrete compressive strength*

12390-3:2009 "Testing hardened concrete – Part 3: Compressive strength of test specimens". Compression testing machine with the accuracy of ±1% was used; the rate of loading was 0.7 MPa/s.

Fig. 2 shows the results from the first set of experiments when natural aggregates were substituted by CAW at level of 100%. Two kinds of natural aggregates were available during the experiments: gravel and crushed stones. As to the results of the compressive strength of CTRL and CTRL1, they don't differ so much, however compressive strength of crashed stones was higher than gravel and this natural aggregates were considered more for experiments. At the age of 7 days mixes with wood CAW and RDRLS showed higher results than mix with DRL fluorescent waste glass powder and coal CAW. At the age of 28 days the results of CAW concrete were lower in comparison to control mixes, only RDRLS had higher result for 7-11% in comparison to control mixes. At the age of 56 days all mixes had equal or higher results on compressive strength in comparison to control mixes. The best results were for RW = 66.4MPa and RDRLS=66.0MPa, but at the age of 112 day mix RDRLS gained higher strength for 8% than mix RW with value of 74MPa.

Fig. 3 shows the results from the second set of experiments when natural aggregates were substituted by CAW at level of 50%. The water amount was increased for this set of experiments in order to improve concrete workability. The compressive strength results were lower for all mixes with CAW in comparison to control mixes and only RDRLS2 mix at the age of 56 days showed equal result to CTRL2, 60.4MPa, not big difference was observed at later ages of curing specimens.

In the third experiment set (Fig. 4) plasticizer was added into mix keeping the same water amount as in the first set of experiments. Plasticizer influenced on workability of control mix and not so much on the CAW mixes. Coal CAW mix had worse workability, RW3 and RDRL3 better as in second experiment set. The compressive strength results of

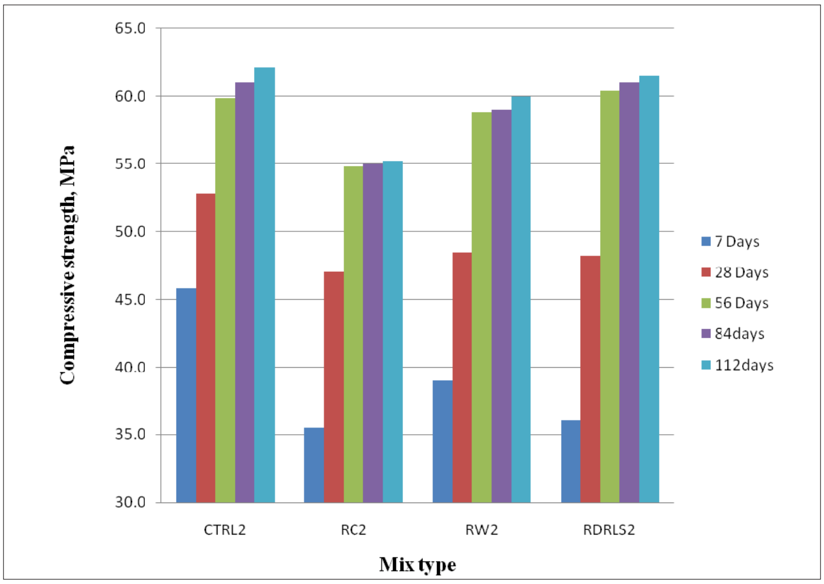

Fig. 3. *Influence of CAW (50%) content and curing time on the concrete compressive strength*

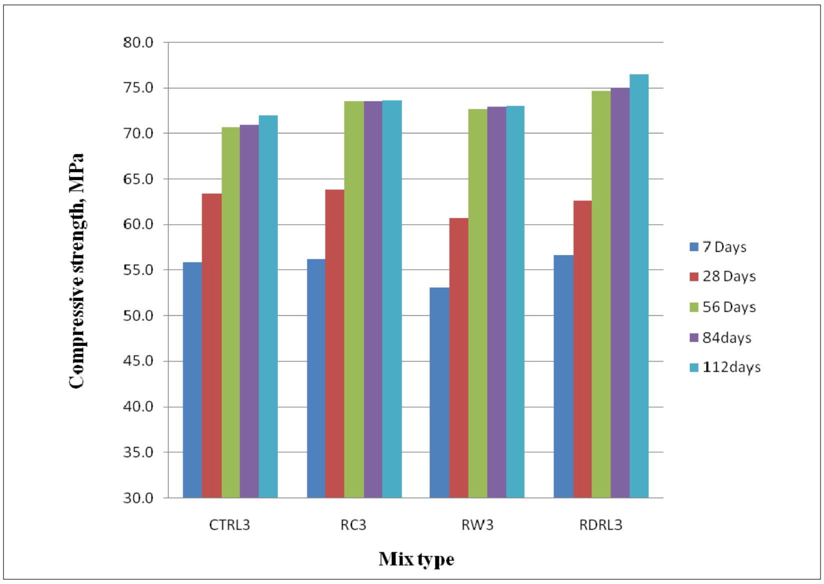

Fig. 4. *Influence of CAW (50%) and plasticizer content and curing time on the concrete compressive strength*

RC3 were equal to control mix within the 7 and 28 days, and were higher at the age of 56-112 days. The best result for this group was mix RDRL3 with the value of 76.5 MPa.

It is possible to see from present research that recycled concrete aggregate is a valuable resource as replacement for virgin aggregate in concrete carrying some environmental benefits. Increasing recycled concrete aggregate content leads to increased water absorption, however it depends on the CAW used. As it was observed from the first set of experiments the slump's value of coal/wood CAW mix was equal to control mix, also with modified w/c ratio CAW mix's slump was equal to control mix, and only mixes with fluorescent waste glass suspension were performing better workability except the third set of experiments with plasticizer. That could be described by the morphology of CAW grains and also chemical composition of old mortar remained from previous studies (Kara 2012).

The optimal natural aggregate substitution level with CAW in concrete could be around 100% with optimized w/c ratio and needed workability taking into account that compressive strength for concrete structural elements is important at the age of 7 days and 28 days. In comparison to control mix only RW and RDRLS mixes could competitive results but taking into account that structural elements compressive strength is in the range up to 50 MPa, the results obtained from this study are satisfied for all mixes.

Waste glass as powder ground to certain surface specific area in order to accelerate beneficial chemical reactions in concrete offers desired chemical composition and reactivity for use it as a supplementary cementitious material (SCM) for enhancing the chemical stability, pore system characteristics, moisture resistance and durability of concrete. As it was observed from present study, the waste glass mixes acted different from coal/wood ash mixes, but more detailed investigation must be carried out in this field. The next step could be the use of waste glass as cement partial replacement at level of 20-30% in mixes with CAW, which could improve the performance characteristics of recycled aggregate concrete and also set of X-ray experiments in order to observe how calcium silicate hydrates are forming.

4. Conclusions

The effect of CAW on compressive strength appears to be dependent on original concrete quality and mix proportions, water/cement ratio and workability. Recycled aggregates from demolished concrete are generally produced by crushing, screening and removing the contaminants by water cleaning, air-shifting and magnetic separation. The quality of such aggregate usually is lower due to remained amount of mortar on original aggregate grains. The utilization of recycled aggregates in structural concrete should help to improve the environmental performance of concrete. According up-to-date state of research in the area of recycled aggregates utilization from demolished concrete in structural concrete is technically feasible but limited since it is not recommended to apply this kind of concrete for structural elements which are expected to have high stresses and deformations in service because the long-term behavior is not well-known yet and also it is not recommended due to its uncertain durability performance. In present study recycled aggregates from concrete specimens with known mix composition have performed good mechanical strength results. The best obtained result was for the mixes with waste fluorescent glass CAW.

Substitution of natural aggregates can be one of possibilities to take care of landfills and increase of CO_2 emissions into the atmosphere in Latvia. There are not developed regulatory standards for recycled concrete use in construction in Latvia. It would be important to develop and implement the rules of the use of recycled concrete aggregates in structural concrete in Latvia after detailed research in this field will be carried out.

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