doi: 10.2478/v10311-012-0003-0
2012 / 13

Evaluation of Properties of Concrete Incorporating Ash as Mineral Admixtures

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Abstract. **Cement industry has a huge environmental impact – it is responsible for a considerable part of man-made CO_2 emissions. The prospective scenario to solve this problem is to substitute part of the cement clinker with industrial by-products or waste materials. In the present study coal ash and wood ash were used as a partial substitution of cement at 3 levels (20%; 30% and 40%) in concrete mixes. Ash was used in two ways – with no additional grinding and additionally ground for 30 minutes. Compressive strength of the hardened concrete samples was determined at the age of 7, 28, 56, 84 and 112 days. Ecological and economical characteristics of the materials were calculated.**

***Keywords*: coal ash, wood ash, concrete admixtures, compressive strength**

INTRODUCTION

A. *An overview of the cement industry*

As large quantities of waste materials and by-products are generated from manufacturing processes, service industries and municipal solid wastes, solid waste management has become one of the major environmental concerns in the world. With the increasing awareness about the environment, scarcity of landfill space and due to its ever increasing cost, there has been a growing emphasis on the utilisation of waste materials and by-products in construction materials, especially concrete. [1]

Concrete is currently the most widely used man-made material in the world. It is a fundamental building material to fulfil the housing and infrastructure needs of our society [3]. However, the current concrete construction practice is considered unsustainable because it consumes huge quantities of stone, sand, drinking water and cement. The essential part of concrete is, of course, cement which is being produced at enormous quantities to satisfy the ever-increasing demand for concrete. [2]

Cement manufacturing has become a major mineral commodity industry to supply the high levels of cement consumption. Output from the cement industry is directly related to the state of the construction business in general, with world cement production growing steadily since 1950.[3] Increased production in developing countries (particularly in Asia) has played an important role in the overall production rise. The recent data show that world cement production rates, although hindered by the economic recession, still continued to rise reaching 3,3 billion tonnes in 2010, double the amount of a decade ago. [4]

B. *Industry's environmental impact*

But cement industry has a huge environmental impact – cement production is not only energy consuming, it is also responsible for a considerable part of man-made CO_2 emissions which, along with other greenhouse gases, lead to global warming. From this point of view, cement is not an environment-friendly material, so it should be industry's top priority to reduce energy consumption and emissions to the air during concrete manufacture. [5]

CO_2 emissions from the production of cement come from the physical and chemical reactions of the raw materials and from the combustion of the fuel used. Approximately 62% of all CO_2 emissions originate in the calcination process and the remaining 38% are related to fuel combustion [10]. The amount of CO_2 produced in the calcination process is about 526 kg/tonne clinker. Emissions resulting from the combustion of the fuel are dependent on the fuel used and the type of kiln.[3] These emissions, however, have been slowly reduced by introducing a more fuel efficient kiln process, reducing emissions of combustion CO_2 by about 30% in the last 25 years. The total amounts of CO_2 emitted are roughly within the range of 720…1140 kg/tonne clinker. [3]

To know the final amount of CO_2 produced per kg of cement, the clinker-to-cement ratio must also be considered, as well as CO_2 emissions from electricity use and transportation.[3] The weighted average at worldwide level in 2009 was approximately 853 kg/tonne cement, while at European level – 846 kg/tonne cement.[11] Demand for cement is forecast to continue increasing worldwide, in particular in emerging economies where much needed housing and infrastructure boosts development. The reduction of CO_2 emissions from cement production is therefore an important and urgent task for the cement sector. [5]

One way to achieve the necessary reductions is by substituting part of the cement clinker with industrial by-products or waste materials, thus producing blended cement. Currently this could be viewed as the most prospective scenario in the near future, because it has relatively low investment needs and therefore is easier to implement worldwide. [5] Worldwide production of blended cement would reduce energy use and CO_2 emissions considerably. However, those would not be the only gains – others benefits include potential improvements of concrete properties, reduced cost for raw materials and higher utilisation of waste products. [12]

The key factor here is the local availability of industrial by-products and waste materials. Transporting such materials over long distances for blended cement production would defeat the main purpose of blended cement, as transporting would require energy and most likely produce greenhouse gases as well. [12] However, the availability of usable local industrial by-products and waste materials is not a problem, as these materials are available in regions with manufacture and processing industries – that means nearly all of Europe and most of the industrialised world. [5]

Two such industrial by-products and waste materials – coal ash (CA) and wood ash (WA) – are locally available in Europe in ample amounts, thus making them perfect for utilisation in concrete and concrete products. Coal ash is widely available in Europe, because according to Eurostat data for year 2009 around 30% of all the power generated in the EU27 is still coal-based which results in gross inland consumption of 292 000000 tonnes of coal. Wood ash, on the other hand, is freely available in Latvia, as wood and wood waste accounted for about 30% of the heat generated in Latvia in 2010, with a total consumption of 7 329 000 solid m^3 of resource (based on data from Central Statistical Bureau of Latvia, 2010). Therefore research on the possible effects and benefits of both of these mineral admixtures on the concrete and its properties are valuable.

C. Coal ash

Coal ash is a by-product from coal-fired power plant. Coal is first passed through a pulveriser where it is ground to fine size, almost powder-like. The powdered coal is then mixed with a steady supply of air and is blown into the furnace where it burns like a gas flame. [6] The properties of coal ash depend on the type of coal burned; the extent to which the coal is prepared before burning; and the operating conditions of the furnace. [9]

The non-combustible material that remains after the pulverised coal is burned is called ash. During the combustion process, the volatile matter and carbon burn off, and the remains are the mineral impurities found in the coal. The proportion of the non-combustible material in coal is termed ash content. [1,6] The ash produced can be divided into the following types: fly ash; bottom ash; and boiler slag. The smaller particles of the fused material are carried out of the combustion chamber along with the flue (exhaust) gases, as they rise, they cool and solidify to form predominantly spherical glassy particles – these are referred to as fly ash. The larger, coarser particles do not rise and therefore agglomerate at the bottom of the furnace and thus form either bottom ash (if the particles have never completely melted) or boiler slag (if the ash particles have melted) – which mainly depends on the design of the furnace, i.e. dry-bottom or wet-bottom. [9]

The diameter of the fly ash particles typically lies in the range of 1–150 μm. [1] All fly ashes are particularly rich in silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3), and also contain other oxides such as calcium (CaO), magnesium (MgO), manganese (MnO), titanium (TiO_2), sodium (Na_2O), potassium (K_2O) and sulfur (SO_3). Notable amount of unburned carbon (LOI) is also present. SiO_2 and Al_2O_3 together make up about 45–80 % of the total content of fly ash. [1,6]

Fly ash also possesses an important property – pozzolanic activity. Pozzolanic activity is the capacity of certain materials to enter into reaction with CaO or $Ca(OH)_2$ in the presence of water at room temperature, to form highly cementitious and water-insoluble masses. [1]

Bottom ash and boiler slag particles are much coarser than fly ash, with the grain size typically ranging from fine sand to gravel in size, generally within a range of 0,5 to 5,0 mm.[6] Chemical composition of bottom ash and boiler slag is similar to fly ash but they typically contain greater quantities of carbon. Bottom ash and boiler slag also are relatively more inert because the particles are larger and more fused than fly ash. Since these particles are highly fused, they tend to show less pozzolanic activity and therefore are less useful as a substitute for cement. [6,9] Fly ash is also generated in larger quantities. In dry-bottom furnaces fly ash usually accounts for 80…90% of the total ash amount generated; bottom ash – for the remaining 10…20%. In wet-bottom furnaces the proportions are 50% fly ash and 50% boiler slag. [1,9]

D. Wood ash

Wood ash is the inorganic and organic residue remaining after the combustion of wood and wood products (chips, saw dust, bark, etc.). [1] Wood and wood products are generally used for energy production at pulp and paper mills, sawmills and wood-product manufacturing facilities or for heat generation. Wood waste is commonly burned with supplementary fuels such as coal, petroleum coke, oil and gas. [7]

On the average, the burning of wood results in about 6–10% of ash. [1] When ash is produced in industrial combustion systems, the temperature of combustion, cleanliness of the fuel wood, the collection location and the process can also have profound effects on the nature of the ash material. [1,8] As a result of the oxidation processes during combustion the generated wood ash retains the overall composition of the mineral nutrients contained in the waste wood with the exception of nitrogen compounds, which are mainly released in the gas phase. [8]

The physical and chemical properties of wood ash vary significantly depending on many factors. The physical and chemical properties of wood ash, which determine its beneficial uses, are dependent upon the species of the tree, tree growing conditions and the combustion methods that include combustion temperature, efficiency of the boiler, and supplementary fuels used. Ash content yield decreases with increasing combustion temperature. [1,7]

Wood ash is a heterogeneous mix of particles of varying size, with the average particle size being 230 μm. [1] Particles are generally angular in shape. [8] Typically, wood ash contains carbon in the range of 5–30 %, which impacts the density of wood ash (higher carbon content means lower density). [1] The major element of wood ash is calcium (7–33 %), in smaller quantities – potassium, magnesium, manganese, phosphorus and sodium. [7]

Pozzolanic activity depends on the chemical composition of wood ash. While chemical analysis of wood ash shows that the ash contains silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3), their combination of the percentage masses is too small, and this reduces the pozzolanic activity of the wood ash. And since wood ash contains appreciable amount of un-burnt carbon, its pozzolanic activity is even further reduced. [1] There are, however, some glass (amorphous) components in wood ash that participate in pozzolanic reactions. Therefore, when ash is used as a cementitious material, a larger amount of glass phase is preferred. [8]

The main aim of this paper is to increase the use of local industrial by-products and waste materials in concrete manufacture, thus making concrete an environmentally sustainable material. Based on the available literature, many attempts have been conducted to achieve this. However, papers focusing on ash in concrete are not that common. Most researchers use only fly ash not coal ash (fly ash is a part of coal ash). Even then it is most likely that ash will be used in high volumes (ash replacement more than 40%), thus achieving high volume ash concrete. Whereas in the case with wood ash, there is a different problem – wood ash is commonly used together with fly ash.

Therefore to achieve the aim of this paper, specific objectives must be fulfilled. The objectives for this research are: to study the characteristics of local industrial by-products and waste materials – coal ash and wood ash – and their potential use in concrete manufacture; and to evaluate the potential improvements in concrete and its properties by partly substituting cement with coal ash and wood ash at low levels (below 40%).

METHODS

A. Mix compositions

An experimental study was carried out to investigate the effects of partial substitution of cement with coal ash and wood ash on the mechanical properties of concrete. The ash was used in two ways – with no additional grinding and additionally ground for 30 minutes in laboratory planetary ball mill Retsch PM400 (with rotation speed 300 min^{-1}). Water-to-cement ratio was maintained constant (W/C=0,49) for all mixes.

For this study the following materials were used:

- Cement: ordinary Portland cement CEM I 42,5 N;
- Admixtures: fly ash (1–150 µm), bottom ash (CA) (100–250 µm) and wood ash (WA) (230 µm);
- Fine aggregate: natural sand (fractioned 0,3-2,5 mm) and quartz sand (fractioned 0-1,0 mm);
- Coarse aggregate: gravel (fractioned 2,0-12,0 mm);
- Water

All materials were obtained from local sources in Latvia, except for cement and fly ash which were obtained outside of Latvia.

A total of 13 different concrete mixes were proportioned. One of them was a control mix with no ash substitution (named CTRL), 6 – with coal ash (CA) (half of the mixes were prepared with fly ash and bottom ash (ratio 1:4) being additionally ground for 30 minutes (grCA)) and 6 – with wood ash (WA) (also half of the mixes with additional ground wood ash (grWA)). Cement was substituted with ash at 3 levels – 20%; 30%; and 40%; the rest of the ingredients were kept constant. Details for different mixes containing coal and wood ash are shown in Table 1.

B. Casting and curing procedure

All concrete mixes were mixed in a power-driven rotary mixer with a moving bottom (but with no blades or paddles). The mixing procedure was as follows:

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

TABLE 1

Selected concrete mix proportions, kg/m^3.

Mix type	W/C ratio	Portland cement CEM I 42,5 N	Gravel (2,0-12,0 mm)	Natural sand (0,3-2,5 mm)	Quartz sand (0-1,0 mm)	Coal/ wood ash	Water
CTRL	0,49	410	1000	650	120	0	200
CA20	0,49	330	1000	650	120	80	200
CA30	0,49	290	1000	650	120	120	200
CA40	0,49	250	1000	650	120	160	200
WA20	0,49	330	1000	650	120	80	200
WA30	0,49	290	1000	650	120	120	200
WA40	0,49	250	1000	650	120	160	200
grCA20	0,49	330	1000	650	120	80	200
grCA30	0,49	290	1000	650	120	120	200
grCA40	0,49	250	1000	650	120	160	200
grWA20	0,49	330	1000	650	120	80	200
grWA30	0,49	290	1000	650	120	120	200
grWA40	0,49	250	1000	650	120	160	200

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 48 hours. 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”.

E. Testing of specimens

To measure fresh concrete properties, as soon as the mixing finished, a slump test was carried out for each mix in accordance with LVS EN 12350-2:2009 “Testing fresh concrete – Part 2: Slump test”. For each mix the slump class was determined according to LVS EN 206-1:2001 “Concrete – Part 1: Specification, performance, production and conformity”. Figure 2 shows the slump test being carried out for coal ash mix.

To evaluate hardened concrete properties compressive strength test was carried out. Before the test, the specimens were dried in an oven for 20 min at 50ºC temperature. The testing was done according to LVS EN 12390-3:2009 "Testing hardened concrete – Part 3: Compressive strength of test specimens" (see Figure 3).

Fig. 1. Specimens with coal ash and wood ash substitution in curing chamber.

Fig. 2. Slump test for mix with coal ash substitution

Compression testing machine with the accuracy of ±1% was used; the rate of loading was 0,7 MPa/s. Compressive strength was measured at 7, 28, 56, 84 and 112 days. Three specimens per mix for each age were prepared and the mean compressive strength value was calculated.

RESULTS

A. Fresh concrete properties

The results for fresh concrete properties – slump test – are summarised in Table 2.

It is evident from the slump test data that wood ash contributed to workability of concrete more than coal ash did, as the slump of wood ash was generally 1,5-2 times greater than the slump of coal ash. This could be explained by the differences in coal ash and wood ash particle size and shape, chemical composition.

The data show that with increasing ash content, the slump decreased for both ash types, and for both non-ground and additionally ground ash. This was especially obvious for wood ash with additional grinding. With increasing ash content the workability of mixes decreased, despite the fact that the water-to-cement ratio remained the same for all mixes, which could indicate that both ash types possess some water absorption qualities that are dependent on particle fineness.

Fig. 3. Testing cube after compressive strength test has been carried out.

TABLE 2

Slump test results for each mix

Mix type	Slump, mm	Slump class
CTRL	135	S3
CA20	105	S3
CA30	65	S3
CA40	70	S2
WA20	160	S4
WA30	140	S3
WA40	145	S3
grCA20	110	S3
grCA30	70	S2
grCA40	80	S2
grWA20	160	S4
grWA30	125	S3
grWA40	115	S3

The test also reveals that there was no significant difference observed in terms of workability between coal ash with no additional grinding and additionally ground coal ash, as the slump results were roughly the same for all coal ash content levels. However, for additionally ground wood ash the workability was generally lower than that of non-ground wood ash. The difference increased with increasing ash content. This could mean that the water absorption qualities of wood ash are influenced more by the fineness of the particles in comparison with coal ash.

B. Hardened concrete properties

As evident from Figure 4, concrete with 20% ash substitution showed slightly worse overall results in comparison with 30% ash substitution. Similarly, 40% ash mix fared worse than 30% ash mix at all ages, and only at 112 days it was better than 20% ash substitution. This indicates that the optimal cement substitution level could be around 30%.

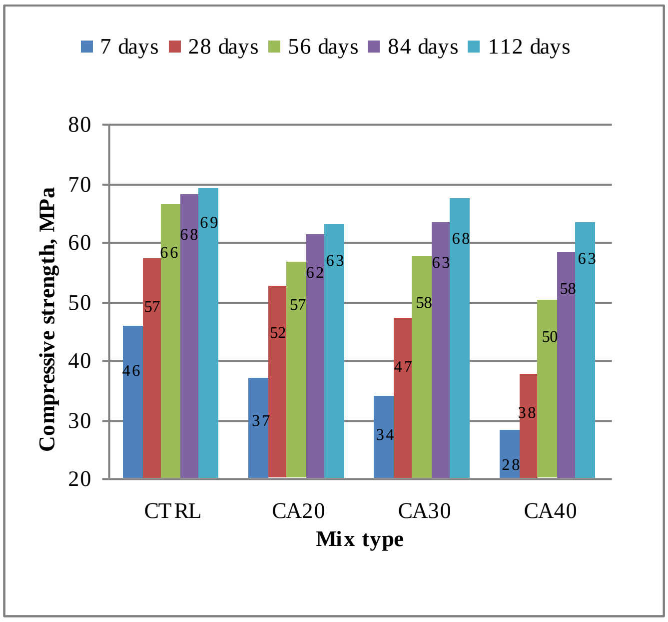

Fig. 4. Influence of coal ash content and curing time on the concrete compressive strength.

Investigations show that early strength levels are considerably lower in comparison with control concrete, but this is expected, as the strength improvements from pozzolanic reactions are mostly seen at later ages, in this case – at 84 days and especially at 112 days, when the differences are much smaller than at the early stages.

In case of wood ash content level (Figure 5), there was a small difference between ash proportions at later age, but significant difference at early age.

This could mean that perhaps pozzolanic activity in wood ash is more limited to a certain extent than it is in coal ash. That would also mean that higher wood ash content is preferable, if early strength is not an important factor.

However, the results were not as good as with coal ash since wood ash particles are larger, with the best strength level for wood ash being with 30% ash substitution which achieved 62 MPa. 40% ash content also was very close to this result with 61 MPa at 112 days and similar results for other ages. This indicates that there is a possibility to explore even higher ash substitution levels to find the optimal ash content, where strength loss would be at acceptable levels.

Figure 6 suggests that the best results overall were obtained with additionally ground coal ash at 20% substitution. This mix surpassed the control concrete strength levels at ages 56, 84 and 112 days (68; 72 and 73 MPa). This clearly indicates that the pozzolanic activity contributes to the strength of concrete at later stages.

With ground ash, it can be observed that higher ash content generally results in a lower strength levels, especially for 40% ash. It could be explained by the fact that the particles of additionally ground coal ash are finer, so they encase the cement particles more compactly, therefore making it harder for water to reach the cement to ensure successful hydration process.

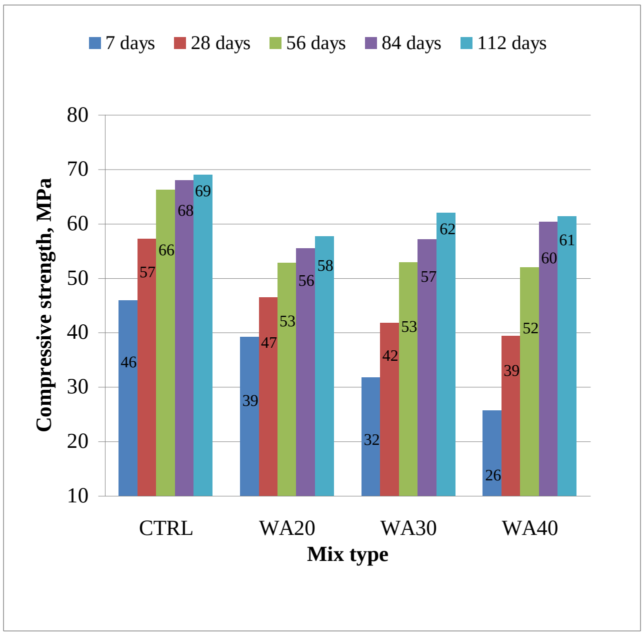

Fig. 5. Influence of wood ash content and curing time on the concrete compressive strength.

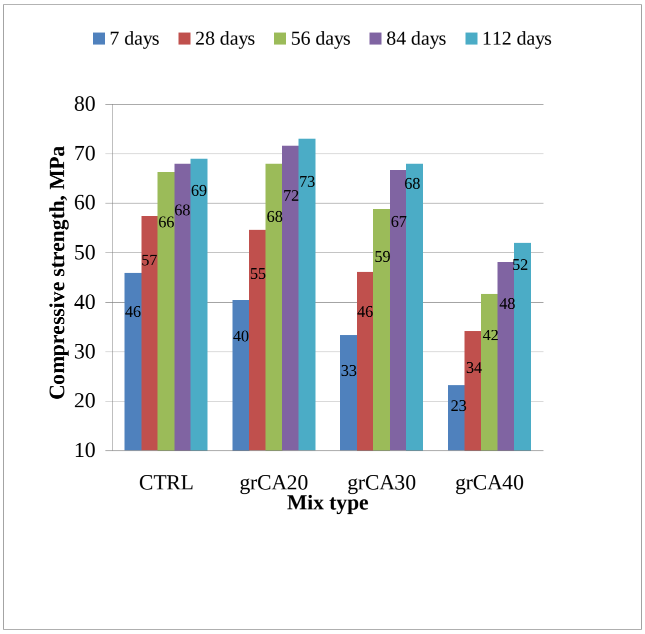

Fig. 6. Influence of additionally ground coal ash content and curing time on the concrete compressive strength.

When comparing the results for coal ash with no additional grinding against the results for additionally ground coal ash, it can be seen that additionally ground coal ash was considerably better at 20% substitution, almost the same at 30% substitution, but considerably worse at 40% substitution.

Therefore it can be concluded that the optimal additionally ground coal ash content is 20%.

Additionally ground wood ash also showed interesting results, as seen in Figure 7. The best strength was achieved at 30% ash content, with compressive strength at 67 MPa being really close to that of control concrete (69 MPa). Unfortunately, there are no results for 20% ash substitution beyond 56 days, so a conclusive claim about the optimal additionally ground wood ash cannot be made. However, it is evident that in this case that concrete with 40% ash fared worse at all ages in comparison with 30% ash content.

Additionally ground wood ash substitution at 30% proved to be slightly better than wood ash with no additional grinding substitution at 30%, with 67 MPa against 62 MPa (at 112 days). In case of ash substitution levels at 20% and 40% the opposite was true – the ash with no grinding showed a little bit higher strength levels, although not conclusively. Thus it can be said that the optimal additionally ground wood ash content might be around 30%. In spite of the obtained tendencies of strength development, the differences between strength results are low (within 3 - 10%).

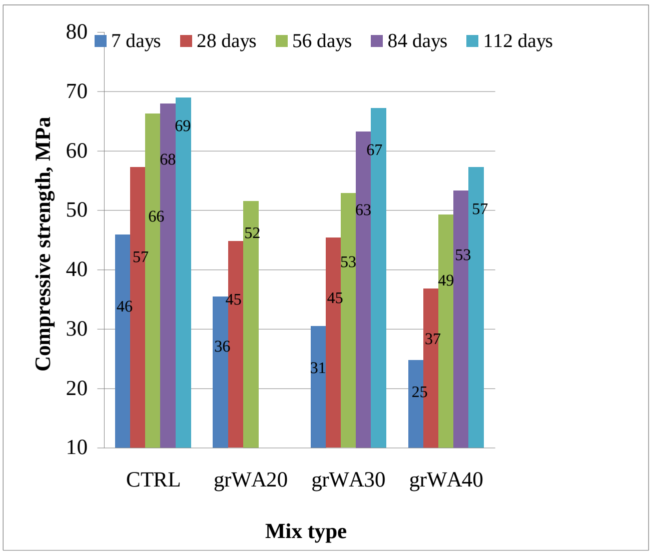

Fig. 7. Influence of additionally ground wood ash content and curing time on the concrete compressive strength.

C. *Ecological and economical characteristics*

To achieve a thorough understanding of the environmental impact of blended cement it is necessary to calculate ecological and economical characteristics of the materials. [13] One of the most important characteristics of modern building material is energy consumption per unit of material. Cement and fine grounded materials are the most energy demanding components in concrete mix, while fine and coarse have negligible impact comparing to cement. Energy consumption for cement production varies depending on the technology and fuel type; based on different literature sources an average range of 3 – 5 MJ/kg is estimated. [14] However, for the present study the value of 3,9 GJ/t (3,9 MJ/kg) was assumed.[15]

A more difficult task is to estimate grinding energy for micro filler components. Energy necessary for grinding largely depends on the fineness of ground material. Additional increase in specific surface requires more energy for the grinding process. According to research [16], grinding energy of cement clinker is close to 0,14 MJ/kg. The average size of cement particles is 10 μm, for coal ash (CA) the particle size is generally similar (1–150 μm), whereas for wood ash (WA) the average particle size is 230 μm. The grinding energy of traditional micro fillers (dolomite, limestone) also may be assumed as 0,14 MJ/kg. An approximate value of 0,2 MJ/kg was chosen for both ash types for this study.

Additional grinding of coal and wood ash increased energy consumption considerably. For example, preparing the samples of 1 kg of coal powder was ground during 30 minutes in the laboratory planetary ball mill machine having electrical power of 0,75 kW, thereby actual energy consumption was 0,75 kWh/kg or 2,7 MJ/kg. This value is 1,4 times more than thermal energy consumption for 1 kg of cement clinker. It may be assumed that efficiency factor of large industrial mill should be higher due to smaller relative loss of energy, therefore a value of 2,0 was assumed for the calculations. The information on energy consumption for rock material grinding is not sufficient. One of the articles [17] presents the following data about grinding energy depending on final fineness of material: 100 μm requires 0,01 MJ/kg, 10 μm – 0,3 MJ/kg, but 1 μm requires 10 MJ/kg.

This data corresponds to real laboratory values. It must be emphasized that finer grinding (< 100 nm) requires more energy (up to 100 MJ/kg). This fact must be taken into account when selecting technology of utilisation of industrial waste.

Table 3 presents values of energy consumption E (GJ) per 1m^3 of concrete. The following formula was used for calculation [18]:

$$E = C \cdot 3{,}9 + CA(WA) \cdot 0{,}2 \qquad (1)$$

where
C – Portland cement amount, kg/m^3;
3.9 – thermal energy consumption per 1 kg of cement;
CA (WA) – coal ash (or wood ash) content in 1 m^3;
0.2 – grinding energy for coal ash (wood ash).

The mix containing additionally ground ash was calculated using this formula [18]:

$$E = C \cdot 3{,}9 + grCA(grWA) \cdot 2{,}0 \qquad (2)$$

where
grCA(grWA) – additionally (30 min) ground coal ash (or wood ash) content in 1m^3;
2.0 – grinding energy for additionally ground coal ash (wood ash) for 30 minutes.

When part of cement is replaced, energy consumption is considerably reduced in the case of coal ash and wood ash with no additional grinding. Energy consumption for both ash types with additional grinding in most cases is slightly lower or at the same levels. Carbon dioxide emissions are decreasing directly proportionally to amount of replaced cement.

CONCLUSIONS

The main aim of this research was to evaluate the potential improvements in concrete and its properties by partly substituting cement with industrial by-products and waste materials – coal ash and wood ash.

It is evident that the properties of the fresh concrete mix and the properties of the hardened concrete are considerably dependant on ash type, ash substitution level and activation by additionally grinding them.

Generally it is clear that partly substituting cement with coal ash or wood ash reduces compressive strength at early ages, but gains higher values at later ages. The improvement over concrete with no ash substitution can sometimes be seen as early as at 56 days, but most likely the contribution to concrete strength from pozzolanic reactions will be observed later – at 84 and 112 days.

The best achieved compressive strength result of 73 MPa is for 20% cement replacement with additionally ground coal ash which showed an improvement over control concrete with no ash at age 56 days and beyond.

TABLE 3

Cement replacement by coal ash and wood ash: mix composition and environmental impact

	Cement (%) replaced by ash				
	Price, EUR/t	**0**	**20**	**30**	**40**
Portland cement CEM I 42.5 N	78	410	330	290	250
Gravel 2/12 mm	15	1000	1000	1000	1000
Natural sand 0,3/2,5 mm	9	650	650	650	650
Quartz sand 0/1 mm	9	120	120	120	120
CO_2, kg/m^3		350	281	247	213
Coal ash (CA)	0	**0**	**80**	**120**	**160**
Water		200	200	200	200
Water-Cement ratio		0,49	0,49	0,49	0,49
Concrete components price, EUR/m^3		58	52	48	45
Energy consumption, GJ/m^3		**1,6**	**1,3**	**1,16**	**1,01**
Energy consumption, MJ/MPa m^3		**23,53**	**21,04**	**17,19**	**15,96**
Additionally ground coal ash (grCA)	0	**0**	**80**	**120**	**160**
Water		200	200	200	200
Water-Cement ratio		0,49	0,49	0,49	0,49
Concrete components price, EUR/m^3		58	52	48	45
Energy consumption, GJ/m^3		**1,6**	**1,45**	**1,37**	**1,3**
Energy consumption, MJ/MPa m^3		**23,53**	**20,11**	**20,42**	**25**
Wood ash (WA)	0	**0**	**80**	**120**	**160**
Water		200	200	200	200
Water-Cement ratio		0,49	0,49	0,49	0,49
Concrete components price, EUR/m^3		58	52	48	45
Energy consumption, GJ/m^3		**1,6**	**1,3**	**1,16**	**1,01**
Energy consumption, MJ/MPa m^3		**23,53**	**22,53**	**18,71**	**16,45**
Additionally ground wood ash (grWA)	0	**0**	**80**	**120**	**160**
Water		200	200	200	200
Water-Cement ratio		0,49	0,49	0,49	0,49
Concrete components price, EUR/m^3		58	52	48	45
Energy consumption, GJ/m^3		**1,6**	**1,45**	**1,37**	**1,3**
Energy consumption, MJ/MPa m^3		**23,53**	**-**	**20,39**	**22,69**

Other notable results include concrete with 20–30% coal ash with no additional grinding (68 MPa) and concrete with 30% additionally ground wood ash (67 MPa). As the compressive strength of concrete with no cement replacement was 69 MPa, it is obvious that all these results are of significance.

The test results show that coal ash itself has pozzolanic characteristics, while wood ash results show that it has

properties that contribute to pozzolanic reactions, and therefore they both can be used as successful partial replacement for cement. By using coal ash and wood ash as mineral micro filler in concrete, an improved effect on workability was observed, but with higher ash content the workability improvements were much less notable.

However, perhaps the most important observation is the evident improvement of mechanical properties of concrete at later ages. This means that it is possible to achieve usable concrete with less cement, but utilising materials which would otherwise be landfilled. The economic and environmental benefits of this are valid even when the compressive strength test results for cement replacement with ash are close to the results for concrete with no ash in it.

The usage of ash as a construction material is a good way to help the environment – landfilling and CO_2 emissions reduction:

1) landfilling is becoming very restrictive due to shrinking landfill space and strict environmental regulations;
2) World Wildlife Fund's experts estimated that to prevent the continuation of global warming, CO_2 emissions into the atmosphere must be reduced by 80% and other greenhouse gas emissions – by 50% in developed countries by 2050;
3) The European Commission published a Decision of 27 April 2011, a document that implements an EU wide clinker benchmark of 766 kg CO_2 per tonne of clinker for grey cement; compared to the actual average emissions of the European cement industry that means that an approximate 10% reduction will be required from 2013 on.

Experimental results indicate that it is possible to achieve environmentally friendly concrete compositions with low cement content utilising coal ash and wood ash. However, the positive impact on environment is only in terms of reduced CO_2 emissions, increased waste product utilisation and reduced energy use.

Acknowledgement

Financial support of the ERAF project Nr. 2010/0286/2DP/ 2.1.1.1.0/10/APIA/VIAA/033 „High efficiency nanoconcretes" is acknowledged.

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Patricija Kara, Aleksandrs Korjakins, Valdemārs Stokmanis-Blaus. Betona mehānisko īpašību novērtējums, izmantojot pelnus kā minerālpiedevas
Cementa ražošanas nozarei ir būtiska ietekme uz vidi, jo tā ir atbildīga par ievērojamu daļu cilvēces radītā oglekļa dioksīda. Pašlaik viens no perspektīvākajiem šīs problēmas risinājumiem varētu būt daļēja cementa klinkera aizstāšana ar rūpnieciskajiem blakusproduktiem un atkritumiem, tādējādi iegūstot jaukto cementu. Akmeņogļu pelni ir rūpniecisks blakusprodukts, kas rodas ogļu kurināmās elektrostacijās un koģenerācijas stacijās. Akmeņogļu pelni kā materiāls mēdz būt ar dažādām īpašībām, jo to daļiņu forma, izmērs un sastāvs var krasi atšķirties. Atšķirības akmeņogļu pelnos veidojas šādu faktoru ietekmē: ogļu tips un mineraloģiskais sastāvs, akmeņogļu pulverizācijas pakāpe, krāsns efektivitāte un oksidācijas pakāpe, kā arī akmeņogļu pelnu savākšanas un uzglabāšanas nosacījumi.

Koka pelni veidojas koksnes un koksnes atkritumu dedzināšanas procesā. Koka pelnu īpašības ievērojami maina daudzi faktori – fizikālās un ķīmiskās īpašības, kas nosaka pelnu pielietojamību, koksnes sugas, augšanas apstākļiem un dedzināšanas metodes, tai skaitā degšanas temperatūras, krāsns efektivitātes un papildus izmantotā kurināmā.

Šajā pētījumā akmeņogļu un koka pelni tika izmantoti, betona maisījumos cementu daļēji aizstājot ar pelniem dažādā apjomā (20%; 30% un 40% apmērā). Pelni tika izmantoti divējādi – bez papildus apstrādes un ar papildus malšanu 30 minūšu garumā. Betona paraugu spiedes stiprība tika noteikta 7, 28, 56, 84 un 112 dienu vecumā. Pārbaudei tika izmantota spiedes stiprības pārbaudes iekārta ar precizitāti ±1% no nosakāmā spēka un slogošanas ātrumu 0,7 MPa/s.

Kontrolmaisījums ar cementa saturu 410 kg/m^3 sasniedza spiedes stiprību 46, 57, 66, 68, 69 MPa attiecīgi 7, 28, 56, 84, 112 dienu vecumā. Vislabākos rezultātus uzrādīja betona maisījums ar 20% papildus maltiem akmeņogļu pelniem (40, 55, 68, 72, 73 MPa attiecīgi 7, 28, 56, 84, 112 dienu vecumā), kas uzrādīja labākus stiprības rādītājus par kontrolmaisījuma betona paraugiem 56 dienu vecumā un pēc ilgāka izturēšanas laika. Tāpat atzīstami labus rezultātus uzrādīja maisījums, kur cements 30% apmērā tika aizstāts ar akmeņogļu pelniem bez papildus apstrādes, kā arī maisījums, kur cements 30% apmērā tika aizstāts ar papildus maltiem koka pelniem. Lai noteiktu jauktā cementa ietekmi uz vidi, tika aprēķināti maisījumu ekoloģiskie un ekonomiskie rādītāji. Aizstājot cementu ar pelniem bez papildus apstrādes, enerģijas patēriņš ir ievērojami mazāks. Izmantojot papildus maltus pelnus, lielākajā daļā gadījumu enerģijas patēriņš ir nedaudz mazāks vai vismaz tādā pašā līmenī kā betonam bez pelniem. Savukārt oglekļa dioksīda izmešu daudzums samazinās proporcionāli samazinātajam cementa daudzumam.

Патриция Кара, Александр Корякин, Валдемарс Стокманис-Блаус. Оценка механических свойств бетона с золой в качестве минеральной добавки

Цементная промышленность имеет огромное влияние на окружающую среду, так как ответственна за значительную часть выбросов CO_2 в атмосферу. В настоящее время наиболее перспективным решением этой проблемы является частичная замена цементного клинкера с помощью промышленных побочных продуктов или отходов, производя таким образом смешанный цемент.

Угольная зола – это промышленный побочный продукт сжигания угля на электростанциях и ТЭЦ. Угольная зола в качестве материала, как правило, отличается свойствами, потому что форма частиц, размер и состав может значительно варьироваться. Различия угольной золы образуются из-за следующих факторов: тип угля и минералогический состав, степень измельчения угля, эффективность печи и степень окисления, а также сбор золы и ее хранение.

Древесная зола образуется в процессе сжигания дров и изделий из древесных отходов и состоит из неорганических и органических остатков. Свойства древесной золы значительно различаются в зависимости от многих факторов. Физические и химические свойства древесной золы, которые определяют ее пригодность к использованию, зависят от породы дерева, условий выращивания и методов сжигания, в том числе температуры горения, эффективности печи и дополнительно использованного топлива.

Зола-унос и древесная зола были использованы в бетонных смесях при частичном замещении цемента, в различных количествах (20%, 30% и 40%). Золы были использованы в двух направлениях – без дополнительного и с дополнительны помолом в течение 30 минут. Прочность образцов бетона на сжатие была определена в возрасте 7, 28, 56, 84 и 112 дней. Тестирование проводилось с помощью оборудования с точностью ±1% от определяемой силы и скорости нагружения 0,7 МПа/сек.

Образцы контрольной смеси бетона с содержанием цемента в 410 кг/м^3 достигли прочности на сжатие 46, 57, 66, 68, 69 МПа в возрасте 7, 28, 56, 84, 112 дней соответственно. Наилучшие результаты показали образцы бетона с 20% дополнительно молотой золы-уноса (40, 55, 68, 72, 73 МПа в возрасте 7, 28, 56, 84, 112 дней соответственно),что превосходит прочность контрольный смеси в возрасте 56 дней и более. Другие особенно хорошие результаты дали образцы бетона с 30% золы-уноса без дополнительного помола и с 30% дополнительным помолом древесной золы.

Для определения воздействия смешанного цемента на окружающую среду были рассчитаны экологические и экономические показатели. Замена цемента угольной золой без дополнительной обработки понижает энергопотребление. Использование дополнительно молотой золы в смесях, в большинстве случаев, составляет практически то же самое потребление энергии, как бетон без золы. В то же время выбросы двуокиси углерода уменьшаются пропорционально снижению количества цемента.