The use of shale ash in dry mix construction materials

L Gulbe¹, J Setina² and I Juhnevica³

¹ SIA Sakret, “Ritvari”, Rumbula, Stopinu novads, LV – 2121, Latvia
², ³ Institute of Silicate Materials, Riga Technical University, 3/7 Paula Valdena Str.,
Riga, LV-1048, Latvia

E-mail: liene.gulbe89@inbox.lv

Abstract. The research was made to determine the use of shale ash usage in dry mix construction materials by replacing part of cement amount. Cement mortar ZM produced by SIA Sakret and two types of shale ashes from Narva Power plant (cyclone ash and electrostatic precipitator ash) were used. Fresh mortar properties, hardened mortar bulk density, thermal conductivity (λ₁₀, dry) (table value) were tested in mortar ZM samples and mortar samples in which 20% of the amount of cement was replaced by ash. Compressive strenght, frost resistance and resistance to sulphate salt solutions were checked. It was stated that the use of electrostatic precipitator ash had a little change of the material properties, but the cyclone ash significantly reduced the mechanical strength of the material.

1. Introduction

Nowadays the most widely used building materials in the world are cement mortar and concrete [1]. Only concrete consumption alone is approximately 10 billion tonnes per year [2]. Despite the fact that basic principles of technologies remains the same, it is apparent significant concrete and mortar technology development that makes it possible to obtain materials with better physical and mechanical properties and durability [3]. These products are made of binders (cement, lime hydrate), several types of aggregates (sand, crushed granite, crushed dolomite, dolomite sand, limestone, etc.) and various chemical additives used to improve material physical and chemical properties (plasticizers, superplasticizers, antifreeze additives, air participatory additives, etc.) [1]. Often, in order to improve physical, mechanical and process binding properties of material, silica dust (micro silica) or fly ash are added to cement [3].

Cement is one of the main raw material in the production of dry building materials. With the development of the construction industry, building materials has been evolved too, including cement. In recent years, more and more are being sought various additives for cement, which could improve the properties of it. Taking into account today’s issues at stake, the potential for reducing CO₂ emissions are sought materials that could partially replace cement, because cement production gives approximately 5% of total global CO₂ emissions. Such materials could be such as pozzolans, ash, etc. Number of preconditions are for ash use. First, the ash is by-product and using or disposing this waste in some kind of industry, it is possible to reduce the amount of ash - to protect the environment. In 2008, Kingston (USA) the ash discharge happened, resulting 4.2 million tons of ash got into the river and nearest neighbourhoods. The water of river was polluted, but the factory adjoining areas were coated with a 1.8 m thick layer of ash. In order to avoid such disasters, ashes should be disposed of or processed [4]. Second, the use of ash in the cement industry allows to reduce the demand for portlandeceement, leading to reduction of CO₂ emissions into the air. According to American scientists, if all the ash that
is produced during the year would be used in the industry of cement, the CO₂ emissions would be reduced by 25% [5]. Third, the use of ash range is very wide:
  • cement industry,
  • brick industry,
  • ceramic industry,
  • road and dam construction,
  • dry mixtures,
  • a variety of floor coverings and so on. [6].

2. Materials and methods
The samples from SIA SAKRET supply of dry building mixtures were used in this analysis: cement mortar with industrial name ZM and two types of shale ash from Estonian Narva power plant - ash obtained using electrostatic precipitator (active surface area - 8.620e+00 m²/g), and ash, generated by using cyclone-type filters (active surface area - 2.469e+00 m²/g). Ashes by their chemical composition, are the same [7].

Experiments were carried out with three types of samples:
  • ZM (reference sample);
  • ZM-e (20% of the amount of cement replaced by the electrostatic precipitator ash);
  • ZM-c (20% of the amount of cement replaced by a cyclone ashes).

Table 1 shows dry mix composition (% by weight):

|                  | ZM     | ZM-e   | ZM-c   |
|------------------|--------|--------|--------|
| Cement           | 16     | 12.8   | 12.8   |
| Ashes            | 0      | 3.2    | 3.2    |
| Fillers (sand+limestone) | 83.71  | 83.71  | 83.71  |
| Chemical additives| 0.09   | 0.09   | 0.09   |

The following methodology was used in the study:
  • Flow ability according to LVS EN 1015-2:2002 [8];
  • Density of raw ash paste according to LVS EN 1015-6:2002 [9];
  • Porosity of ash paste according to LVS EN 1015-7:2002 [10];
  • Hardened mortar bulk density according to LVS EN 1015-10: 2007 [11];
  • Thermal conductivity (λ₁₀, dry) coefficient (table value) according to LVS EN 1745: 2007 [12];
  • Ash flexural and compressive strength according to LVS EN 1015-10:2001 [11];
  • Resistance to sulphate salt solutions according to LVS EN 12370:2001 [13];
  • Frost resistance according to LVS EN 12371:2001 [13].
3. Results and discussion

3.1. Fresh mortar properties
Discharge on Hagerman flow-table, density and porosity of fresh mortar samples were evaluated – Table 2.

| Test                                      | Sample  | ZM    | ZM-e   | ZM-c   |
|-------------------------------------------|---------|-------|--------|--------|
| 1. H₂O per 1 kg of dry mix                | ZM      | 140   | 136    | 134    |
| 2. Flowability, mm                        | ZM-e    | 161   | 162    | 162    |
| 3. Density, kg/m³                         | ZM-c    | 1883  | 1903   | 1856   |
| 4. Air content,%                          | ZM      | 17    | 16     | 19.5   |

The amount of water to reference sample was added by the manufacturer's recommendations, in experimental samples amount of water was adjusted to achieve equal flow ability for all samples. Less amount of water was necessary for the samples with the ashes in the composition in order to achieve the same flow ability.

There is coherence between fresh mortar density and pore size range. The samples with electrostatic precipitator ashes had the highest density (1903kg/m³) and they had the smallest amount of pores – 16% and according the sample with cyclone ashes had the lowest density (1856kg/m³) and the largest pore content - 19.5%.

Such results can be explained by the fact that the electrostatic precipitator ash is very fine and is able to fill the pores of the material so the mass formed was denser, but the cyclone ash is coarser - formed mass was more porous with a lower density.

3.2. Hardened mortar bulk density and thermal conductivity coefficient
Hardened mortar sample bulk density and thermal conductivity coefficient was determined using 5 samples of each mortar. Thermal conductivity coefficient values are the values taken from table of the standard - LVS EN 1745: 2003 " Masonry and masonry products - Methods for determining design thermal values " [11]. Average results are shown in Table 3:

| Sample | Size of prisms, mm | Bulk of prisms, m³ | Density kg/m³ | Thermal conductivity coefficient (λ₁₀,dry):   |
|--------|--------------------|--------------------|---------------|---------------------------------------------|
| ZM     | 160x40x40          | 0.000256           | 1814,58       | P=50% 0.83                                 |
|        |                    |                    |               |                                             |
|        |                    |                    |               | P=90% 0.93                                 |
| ZM-e   | 160x40x40          | 0.000256           | 1878,64       | P=50% 0.83                                 |
|        |                    |                    |               |                                             |
|        |                    |                    |               | P=90% 0.93                                 |
| ZM-c   | 160x40x40          | 0.000256           | 1778,91       | P=50% 0.67                                 |
|        |                    |                    |               |                                             |
|        |                    |                    |               | P=90% 0.76                                 |

*P – humidity.
The thermal conductivity coefficient depends on bulk density of the samples, the higher the density, the higher the coefficient of thermal conductivity and materials has lower heat insulation properties.

Electrostatic precipitator ash didn’t change the thermal conductivity of mortar. There was observed decrease in bulk density in samples with cyclone ashes and consequently these samples are better heat insulators.

3.3. Compressive strength

The results of mechanical strength of all three types of mortar samples are shown in Fig. 1, 2.

![Figure 1. Flexural strength.](image1)

Flexural strength of reference sample reaches 4.5 N/mm² compressive strength - 14 to 15 N/mm². Samples with electrostatic precipitator ash show very similar, if not slightly better mechanical properties results as reference samples, but samples with cyclone ash show 1 N/mm² worse flexural strength results and about 5 N/mm² decrease in compressive strenght. Such results can be explained by the variety of active surface area because of great dispersity of electrostatic precipitator ash formed it denser and therefore mechanically more durable mass.

3.4. Resistance to sulphate salt solutions

The results of the resistance to sulphate salt solutions of mortar samples are shown in Fig. 3. One cycle in saline solution lasts for 24 hours, samples are soaked in 14% Na₂SO₄ for 2 hours then dried at the temperature 103°C for 19 hours and chilled for 3 hours, at the end of each cycle samples are weighted.
The first 12 cycles all samples passed equally. After 12th cycle, the samples showed rapid weight loss. The highest weight loss occurred in samples with electrostatic precipitator ash, but the best resistance to sulphate salt solutions had the reference samples without any ash. It’s possible that ash chemical composition reduces material’s resistance to soluble sulphates.

### 3.5. Frost resistance

The results of frost resistance are shown in Fig. 3. Before being tested the samples were dried at the temperature 60°C for 24 hours until they gained constant weight then saturated with water for 48 hours. Each cycle of frost resistance lasted for 24 hours - 8 hours in a freezer at temperature – 15°C to -20°C and 16 hours of thawing in water at the room temperature (20 +/- 5°C).

All three types of samples passed more than 15 freeze cycles, in time of this experiment, none of the samples showed any signs of collapsing. Samples were weighted after each refrigeration cycle it was observed that the sample ZM-e and ZM-c weight fluctuates slightly, while the reference sample ZM weight remains constant.
4. Conclusions

1. The research was made to determine the use of shale ash usage in dry mix construction materials by replacing part of cement amount.
2. There is coherence between fresh mortar density and pore size range. The samples with electrostatic precipitator ashes had the highest density (1903kg/m$^3$), the smallest amount of pores – 16%, accordingly the sample with cyclone ashes had the lowest density (1856kg/m3) and the largest pore content - 19.5%.
3. Electrostatic precipitator ash didn’t change thermal conductivity of mortar. There was observed decrease in bulk density in the samples with cyclone ashes and consequently these samples were better heat insulators.
4. Cyclone ash reduced the mechanical properties of the material, but the electrostatic precipitator ash - did not affect (even slightly improved) material compressive and flexural strength, due to their high dispersity.
5. Shale ash reduced the material resistance to soluble sulphate salt solutions, but did not affect the material frost resistance.

Cement mortar is a structural building material, so the main criteria for mortar recipe development is acquiring a material with a certain mechanical strength. From the results obtained it can be seen that shale ash can be used to replace amount of cement in constructive building materials. The optimal results were obtained using dispersive electrostatic precipitator ash, but cyclone ash impairs mechanical properties which were studied in this research.

References

[1] M. C. Nataraja, T. S. Nagaraj, and S. B. Basavaraja, “Reproportioning of steel fibre reinforced concrete mixes and their impact resistance,” Cem. Concr. Res., vol. 35, no. 12, pp. 2350–2359, Dec. 2005.
[2] G. Šahmenko, P. Kara, U. Lencis, and A. Korjakins, “Betonmācības laboratorijas darbi,” Rīga: RTU, 2010, p. 43.
[3] T. Gonen and S. Yazicioglu, “The influence of mineral admixtures on the short and long-term performance of concrete,” Build. Environ., vol. 42, no. 8, pp. 3080–3085, Aug. 2007.
[4] Nasa Earth Observatoty. Natural Hazards. Coal Ash Spill, Tennessee. http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=36352 (lapa skatīta 09.01.17.).
[5] Historical Perspective of Coal Ash Marketing and Promotion in the USA. http://www.flyash.info/2005/11man.pdf (lapa skatīta 09.12.16.).
[6] J.G.Spieght. The Chemistry and Technology of coal. 3rd ed.; CRC Press Taylor & Francis Group, Ed.; New York, 2012, 37-58.
[7] L.Gulbe, J.Setina, I.Vitina “Fly ash chemical content impact on its mechanical and physical properties,” MSCA, Rīga: RTU, 2016, p. 69.
[8] LVS EN 1015-2:2007 “Methods of test for mortar for masonry - Part 2: Bulk sampling of mortars and preparation of test mortars”.
[9] LVS EN 1015-6:2007 “Methods of test for mortar for masonry - Part 6: Determination of bulk density of fresh mortar”.
[10] LVS EN 1015-7:2003 “Methods of test for mortar for masonry - Part 7: Determination of air content of fresh mortar”.
[11] LVS EN 1015-10:2007 “Methods of test for mortar for masonry - Part 10: Determination of dry bulk density of hardened mortar”.
[12] LVS EN 1745:2003 “Masonry and masonry products - Methods for determining design thermal values”.
[13] LVS EN 12370:2000 “Natural stone test methods - Determination of resistance to salt crystallisation”.
[14] LVS EN 12371:2010 “Natural stone test methods. Determination of frost resistance”.