MATTER: International Journal of Science and Technology
ISSN 2454-5880

Luga et al., 2017

Volume 3 Issue 3, pp. 125-141

Date of Publication: 24th November 2017

DOI-https://dx.doi.org/10.20319/mijst.2017.33.125141

This paper can be cited as: Luga, E., Paja, A., & Atis, C., D. (2017). An Investigation on the Partial Replacement of Portland cement with Kosovo Fly Ash in Cement Mortars. MATTER: International Journal of Science and Technology, 3(3), 125-141.

AN INVESTIGATION ON THE PARTIAL REPLACEMENT OF PORTLAND CEMENT WITH KOSOVO FLY ASH IN CEMENT MORTARS

Erion Luga
Department of Civil Engineering, EPOKA University, Tirana, Albania
eluga@epoka.edu.al

Alban Paja
Department of Civil Engineering, EPOKA University, Tirana, Albania
apaja11@epoka.edu.al

Cengiz Duran Atis
Department of Civil Engineering, ERCİYES University, Kayseri, Turkey
cdatis@erciyes.edu.tr

Abstract

The energy sector is one of the biggest polluters of environment in Kosovo. More than 40 million tons of ash and about 400 hectares of arable land are occupied from the landfill of Kosovo-A and Kosovo-B power plants. On the other hand, the use of fly ashes with proper characteristics, as pozzolanic material in concrete production is a well-known fact. In this context the effect of the partial replacement of Portland cement with Kosovo fly ash in cement pastes and mortars has been investigated. For that purpose, six different series of (0/100, 5/95,10/90,15/85.20/80 and 25/75) fly ash to cement ratios (FA/PC) have been studied. Normal consistency, initial and final setting time of the cement pastes, and water absorption, flexural strength, compressive *strength and shrinkage deformation of the mortar specimens were investigated. Test results show that Kosovo fly ash has good parameters that improve the compressive strength of cement mortars and concrete by replacing the Portland cement up to 10%. On the other hand, it increases slightly the water absorption capacity of the mortars. Nevertheless, it can be concluded that the use of Kosovo fly ash in concrete could be a good alternative to be used as a pozzolanic material. Future studies should be focused on the durability effect of Kosovo fly ash on concrete.*

Keywords

Kosovo, Fly Ash, Cement Mortar, Pozzolanic Material

1. Introduction

Estimated to exceed 10 billion tons per year, concrete is actually the most important material in the construction sector. The high demand for Portland cement concrete and the simplicity in its use has made Portland cement the most widely used commodity in the construction industry (Luga et al., 2017). In parallel with this, the cement production industry is responsible for more than 7% of CO_2 released in the atmosphere, for the consumption of about 3% of global primary energy and for the use of large amounts of natural resources (Luga & Atis, 2016). Therefore, the use of by-products mineral admixtures such as fly ash as cement replacement in Portland cement concrete is a widespread practice (Atis et al., 2015).

Fly Ash is a solid material, one of the residues generated in the combustion of pulverized coal in electric power generating plants (Neville, 2003). It can react with $Ca(OH)_2$ at room temperature and can act as a pozzolanic material, due to the presence of SiO_2 and Al_2O_3 in amorphous form, so when mixed with Portland cement and water, it reacts with the calcium hydroxide released by the hydration of Portland cement to produce various calcium-silicate hydrates (C-S-H) and calcium-aluminate hydrates (Wesche, 2004).

The two processes most widely used in coal fired power plants are the pulverized coal combustion (PCC) and the fluidized bed combustion (FBC). Most of the fly ash from PCC power plants can be recycled and the products can be used in the cement industry, in road construction and in other places (Thomas, 2007).

According to their origin, Fly Ashes may be divided in two categories: Class C usually derives from coal that produces an ash with higher lime content, usually 15% or to 30%. The upraised CaO might give unique self-hardening features to Class C fly ash. Besides showing pozzolanic characteristics it shows also some cementitious properties. The second one is Class F fly ash, which is produced from the burning of anthracite or bituminous coal. It has a low lime content, usually fewer than 15% and contains a combination of alumina iron and silica. This class of ash is very pozzolanic, which makes it react with extra lime produced in the hydration of Portland cement (ASTM.C618-94a, 1998)

Researchers report that, replacing Portland cement with Class C fly ash up to a controlled percentage can improve or at least can obtain similar compressive strength to that of Portland cement concretes (Yuan & Cook, 1983; Gebler & Klieger, 1986; Naganathan & Linda, 2013; Islam & Islam, 2010).

On the other hand, the utilization of fly ash as a mineral admixture can restrict the chloride dispersion in concrete (Short & Page, 1982; Bijen, 1996).

Furthermore, the use of fly ash improves the workability of concrete, decreases shrinkage, reduces bleeding, heat of hydration, permeability and porosity, increases abrasion resistance, reduces alkali aggregate reaction, decreases the cost and solves the storage problem (Atis, 2004).

The properties of fly ash have been known for some decades, but its use became more widespread after large amounts of the material had become available. This happened after the clean air regulations, forced power plants to install scrubbers and electrostatic precipitators to trap the fine particles, which were previously released into the environment. At the moment the utilization rates of fly ash vary greatly from country to country, from as low as 3.5% for India to as high as 93.7% for Hong Kong (Meyer, 2009).

In many countries the disposal of fly ash has become a serious environmental and economic problem (Al-Zboona et al., 2011). For example; in Kosovo the energy sector is one of the biggest environment polluters. About 97 % of the electric power demand is generated by Kosova A and B power plants, placed in the municipality of Obiliq near the Capital, Pristine (Morina et al., 2012). Additional problems are dumped from the storage of more than 6 million tons of ash per year, occupying about 400 hectares of arable land (Krasniqi & Latifi, 1996).

In order to suggest a sustainable solution, the present experimental work investigates the effect of the partial replacement of Portland cement with Kosovo Fly ash in the properties of cement pastes and cement mortars.

2. Materials and Methods

2.1 Properties of the Materials Used

In this part the properties of the materials such as: sand, water, Portland cement and fly ash used for the production of the mortars have been presented.

2.1.1 Sand

The crushed limestone sand used in this experimental work was taken from Fushe-Kruja, Albania. It has a specific gravity of 2.56 and a maximum aggregate size of 4mm. The *(Table 1)* shows the grading of sand used in the experiment.

Table 1: *The grading of sand used in the experiment*

Sieve size	4	2	1	0.5	0.25	0.125	0.063	pan
Cumulative % retained	0	16.5	53.8	71.4	83.9	92.6	98.8	100

2.1.2 Water

Based on standard (TS-EN 1008, 2003) there are defined some rules concerning suitable water for concrete mixture and also determining if the water is potable and if so, how suitable can it be in production of concrete mortars. All urban waters cannot be similar with each other in quality. Foreign contents that are found in water are not in that large amount so that the concrete could be damaged. In this study tap water of Epoka University Campus is used for the production of the mortar mixtures.

2.1.3 Cement CEM 1 52.5 R

The cement used in this experimental work is CEM I 52.5 R produced by Heracles ™ Company in Greece. It complies with the requirements of (EN 197-1, 2000) and it is cement certified by an independent body and carries a CE Mark Heracles ™. The **c**ement used in this work is white cement 52.5 R which can be used for plaster as well as for concrete applications. This cement was brought from Greece purposely for this study, because in the Albanian construction market there is no Ordinary Portland Cement.

Table 2: *The chemical characteristics of CEM I 52.5*

Oxide	As Cement Declaration %	EN 197-1 Standard
SiO_2	20,09	
Fe_2O_3	3,87	
Al_2O_3	4,84	
CaO	64,02	
MgO	1,15	Max 5,0
SO_3	2,83	Max 4,0
Loss On Ignition	2,36	Max 5,0
Insoluble Residue	0,34	Max 5,0
Free Lime	0,80	
Alkali Equivalent (Na_2O)	0,65	
Total Additive	3,85	

Table 3: *The Physical characteristics of CEM I 52,5 R*

Physical Properties	As Cement Declaration	EN 197-1 Standard
Initial Setting Time (min)	165	Min 45
Final Setting Time (min)	275	-
Specific Gravity (g/cm^3)	3,156	-
Expansion	1,00	Max 10
Strength for 2 days (MPa)	31,10	Min 30
Strength for 28 days (MPa)	56,40	Min 52,5

2.1.4 Fly ash FA

The Fly ash used in this study was obtained from the thermal power plants placed in the municipality of Obiliq near the Capital city of Kosovo, Pristine. It is Class C fly ash with a specific gravity of 2400 kg/m^3, bulk density of 626.9 kg/m^3 and mass density of 941.5 kg/m^3

The Chemical analyzes of the fly ash shown in Table 4 were made by the Electro-Energy Corporate of Kosovo "KEK

Table 4: *Fly ash components analysis*

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
FA	27.13	8.46	6.92	33.56	3.15	11.28	0.56	1.22

2.2 Experimental Program

In this part the study the preparation of the samples for each test and the preparation of the respective samples has been explained. The partial replacement of Portland cement in cement pastes and mortars with Kosovo fly ash has been investigated. Six different series of 0/100, 5/95,10/90,15/85.20/80 and 25/75 fly ash to cement ratios (FA/PC) were used. Several physical, physic-chemical and mechanical properties of the pastes and mortars such as: normal consistency, initial and final setting time of the cement pastes, and water absorption, flexural strength, compressive strength and shrinkage deformation of the mortar specimens were investigated

2.2.1 Defining the normal consistency, initial and final setting time

The Normal consistency, initial and final setting time have been defined based on (EN 196-3, 1994) standard. According to this procedure 500g of (FA+PC) were placed in an enameled tray, after that about 25% water by weight of dry cement was added to get a cement paste. Then the vicat mold placed upon a glass plate, is filled with the cement paste and the surface of the paste was smoothed. After that the whole equipment (i.e. mould + cement paste + glass plate) is placed under the rod bearing plunger. The plunger is lowered gently so as to touch the surface of the test sample and quickly released allowing it to sink into the paste. Then the depth of penetration is measured and recorded. Trial pastes with varying percentages of water content are prepared following the steps described above, until the depth of penetration becomes 6±1mm from the bottom of the mold. Then the ratio of water to cement used for mix that reached the normal consistency is calculated. The test was repeated six times, once for each cement/fly ash ratio.

For the calculation of the initial setting time the test sample confined in the mold and resting on the non-porous plate is placed under the rod bearing the needle. The needle is lowered gently until it comes in contact with the surface of test block and quickly released, allowing it to penetrate into the test sample. In the beginning the needle completely pierces the sample. The procedure is repeated after every 2 minutes till the needle fails to pierce the sample for about 4±1mm measured from the bottom of the mold. The time passed from the preparation of the sample up to this moment is the initial setting time.

For the calculation of the final setting time the test sample confined in the mold and resting on the non-porous plate is placed under the rod bearing the needle with an annular attachment. The needle is lowered gently until it comes to the surface of the sample; the needle makes an impression thereon until the attachment fails to do so. The procedure is repeated after every 30 minutes. The time passed from the preparation of the sample up to this moment is the final setting time.

Table 5: *Portland cement and Fly ash amounts used for the preparation of the pastes*

Series	Fly ash (%)	Portland Cement (g)	Fly ash(g)
S1	0%	500	0
S2	5%	475	25
S3	10%	450	50
S4	15%	425	75
S5	20%	400	100
S6	25%	375	125

2.2.2 Preparation of the mortar mixtures

Six different series of 0.5 water to binder ratio and (0/100, 5/95,10/90,15/85.20/80 and 25/75) fly ash to cement ratios (FA/PC) were used. All the materials used for the preparation of the specimens were weighed separately according to their rates on a precision scale. The ingredients of the mortar mixtures are given in Table 6. For all the mixtures, the sand weight is given in dry condition.

Table 6: *Preparation of specimens*

Series	Fly ash percentage	sand (g)	CEM 1 52.5 R(g)	water (g)	(FA) fly ash(g)
S1	0%	1350	450	225	0
S2	5%	1350	427.5	225	22.5

S3	10%	1350	405	225	45
S4	15%	1350	382.5	225	67.5
S5	20%	1350	360	225	90
S6	25%	1350	337.5	225	112.5

2.2.3 Casting of the mortar specimens

The mixes were prepared according to the mix proportions given in *(Table 6)* and mixed in the Hobart mixer in a certain order in conformity to (TS EN 196-1, 2009). The specimens were casted into prismatic molds of 40 x 40x 160 mm and tested for 14 and 28 days flexural and compressive strength. The fresh mortars were put into the molds in two layers and impacted 60 times in one minute, then the mortars surface were finished. After 24 hours, the specimens were taken out of the molds and cured for 14 and 28 days in water at 21±1 ºC.

2.2.4 Determination of the water absorption of the mortar specimens

The water absorption was measured from 40x40x160 mm prismatic specimens immersed in water for 24 hours. After taking the specimens out of water, firstly each sample was weight in saturated surface dry conditions (SSD) after this process they were placed in the oven at 105°C for 24 hours. The samples were taken out of the oven and cooled up to room temperature, then weighed in dry condition. The water absorption was found as shown in the formula, where:

$$WA\ (\%) = [(SSD-CD)/\ (CD)] \times 100 \quad (1)$$

- WA: The water absorption (%)
- CD: The mass of the completely dried specimen (g)
- SSD: The mass of the saturated surface dry specimen (g)

2.2.5 Determination of the flexural strength

The flexural test of the specimens was performed according to (EN 1015-11, 1999) Standard. In order to determine the flexural strength of the mortars 40x40x160 mm specimens were used. The specimens were tested for 14 and 28 days strength under three-point loading and the span between the supports is 100 mm. The tensile strength was calculated as below:

$$\sigma = 3PL/2bd^2 \quad (2)$$

Where:

- σ: Flexural Strength (Newton/mm^2)
- B: Width of the Prisms Cross-Section (mm)
- D: Height of the Prisms Cross-Section (mm)
- P: Average load that causes the specimen failure (N),
- L: Distance between the Supports (mm).

2.2.6 Determination of the compressive strength

The compressive strength test was carried out in accordance with relevant specification (TS EN 196-1, 2009). The two broken parts of the 40 x 40 x 160 mm retained after the flexural strength test were used for compressive strength. The loading rate is 500 N/s. The loading area is 40 x 40 mm. The average of results obtained from six broken pieces was reported as compressive strength.

2.2.7 Determination of the shrinkage of mortars

This test checks the length change of mortar samples from their initial measurement in different time periods after removing them from the molds. The length change evaluation of mortar samples is performed based on (ASTM C157, 2008). According to this standard the test is done on prismatic samples of 25x25x285mm dimensions. There were prepared 2 samples from each mixture and the measure of contraction was taken as the average of both samples. After removing them from the molds, where the mortars are left for 24 hours, is taken the initial length of the mortars. After the first measurement the specimens are kept in room temperature conditions at 21±1 ºC and in an environment with 65% humidity. The samples have been monitored for 28 days after being removed from the molds.

3. Results and Discussion

3.1 Normal consistency, initial and final setting time test results

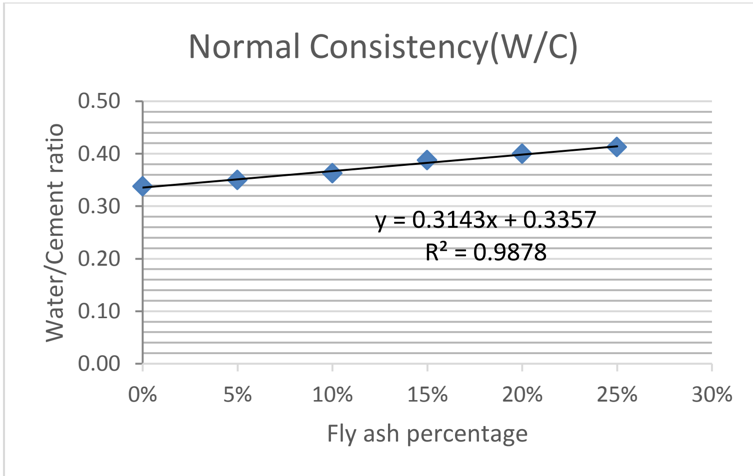

Figure 1: *Normal Consistency*

According to the test results of the measurement of normal consistency defined as water to binder ratio, as it can be seen in (Figure 1), the water demand to reach to normal consistency increases as the percentage of fly ash used in the mix increases. This can be explained also with the higher fineness of the fly ash used in the study related to that of the Portland cement. The water demand increases almost linearly.

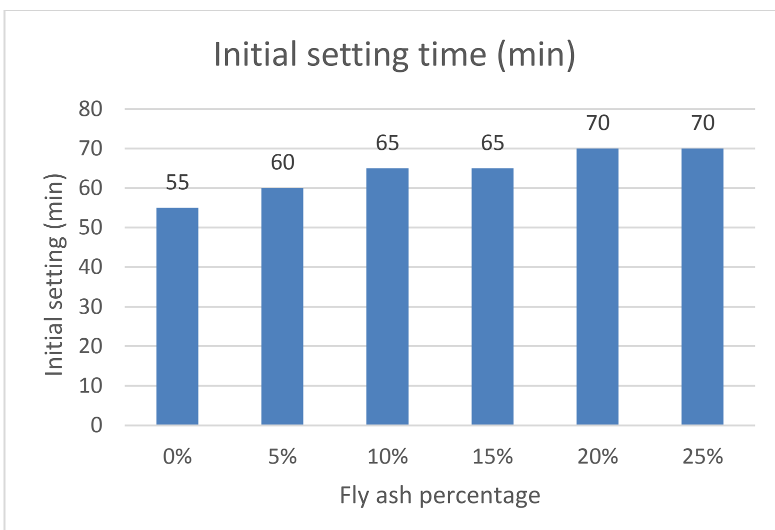

Figure 2: *Initial setting time*

According to the test results of the measurement of initial setting time defined as the time measured till the Vicat needle fails to pierce the block for about 4±1mm measured from the bottom of the mold., as it can be seen in (Figure 2) the initial setting time increases as the percentage of fly ash used in the mix increases. This can be explained with the pozzolanic activity of fly ash. It is well known that the pozzolanic reaction is slower than the hydration reaction of cement. In the study made Feng and Clark in their study achieved similar results (Feng and Clark, 2011).

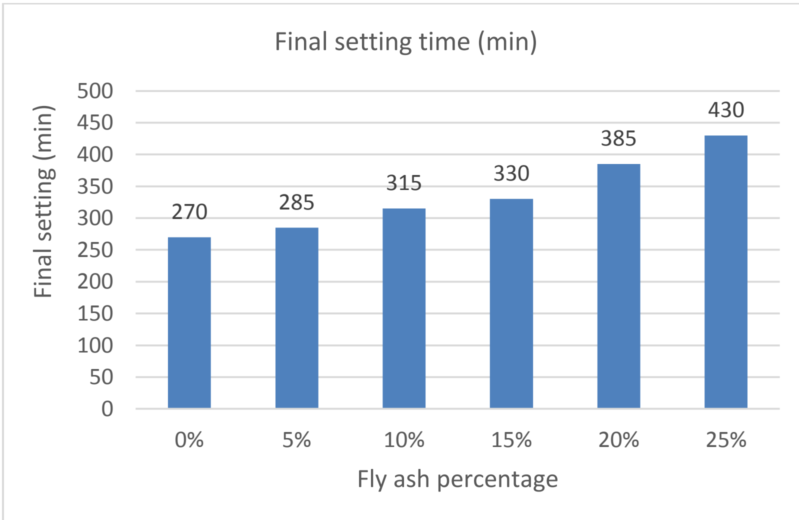

Figure 3: *Final setting time*

The test results of the final setting time show similar trend as the initial setting time results. The time of setting increases as the percentage of fly ash content increases. The same logical explanation can be followed also in this case.

3.2 Water Absorption results of the mortar samples

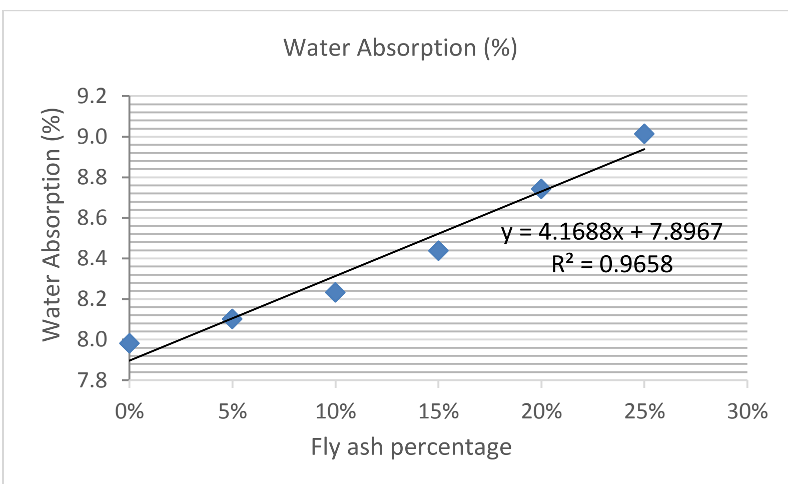

Figure 4: *Determination of the Water Absorption of mortar samples in percentage*

The values of the water absorption of the mortar samples show an increase in the water absorption capacity as the percentage of the Fly ash increases. The increase is linear, which shows that this value is directly proportional to the fly ash content. The lowest value is that of the control specimen prepared with 100% Portland cement which is equal to 8% whereas the highest one is that of the specimen prepared by replacing 25% of Portland cement with Fly ash equal to 9%. The change in absorption is only totally 1% or 0. 1-0.3% for every 5% of Portland cement replaced.

3.3 Flexural strength test results

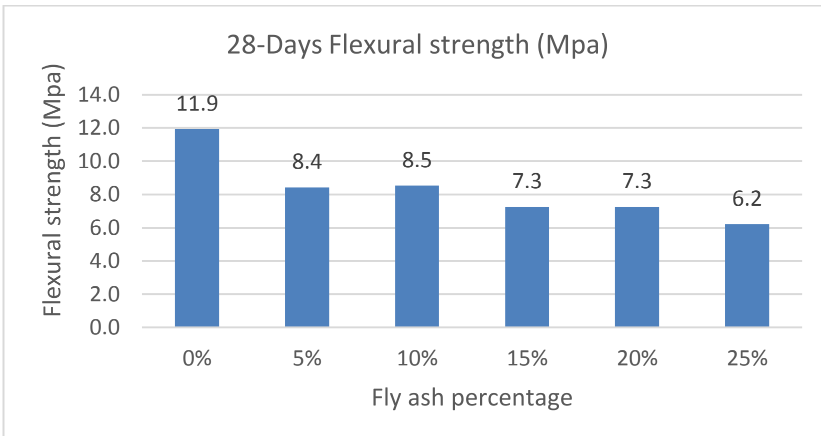

Figure 5: *The evaluation of 28-days flexural strength according to fly ash percentage*

The Flexural Strength of the mortar samples decreases as the percentage of the Fly ash increases. The highest value is that of the control specimen prepared with 100% Portland cement which is equal to 11.9 MPa whereas the lowest one is that of the specimen prepared by replacing 25% of Portland cement with Fly ash equal to 6.2 MPa.

3.4 Compressive strength test results

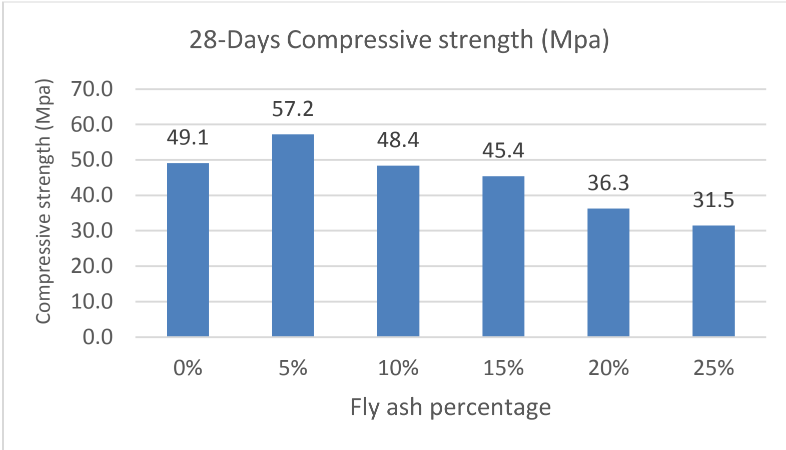

Figure 6: *The evaluation of 28-days compressive strength according to fly ash percentage*

The most important parameter of this study and also the most important one for the properties of cement mortars is for sure the compressive strength. In this test there were obtained very interesting results which strengthen the idea of the usability of Kosovo Fly ash in cement mortars or in concrete. As it can be distinguished from the graph the use of fly ash up to 5% increases the compressive strength more than 16%, whereas the use of fly ash up to 10% shows similar values to those of control specimens, it starts to decrease at 15% of fly ash but still with acceptable values less than 10% lower to those of control specimens. Higher fly ash content decreases considerably the compressive strength of the mortars. Other studies also have reached to similar results with the replacement of cement with fly ash from 10% to 15% (Christy and Tensing, 2010; Naganathan and Linda, 2013; Islam & Islam, 2010; Pitroda, 2012).

3.5 Determination of shrinkage

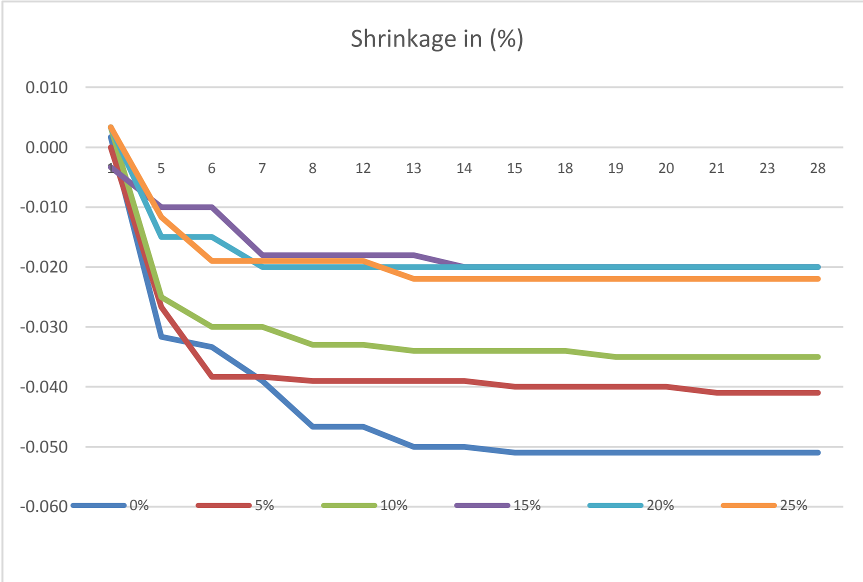

Figure 7: *The evaluation of shrinkage mortar samples*

According to the monitoring of the length change of the mortar samples for 28 days the values shown in the graph above were obtained. As it can be observed the trend of the shrinkage values of each mortar series up to 2 weeks the shrinkage is notable after that not distinguishable shrinkage is measured. This can be explained with the type of cement 52.2 R which has an earlier hydration reaction. The increase in fly ash content decreases the 28 days shrinkage which is one of the advantages of using fly ash in concrete.

4. Conclusion

In this experimental study the partial replacement of Portland cement with Kosovo fly ash has been investigated.

The test results show that the increase of fly ash percentage increases the water demand for normal consistency, delays the initial and final setting time of cement pastes, and increases slightly the water absorption capacity of the mortars.

The results also show that the increase of fly ash percentage of decrease gradually the flexural strength, but up to 10% it improves or at least does not decrease the compressive strength.

On the other hand, the replacement of Portland cement with Kosovo fly ash up to 25% decreases the shrinkage of the cement mortars.

These results show that Kosovo fly ash has good parameters which imply that the use of Kosovo fly ash in concrete could be a good alternative to be used as a pozzolanic material.

Future studies should be focused on the effect of Kosovo fly ash on the durability properties of concrete, and long term investigation should be conducted in order to come to a more specific conclusion regarding the proper use of Kosovo fly ash.

References

Al-Zboon, K., Al-Harahsheh, M. S., & Hani, F. B. (2011). Fly ash-based geopolymer for Pb removal from aqueous solution. Journal of hazardous materials, 188(1), 414-421. https://doi.org/10.1016/j.jhazmat.2011.01.133

ASTM C 618-94a, (1998). Standard Specification for Coal and Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete, Annual Book of ASTM Standards, V. 04.02, Concrete and Aggregates. American Society for Testing and Materials, Philadelphia.

ASTM C 157, (2008). Standard Test Method for Length Change of Hardened Hydraulic Cement Mortar and Concrete. Annual Book of ASTM Standards. American Society for Testing and Materials, Pennsylvania:

Atiş, C.D., Görür E.B., Karahan O., Bilim C., İlkentapar S., Luga E. (2015). Very high strength (120 MPa) class F fly ash geopolymer mortar activated at different NaOH amount, heat curing temperature and heat curing duration. Construction and Building Materials 96, 15 October 2015, Pages 673-678 https://doi.org/10.1016/j.conbuildmat.2015.08.089

Atiş, C. D., Sevim, U. K., Özcan, F., Bilim, C., Karahan, O., Tanrikulu, A. H., & Ekşi, A. (2004). Strength properties of roller compacted concrete containing a non-standard high calcium fly ash. Materials Letters, 58(9), 1446-1450. https://doi.org/10.1016/j.matlet.2003.10.007

Bijen, J. (1996). Benefits of slag and fly ash. Construction and building materials, 10(5), 309-314. https://doi.org/10.1016/0950-0618(95)00014-3

Christy, C. F., & Tensing, D. (2010). Effect of Class-F fly ash as partial replacement with cement and aggregate in mortar. Indian Journal of Engineering and Materials Sciences, 17, 140-144.

EN 1015-11, (1999). Methods of Test for Mortar for Masonry-Part 11: Determination of Flexural and Compressive Strength of Hardened Mortar, European Committee for Standardization, Brussels, Belgium.

EN 196-3, (1994). Methods of Testing Cement—Determination of Setting Time and Soundness, European Committee for Standardization, Brussels, Belgium.

EN 197-1. (2000). Cement: composition, specifications and conformity criteria. Part 1: Common Cements, European Committee for Standardization, Brussels, Belgium.

Feng, X., & Clark, B. (2011, May). Evaluation of the physical and chemical properties of fly ash products for use in Portland cement concrete. In 2011 World of Coal Ash Conference, Denver, CO, USA.

Gebler, S., & Klieger, P. (1986). Effect of fly ash on physical properties of concrete. In V. M. Malhotra (Ed.), Proceedings of the 2nd International Conference on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete. 2. Farmington Hills: American Concrete Institute. Special Publication, 91, 1-50.

Islam, M. M., & Islam, M. S. (2010). Strength behavior of mortar using fly ash as partial replacement of cement. Concrete Research Letters, 1(3), 98-106.

Krasniqi, D., & Latifi, M. (1996). Teknika e tensioneve te larta. Prishtine. (in Albanian)

Luga, E., & Atis, C. D. (2016). Strength Properties of Slag/Fly Ash Blends Activated with Sodium Metasilicate and Sodium Hydroxide+ Silica Fume. Periodica Polytechnica. Civil Engineering, 60(2), 223. https://doi.org/10.3311/PPci.8270

Luga, E., Atis, C. D., Karahan, O., Ilkentapar, S., & Gorur, E. B. (2017). Strength properties of slag/fly ash blends activated with sodium metasilicate. GRADEVINAR, 69(3), 199-205. https://doi.org/10.14256/JCE.1468.2015

Meyer, C. (2009). The greening of the concrete industry. Cement and concrete composites, 31(8), 601-605. https://doi.org/10.1016/j.cemconcomp.2008.12.010

Morina, I. L. I. R., Dragusha, B. E. D. R. I., Dvorani, S., & Riesbeck, F. (2012). Chemical characteristics of lignite ash from Power Plant Kosova A and local geological settings in Kosova near Prishtina. WSEAS Trans. Environ. Dev, 4(8), 1.

Naganathan, S., & Linda, T. (2013). Effect of fly ash fineness on the performance of cement mortar. Jordan Journal of Civil Engineering, 7(3), 326-331.

Neville, A., (2003). Properties of Concrete, John Wiley & Sons, Inc., London.

Pitroda, J., Zala, L. B., & Umrigar, F. S. (2012). Experimental Investigations on Partial Replacement of Cement with Fly ash in design mix concrete. International Journal of Advanced Engineering Technology, IJAET, 3(4), 126-129.

Short, N. R., & Page, C. L., (1982). The diffusion of chloride ions through Portland and blended cement pastes. Silicates Industrials, 10, 237-240,

Thomas, M. D. A. (2007). Optimizing the use of fly ash in concrete (Vol. 5420). Skokie, IL: Portland Cement Association.

TS EN 1008, (2003). Mixing water for concrete – Specification for sampling, testing and assessing the suitability of water, as mixing water for concrete. Turkish Standard Institute, Ankara, Turkey.

TS EN 196-1, (2009). Methods of Testing Cement – Part 1: Strength Determination Turkish Standard Institute, Ankara, Turkey.

Wesche, K. (Ed.). (2004). Fly ash in concrete: properties and performance (Vol. 7). CRC Press.

Yuan, R. L., & Cook, J. E., (1983). Study of a Class C fly ash concrete in Fly Ash, Silica Fume, Slag and Other Mineral Byproducts in Concrete. American Concrete Institute. Farmington Hills.