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KOSOVO FLY ASH: UTILIZATION IN CONCRETE AS PARTIAL CEMENT SUBSTITUENT AND THE ENVIRONMENTAL IMPACT

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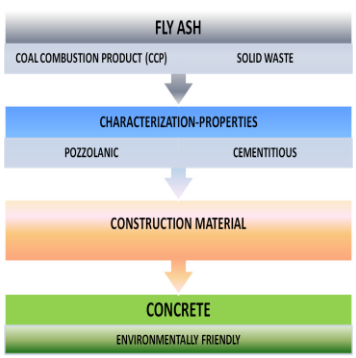
Graphical abstract



Abstract

In Kosovo, except electrical energy, thermal power plants (TPP) annually produce more than 1.5 Mt of solid waste: Fly Ash (FA) and Bottom Ash (BA). Kosovo's construction sector annually consumes around 1 Mt of cement. The environmental impact from cement production (consumption) is the emission of around 1 Mt of CO_2. The focus of this study is the utilization of FA in concrete as cement replacement, which will indirectly mitigate the CO_2 emissions from cement production. The properties of concrete with FA were investigated. For determining the optimum quantity of FA in concrete, four concrete mixes with different content of class C FA were tested. Density and consistence tests of FA fresh concrete, as well as tests of mechanical properties: compressive, tensile and splitting strength of FA hardened concrete specimens were performed. Concrete resistance to permeability was tested by measuring the depth of water penetration under hydrostatic pressure. The correlation between test results of concrete specimens with FA to reference concrete without FA was done. A 30% cement replacement by fly ash showed experimentally to be reasonable. The environmental benefit would be twofold: indirect decrease of 300,000 t of CO_2 and removal of 125,000 m^3 of industrial waste (FA).

Keywords: Fly ash, cement replacement, green concrete, CO_2 mitigation, Kosovo

1.0 INTRODUCTION

Concrete, after the water is the most used material by humans [1]. A standard concrete mixture is made of coarse and fine aggregates (60%-75%) and cement, which in reaction with mixing water forms a paste with binding properties. Although the cement quantity in a standard concrete mixture is around 12%, around 300 kg cement in 1m^3, it represents the most expensive component of concrete [2]. The demands of construction industry for concrete over the years required the increase of cement production. In 1994, 2006 and 2014 the world's cement productions were around 1.37 Bt, 2.5 Bt and 4.2 Bt, respectively. This quantity of cement (referred to 2014) was sufficient to produce around 12 Bm^3 of ordinary concrete [3]. In the world, the annual consumption of cement is around 550 kg per capita [4]. In the Republic of Kosovo, in 2014 there were produced around 3 Mm^3 of concrete. For this concrete production, the consumption of ordinary Portland cement (OPC) was around 1 Mt. Half of this quantity, around 543,500 t, was produced in Kosovo and the other cement quantity of around 542,342 t came from imports [5, 6]. The process of cement production is highly–energy-intensive and is associated with great gaseous emissions due to the requirements of high energy needed for the production of its basic ingredient- the clinker. The global emission of CO_2, a greenhouse gas (GHG), only from cement industry is around 5% of overall CO_2 emissions [7]. The increase of CO_2 emission in the atmosphere affects the rise of earth's temperature, and scientists have commonly proved that this increase of this GHG (CO_2) is of anthropogenic origin. For the first time the rise of CO_2 level has been reported in 1958. That year's level was 316 ppm, which was greater than the records of 280 ppm of two centuries before the industrial era [8]. In 1990 the CO_2 level was 350 ppm, in 2013-396 ppm. Based on this rate of increase, the anticipated level of CO_2 will exceed the threshold of 400 ppm by 2015, 2016 [9]. As above-mentioned, around 5% of earth's CO_2 is emitted from cement industry, therefore, it is the focus and the contribution of this study to provide a solution for mitigation the emissions of CO_2 from cement, respectively concrete industry in the case of R. of Kosovo as part of global attempts in cutting the CO_2 emissions [7, 10]. Therefore, it is an environmental and commercial necessity to find alternative ways to mitigate the CO_2 emission from cement industry either by cutting down its production or replacing it with a material featuring same binding properties. The first option is not relevant because it would directly affect the shortage of concrete. The second option is a reliable solution towards a sustainable development for the construction sector with concrete as an environmentally friendly material.

One other aspect of this study is the solid residue known as fly ash (FA) from TPP. More than 97% of electrical energy in R. of Kosovo is generated from lignite-fired power stations. The exploitable lignite deposits of Kosovo are around 14 Bt [11, 12]. The other issue regarding the generation of electrical energy is that Kosovo has no other alternative-renewable resources. Therefore, the lignite is considered as the only fuel for planning a sustainable energy production. In economical aspect, this is a valuable resource, but the environmental impact of lignite combustion, either through gaseous emissions or generation of solid matter in the form of ash, is of great concerns. The annual ash production, as an industrial waste, from Kosovo TPP is more than 1.5 Mt. Only the quantity of FA, which is a combustion byproduct (CCP) that flies with flue gases, is more than 1 Mt/yr. For the collection of FA after combustion, TPPs are equipped with electrostatic precipitators (ESP), which capture the particles of FA. Afterwards, this collected ash is discharged only as hard solid powder waste without any use ore treatment. As over the last ten years, due to the increase of energy consumption, the increased annual lignite consumption has reached levels of 7-8 Mt [13]. In 2013, 2014 the energy generation of 5864 GWh and 5324 GWh, respectively, consumed, respectively 9.38 Mt and 7.20 Mt of lignite. From the combustion of this quantity of lignite, the fly ash production was 1.2 and 1.0 Mt, respectively [13, 14]. The FA from lignite combustion process, due to its pozzolanic and cementitious properties, used as partial cement replacement in concrete could be a promising material for mitigation of CO_2 from cement industry. Its use could decrease the quantity production of cement, consequently the CO_2 emissions. The tests of properties of fresh and hardened concrete produced with fly ash from Kosovo TPPs as cement replacement have shown that fly ash could be used at a high percentage, up to 30% without causing any negative impact on concrete's physical and mechanical properties.

2.0 AN OVERVIEW ON THE MITIGATION OF CARBON DIOXIDE EMISSIONS FROM CEMENT MANUFACTURING THROUGH THE PERSPECTIVE OF FLY ASH UTILIZATION IN CONCRETE AS PARTIAL CEMENT REPLACEMENT

2.1 The Specific Emission of CO_2 from Cement Production in Kosovo

In the last decade, in Kosovo the construction sector has increased significantly. This consequently increased the demands for more cement production. The CO_2 emission from cement production is very high. In this paper, a review of CO_2 emission from Kosovo's only cement factory is presented. The calculations were based on the technology used in this factory (Sharrcem, Titan Group). Based on this, the CO_2 emissions were calculated as the sum of two kinds of emissions: direct emission from calcination process and indirect emissions from burning of fossil fuels and emissions from consumption of electrical energy in the cement production process.

The direct emission of CO_2 is from the calcination process of limestone as the basic raw material for producing cement. Generally, for production of 1 ton of cement clinker, about 1.5 t of limestone are required. Through the calcination process, calcium oxide as one of the basic ingredients of clinker (around 65% by weight), is formed and CO_2 is emitted according to this reaction [15]:

$$CaCO_3 + heat \rightarrow CaO + CO_2 \quad (1)$$

Knowing the fact that for the production of 1 ton clinker around 1.5 ton of limestone are required, based on the Eq. (1) and the molar masses of compounds, the calculated CO_2 emission, from production of 1 ton of clinker is 0.507 ton. That is, for the production of 1 ton of clinker almost 0.5 ton of CO_2 is emitted as direct emission.

Based on the factory's technology, the specific consumption of electrical energy for 1 ton of cement is around 110–120 kWh [16]. The electrical energy that cement factory consumes is from lignite fired TPP. The CO_2 emission for production 1 MWh from combustion of lignite is 1.3 ton CO_2/MWh. From the generation of 1 kWh, around 0.0013 ton CO_2 is emitted. Taking into calculations the electrical energy consumption of 110–120kWh for 1 ton of cement, the indirect CO_2 emission is about 0.15 ton of CO_2/ton of cement [14]. Another indirect CO_2 emission is from fossil fuel burning for heating the rotary kiln where the calcinations process takes place. In the case of cement manufacturing in Kosovo, the fossil fuel used is the petroleum coke. The specific CO_2 emission from petroleum coke burning is 0.306 ton of CO_2/ton clinker. The sum of two calculated indirect CO_2 emissions during the process of cement (clinker) production is around 0.5 ton CO_2/ton of lime as a byproduct of calcination during the clinker production. This sums the other 50% of CO_2 emitted in the atmosphere from cement production as indirect emission [17]. The total quantity of direct and indirect CO_2 emission from cement production, calculated for the case of cement produced in Kosovo, is around 1 ton CO_2 for 1 ton of cement. That is too high as we take into account the 1million tons of cement consumption annually in Kosovo with around 1.8 million inhabitants.

The focus of this paper is to put forwards efforts to mitigate the CO_2 emissions from cement industry by reducing its quantity (use) in concrete through its replacement by a certain quantity of fly ash (FA)-the industrial waste from TPP of Kosovo. The tests of concrete with FA encouraged this FA utilization, as it is shown later up to 30% by cement weight.

2.2 Characterization of Fly Ash of Kosovo TPP for Use in Concrete as Cement Substituent for Producing Green Concrete

In TPPs the fuel used is lignite. Lignite combustion, except gaseous matter, generates solid waste, non-combustible matter in the form of ash. Around 20% of this ash is collected from the bottom of furnace and it is called bottom ash (BA). The other part, around 80% of ash-fly ash (FA) flies with flue gases. Installed electrostatic precipitators (ESP) capture this FA, and then this FA is conveyed and collected in silos. This fly ash is of interest of this study for utilization in concrete. The quantity of this residue ash (FA&BA)) from lignite combustion process depends on the ash content of lignite. The analyses of Kosovo lignite showed that ash content is about 14-17% [18]. Quantity calculation of generated ash, respectively fly ash is done based on the lignite consumption in TPPs during the electrical energy generation. The average specific lignite consumption of Kosovo TPP is around 1.6 t/MWh [19]. The electricity generation, lignite combustion and ash, both bottom and fly ash are presented in Table 1. As shown below, the annual electrical energy generation is almost 6000 GWh, annual lignite consumption is more than 9 Mt, and fly ash production exceeds 1 Mt. This waste is an environmental concern as it is stockpiled as solid waste that needs a huge space to be dumped. From the Table 1, it can be observed that the increase of energy generations in the last decade directly led to the increase of quantity of FA.

Table 1 Fly ash generation from TPP units of Kosova A and B [9, 19, 20]

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Energy generation (GWh)	3841	3999	3970	4309	4505	5260	5481	5696	5847	5864	5324
Lignite consumption (Mt)	5.59	6.27	6.35	7.11	7.46	8.41	9.34	9.11	9.35	9.38	7.20
Total Ash (Mt)	0.89	1.00	1.02	1.14	1.19	1.35	1.49	1.46	1.50	1.50	1.15
Bottom Ash (Mt)	0.18	0.20	0.20	0.23	0.24	0.27	0.30	0.29	0.30	0.30	0.23
Fly ash (Mt)	0.72	0.80	0.81	0.91	0.95	1.08	1.20	1.17	1.20	1.20	1.00

This environmental pollution from FA is aimed to be mitigated by using it up to a certain percentage in concrete industry as partial cement replacement [21]. This alternative way of "consuming" this waste is used in making concrete with ordinary Portland cement (OPC) and FA. Therefore, test results regarding some concrete properties were performed. Prior to that use in concrete, the FA of Kosovo TPP has been analyzed and tested in regard for its chemical and mineralogical composition. The testing method for this purpose was with XRF spectrometry [22]. FA chemical composition is shown in Table 2.

Table 2 Elemental and chemical composition of fly ash from Kosovo B TPP [9]

Composition	(Wt. %)
Silica (SiO_2)	29.7
Alumina (Al_2O_3)	10.65
Iron Oxide (Fe_2O_3)	6.18
Lime (CaO)	32.92
Magnesium oxide (MgO)	5.93
Sulfur (SO_3)	9.98
Sodium oxide (Na_2O)	0.74
Potassium oxide (K_2O)	0.61
Loss on ignition (LOI)	2.09

According to EN 197-1 (2011) all main types of cements consist of almost the same oxides: lime (CaO), silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3) etc., but the participation percentage is different in different types [23]. From the chemical composition of Kosovo FA it is observed the presence of the same basic minerals as in ordinary Portland cement. This is the scientific foundation for utilizing the Kosovo FA in concrete either as cement replacement or as admixture for improving certain properties of fresh or/and hardened concrete [24]. According to the presence and percentage of these minerals, Kosovo FA should feature pozzolanic and cementitious properties. In European Union (EU) there is a standard EN 450-1, which depicts the requirements in regard to chemical, physical and mechanical properties of FA for use in concrete. According to EN 450-1 (2012), fly ash is a: "Fine powder of manly spherical, glassy particles derived from burning of pulverized coal, with or without co-combustion materials, which has pozzolanic properties and consists essentially of SiO_2 and Al_2O_3 [25]. American Standard ASTM C618 12a (2012) classifies the fly ashes based on their lime content (CaO). As lime content of Kosovo FA is 32.92% by weight, which is greater than the standard limit for classification (20% by weight), therefore Kosovo FA belongs to Class C, i.e. calcareous fly ash [26]. The specific content of reactive lime (CaO), reactive silica (SiO_2) and aluminum oxide (Al_2O_3) makes calcareous fly ash. This type of fly ash has both pozzolanic and hydraulic (cementitious) properties [27].

3.0 THE EXPERIMENTAL DETERMINATION OF OPTIMAL QUANTITY OF FLY ASH IN REPLACING CEMENT FOR PRODUCING GREENER CONCRETE

3.1 Concrete Mix Designs

For investigating the impact of fly ash addition in concrete, there were designed and produced several concrete mixes: two reference without FA and four with different FA content. The focus was the feasibility of fly ash utilization in concrete as cement substituent for producing concrete that does not differ from ordinary concrete (in this study reference concrete mixes), or even concrete with enhanced properties. The procedures of concrete production, curing and testing were performed in conformity with European standard for concrete EN 206-1 [2]. The methodology followed in tests consisted in the comparison of properties of concrete specimens with different percentage of FA to the ones without FA (reference mixes). In this realm, the test of density of fresh concrete, consistence, compressive strength of cube and cylindrical specimens, and tensile splitting strength were planned to be performed [28]. The cement used in all concrete mixtures was ordinary Portland cement CEMI 52.5 N, from Kosovo cement factory "Sharrcem" [29]. Aggregates were of well-defined granulometry of fine and crushed aggregates from a local quarry "V. e Bashkuar", Shpk, Kosovo. Properties of used aggregates were in full compliance with European standard for aggregates EN 12620 [30]. All properties of aggregates: particle density, particle size through sieving method, sand equivalent, shape index, water absorption, resistance to fragmentation, freezing and thawing resistance, resistance to slat crystallization, chemical analyses and the petrographic examination were tested. The mixing water was drinking water that is allowed to be used conform EN 1008:2002 [31]. The fly ash was class C fly ash from Kosovo B TPP unit and has been tested for chemical, physical and mechanical properties in accordance with standard EN 450-1 [25]. Concrete content ingredients for six concrete mixes, RMC, RMH, M15, M20, M25 and M30 are presented in Table 3.

Table 3 Concrete mixtures and content of ingredients

Mix ID	Cement (kg/m^3)	Fly ash (kg/m^3)	Agg. (kg/m^3)	Water (kg/m^3)	Admixt. (kg/m^3)
RMC	300	0	1888	190	0
RMH	300	0	1888	190	1.2
M15	255	45	1888	190	1.2
M20	240	60	1888	190	1.2
M25	225	75	1888	190	1.2
M30	210	90	1888	190	1.2

For testing the properties of concrete with FA from each concrete mixture three specimens were cast in cube and cylinder moulds. After the mixing, moulds were filled up with fresh concrete and cured by immersing them in a water tank in constant temperature at (20±2)°C. As mentioned above, six concrete mixes were designed and prepared. Two reference concrete mixes with ID: RMC and RMH were without FA. The first reference concrete mix-RMC comprised 300 kg/m^3 cement type CEM I 52.5N, fine and coarse aggregates and water. The second reference mix-RMH had the same content of cement, aggregates and water, and addition of superplasticizer admixture [24, 32]. Four other concrete mixtures with ID: M15, M20, M25 and M30 were made of the same content/granulometry of aggregates and water, but the cement content was different due to its replacement with FA of class C from Unit B of Kosovo TPPs. The percentage of cement replacement by FA in concrete mixtures: M15, M20, M25, M30 was 15, 20, 25 and 30%, respectively. The content of cement CEM I 52.5 in concrete mixtures: M15, M20, M25, M30 was 255, 240, 225 and 210 kg/m^3, respectively. The content of FA in concrete mix M15, M20, M25, M30 was 45, 60, 75 and 90 kg, respectively. The ratios of water-to cement, water effective-to-cement, water-to-cement & fly ash, and water-to-binder are as presented in Table 4.

Table 4 Ratios: Water-to-cement, water effective-to- cement, C+fly ash, water –to- binder

Mix ID	W/C	Weff/C	W/(C+k x FA	W/Binder
RMC	0.63	0.660	0.63	0.530
RMH	0.63	0.600	0.630	0.480
M15	0.74	0.710	0.696	0.480
M20	0.79	0.747	0.720	0.480
M25	0.84	0.797	0.745	0.480
M30	0.905	0.854	0.770	0.480

From the data shown in the Table 4, it can be observed that concrete mixes with greater FA content had greater water-cement ratio. This is due to the fact that FA has been added in account of cement. The other concrete mixes that are slightly near this ratio are those with 15% and 20% FA [33]. As FA features pozzolanic and hydraulic properties, according to European standard for concrete EN 206-1, the FA is classified as type II additive. In this regard, in the calculations of the ratio water- to- cement and water–to-cement & fly ash, the k-value has been taken into account. The k-value is a determining value for the quantity of fly ash to be used in a concrete mix [34]. According to EN 450-1:2012 fly ash belongs to type II additive, therefore the ratio fly ash-to-cement shall not be greater than 0.33. If it is used any excessive quantity of fly ash, that extra quantity should not be taken into calculation for ratios water-to cement and water to cement & fly ash. European standard for cement EN 197-1 (2011), for the type of cement CEM I 52.5 N has set the limit of k-value to be ≤0.33. From all four mix designs with FA, only at the concrete mixture with 30% FA by cement weight, the ratio cement/fly ash was 0.4, i.e. it has exceeded the standard requirement of ≤ 0.33 [25]. Although greater, the test of concrete mix with 30% OPC replaced by FA showed no significant deviation of properties in comparison to reference concrete mixtures.

3.2 Test Results of Fresh and Hardened Concrete Properties

3.2.1 Fresh Concrete: Density and Consistence (Slump Test)

The determination of fresh concrete density was carried out in accordance with standard EN 12350-6 (2009). The density measurement was done by calculating the ratio of mass of fresh concrete to volume of cube specimens with dimensions 15 cm and cylinder specimens with base diameter 15 cm and height 30 cm. With this method, the density of fresh concrete mixes: M15, M20, M25 and M30, i.e. concrete mixes with 15, 20, 25, and 30% FA replacement of OPC, was measured and investigated the possible change in density due to the replacement of OPC by FA. Cube and cylinder moulds with fresh concrete were vibrated for two minutes on vibrating table for removing any entrapped air, and afterwards their mass was measured. After the measurement and calculations, the density of these mixtures with FA was compared to reference mixtures RMC and RMH. The values of calculated densities are presented in Table 5. As it is observed the addition of fly ash in concrete mixtures did not change the density of concrete. As the density of concrete mixture is greater than 2000 kg/m^3, and smaller than 2600 kg/m^3 according to EN 206-1, all concrete mixtures with FA concerning the density belong to standard concrete-normal-weight concrete [2].

Table 5 Consistence and density of fresh concrete

Mix ID	Fresh Concrete Density (kg/m^3)		Consistence (Slump in mm)
	Cube specimens	Cylinder specimens	
RMC	2338	2365	100
RMH	2412	2459	180
M15	2387	2392	130
M20	2389	2405	140
M25	2400	2394	90
M30	2370	2398	80

Consistence (workability) of fresh concrete, being an important property of fresh concrete, was determined [35]. According to Glanville et Al. (1947), the workability is "the property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished." The test of consistence was determined by slump method conform EN 12350-2 [36]. Tests were performed in concrete mixtures with fly ash: M15, M20, M25, M30 and reference mixture: RMC, RMH. As there were designed and produced different concrete mixtures with different content of cement and fly ash, there were achieved different values of consistence. The individual slump results of each concrete mixes are shown in Table 5. From the obtained data it was observed a variation in consistence in all concrete mixtures. The anticipation regarding this property was that the addition of fly ash should increase the consistence of fresh concrete. Contrary to predictions, in this case, the addition of Kosovo FA showed to decrease the concrete consistence. This is somehow an exception. This can be justified as Kosovo FA absorbs more water than CEM I 52.5. The test of water for standard consistence in the case of pure cement paste for CEM I 52.5 N was 30% by weight of cement. Whilst, the water for the standard consistence for paste CEM I 52.5 N plus FA was 31.8%. As presented in the Table 5, it can be concluded that the replacement of OPC by FA reduces the concrete consistence (workability). Therefore, this fact should be taken into consideration when one producer decides to use FA in concrete.

3.2.2 Hardened Concrete Strength: Compressive, Tensile Splitting, Tensile. Depth of Water Penetration

A concrete mix is always designed by engineers to achieve a certain resistance against different mechanical loads. The compressive strength (CS) is the most assessed property of hardened concrete that structural engineers take into account. In this study, the test of CS was performed with a compression test machine in cube and cylinder specimens at three ages: 2, 7 and 28 days. The CS determination is based on the applied uniaxial load on the cross section of cube and cylinder concrete specimens. The results of measurement are in unit megapascal (MPa). The test procedure was carried out in accordance with EN 12390-3 [37]. Following this procedure, the CS of concrete cube and cylindrical specimens with FA: M15, M20, M25 and M30 was measured. The obtained results then were compared to the CS of reference specimens without FA, RMC and RMH. The results for the mean CS, at ages 2, 7 and 28 days for cube specimens, and at age 28 days for cylindrical specimens, are presented in Table 6. The results of each test are presented in the Table 6. The main aim for testing this property was to experimentally determine the optimal maximum quantity of FA addition in concrete without decreasing/affecting the compressive strength comparing to ordinary concrete with OPC only. In this regard, it was observed only a slight decrease of CS at mixtures with FA in comparison to the reference mix RMC. The obtained results of CS showed that there was an increase in CS with age increase for all types of concrete mixtures. The CS of concrete mix M15 in all ages, showed to be slightly close to the CS of reference mixes; CS of RM30, with the highest content of FA (30%) showed to have same or higher CS than reference mix RMC. In general, the four concrete mixtures that contain FA: M15, M20, M25, M30 definitely showed higher compressive strength than reference concrete RMC (no FA, no superplasticizer). The CS test of cylindrical specimens at 28 days age, showed that CS of concrete mix M30 with 30% FA was greater (35.60 MPa) than CS of reference mix RMC (30.70 MPa). All these test results are in favor for using the Kosovo FA in concrete as partial cement replacement up to 30% of OPC weight. This 30% FA use means 30% decrease of cement consumption, respectively production, which will indirectly lead to 30% cut of CO_2 emission from cement [38].

Another important mechanical property of concrete is the tensile strength (ft). Due to its brittleness, concrete concerning the tensile strength is more "vulnerable" as its tensile strength is very low compared to compressive strength. The direct experimental determination of tensile strength is difficult because the testing is very sensitive to positioning and holding of the specimens in machine and application of uniaxial load. Consequently, the tensile splitting strength (ftsp) is used as indirect method to calculate the tensile strength [39]. In this study, the tensile splitting strength (ftsp) of cube specimens, at age 28 days was performed in accordance with EN 12390-6 2010) [40]. The test is carried out by loading diametrically concrete cube specimen in a compression machine, with the specimen placed between two plates. The applied force until the specimen fails to resist is recorded. The calculation of tensile strength (ft) is done by multiplying the tensile splitting strength (ftsp) with a conversion factor λ=0.9 [41]. The test results of tensile splitting strength(ftsp) of concrete mixtures: RMC, RMH, M15, M20, M25 and M30 were 5.6 MPa, 7.2 MPa, 5.3 MPa, 4.4 MPa, 4.2 MPa, and 4.6 MPa, respectively. The calculated tensile strength for mixtures RMC, RMH, M15, M20, M25 and M30 were: 5.0 MPa, 6.4 MPa, 4.7 MPa, 3.9 MPa, 3.8 MPa and 4.1 MPa, respectively. These results for tensile and tensile splitting strength are present in the Table 6. To investigate the effect of FA in tensile splitting strength(ftsp) and tensile strength (ft the comparison between reference mix RMC and concrete mixes with fly ash was done. The tensile splitting strength (ftsp) of concrete mix M30 (with 30% FA by cement weight) was 4.6 MPa and at RMC was 5.6 MPa, i.e. only 1 MPa lower than the (ftsp) of reference mix. The same difference was recorded for tensile strength(ft): the tensile strength(ft) of M30 was 4.1 MPa, whilst the tensile strength (ft) of reference mix RMC was 5.0 MPa.

A measure that characterizes the concrete long-term durability and resistance to water, liquids and other liquid chemicals is the property known as depth of penetration. This is a method that one side of concrete specimen is held under static water pressure of 5 Bars for a period of 72 hours. This method was performed in cube concrete specimens according to EN 12390-8:2009 [42]. The effect of FA in concrete mixtures in regard to penetration of water under pressure was measured. After 72 hrs, the specimens were split and the depth of penetration was measured by marking it visually. The depth of water in concrete mix MRC, MRH, M15, M20, M25 and M30 was 21, 19 mm, 23 mm , 49 mm, 34 mm and 39 mm, respectively. These results are presented in Table 6. From the data, it is observed an increase of water penetration with the increase of FA content. This parameter somehow restricts the use of concrete with FA in environments with aggressive exposures and in water-retaining structures.

Table 6 Compressive strength ($f_{c,cyl}$; $f_{c,cube}$), tensile splitting (f_{tsp}) and tensile strength (f_t). Depth of water penetration

Mix ID	Compressive strength						Tensile splitting strength (f_{tsp}) (MPa)	Tensile Strength (f_t) (MPa)	Depth of water penetration (mm)
	$f_{c,cyl}$ (MPa)	$f_{c,cube}$ (MPa)							
	Age (days) 28	Age (days			Increase of $f_{c,\ cube}$ (%)				
		2	7	28	2/7 days	7/28 days			
RMC	30.70	14.95	24.35	34.38	61.40	70.83	5.6	5.0	21
RMH	41.27	26.95	37.6	47.43	71.68	79.27	7.2	6.4	19
M15	43.30	25.05	36.15	49.03	69.29	73.73	5.3	4.7	23
M20	38.53	21.43	31.7	46.02	67.60	68.88	4.4	3.9	49
M25	41.46	19.21	32.45	47.86	59.20	67.80	4.2	3.8	34
M30	35.60	13.94	23.96	39.37	58.18	60.86	4.6	4.1	39

4.0 CONCLUSIONS

In Kosovo, TPPs annually produce more than 1 Mt of fly ash. Based on the chemical and mineralogical analyses Kosovo fly ash belongs to Class C with pozzolanic and cementitious properties. This chemical similarity with ordinary cement was the ground for using it in concrete as cement replacement. In order to find the optimal quantity of fly ash use in concrete, four concrete mixes were designed and tested their properties. The test of the density of fresh concrete with fly ash proved that the replacement of cement by fly ash did not change the density type of concrete: all mixes were normal weight concrete. The test of consistence (workability), for the same water-to-cement ratio showed that addition of fly ash decreases concrete slump, i.e. decrease of consistence. Compressive strength (CS) test of cube specimens (fc, cube) showed that (fc, cube) of concrete mix with the highest quantity of fly ash, 30 % by cement weight, at age 28 days was 39.37 MPa, which was higher than the CS of reference mix without fly ash (34.38 MPa). The corresponding CS (fc,cyl) at 28 days of cylindrical specimen with 30% fly ash was 35.6 MPa, that was greater than the CS of reference mix (30.70 MPa). The tensile strength (ft) of concrete specimens was determined indirectly by test of tensile splitting strength (ftsp) test. The difference in tensile and tensile splitting strength of concrete with 30% fly ash was only 1 MPa lower. For testing durability and resistance of concrete to liquids, i.e. permeability of concrete with fly ash, test of water penetration under pressure was performed. The test showed that the increase of fly ash content decreases concrete impermeability. Therefore, it is recommend further investigation of this property as it directly affects the durability of concrete and resistance in aggravated environmental conditions and its use in water retaining structures.

Based on these tests, the highest optimal-maximal quantity of fly ash that can be used as cement replacement in concrete was up 30% by cement weight. This high percentage indicates that fly ash use can indirectly affect the decrease of CO_2 emissions from cement production. As from 1 ton of cement production around 1 ton of CO_2 is emitted, the use of fly ash in concrete will indirectly reduce CO_2 emission by 30%. Therefore, we would produce concrete with almost same or even enhanced properties with lower emission of GHG (CO_2). This utilization of fly ash in concrete proved the fact that fly ash as an industrial waste from lignite combustion can be standardized to a construction material. The benefit of its use is that emissions of CO_2 from cement production will be decreased for 30% as we directly decrease the cement content in concrete. In the other hand, the replacement of 90 kg cement with 90 kg fly ash (30% fly ash by cement weight) in 1 m^3 cement will have twofold environmental effects: 30% replacement of OPC with fly ash would cut down the emission of CO_2 for around 300,000 tons, and the utilization of 300,000 tons of fly ash in concrete would transform around 125,000 cubic meter of industrial waste (fly ash) into construction material. Thus, fly ash utilization makes concrete really "greener".

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