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THE IMPACT OF POZZOLANS ON PAVEMENT CONSTRUCTION COSTS

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ABSTRACT
Abstract: In our country due to the abundant oil resources most pavements are of asphalt. Asphalt pavements besides their easy implementation suffer from disadvantages such as changes in properties with temperature and permanent deformations of the pavements. In contrast concrete pavements have lower maintenance costs compared to asphalt pavements and their useful life is longer. Given that RCC pavements have higher implementation speed and require lower costs in comparison with conventional concrete pavements and require the least maintenance, they can be a good alternative for asphalt pavement and reduce the cost of government for the maintenance of roads. Since similar to other concrete pavements cement materials are one of the main components in the construction of RCC pavement , given the pollution from cement production and high emissions of carbon dioxide, the use of natural and synthetic pozzolan as complementary cement material and alternative for cement has obtained a special significance and the number of studies conducted in this area is increasing day by day because the use of these materials in addition to reduce cement which saves costs, improves concrete properties as well. In this study, RCC pavement and pozzolan effect on the properties of the road RCC pavement is examined. RCC pavement and the effect of pozzolans (silica fume, fly ash, zeolite and slag cement concrete) on the properties of RCC pavement and the effect of compressive strength in laboratory studies is analyzed.

KEYWORDS: Pozzolan, Construction Costs, pavement

INTRODUCTION

Roller-compacted Concrete or RCC is a new method for the implementation of mass concrete the ide of which goes back to 1960s and the development of its use refers to 1980s. Concrete pavements are used for highways, roads, local roads, parking lots and other types of infrastructure. If concrete pavements are properly designed and made of durable materials, they can successfully survive many utilization and services without the need for maintenance (1). RCC was used for the first time by US Army Engineers to construct industrial floors in 1930. Later that group used RCC to build a runway at the Washington airport in 1942. RCC was used on a large scale in an industrial area in Vancouver, Canada in 1976 (2). RCC components are cement, water and sand. Nowadays the use of pozzolan as materials with cement properties and replacement for a part of Portland cement in concrete mixes is highly considered that while reducing the consumption of cement, can also improve concrete properties. This study analyzes different pozzolans and their effect on the properties of RCC pavement. Cements materials used in the RCC contain portland pozzolan (P-P) or overhead added separately. The cement selection is according to the plan strength and the age considered for the plan strength (3).

With the high price of bitumen and reduced life of asphalt pavements, the use of concrete pavements including RCC pavement is increasing (3). Like other concrete pavements cement material is one of the major components in the construction of RCC pavements. With regard to pollution from cement production and high emissions of carbon dioxide, the use of natural and synthetic Pozzolanic cement materials as the supplementary for cement has become very important and the number of studies in this field is increasing day by day (4).

1. **Pozzolans**

Pozzolanic materials include silica or silica – Aluminum which lacks or has very low adhesive property bun in very fine forms present combinations with cement properties in the presence of moisture during the chemical reaction with calcium hydroxide at room temperature (2). The presence of pozzolans in cement can be combined with the lime in the cement paste and water (alite (C3S) and belite (C2S) phases are formed with water) and produce silicate hydrates as adhesive gel. Production of these adhesive materials fills voids over time because their volume is more than the raw materials. Filling the empty spaces increase resistance and elasticity modulus, reduce Poisson's ratio and improve the mechanical properties of the cement paste (5). Portland cements present a good strength against sulphate attack and some destructive elements. This is due to pozzolanic reaction leaving lower lime that could make its way to the outside and also reduces concrete permeability. Therefore resistance to freezing and melting cannot be created until the next age in which pozzolan reaction has reduced cement paste porosity (6).

2. **Types of pozzolan**

Based on the classifications of pozzolanic materials are classified into the natural and synthetic materials.

Natural pozzolans are materials used to produce a pozzolan from the materials used in the land. Usually the production process includes crushing, grinding, separating size and some of the cases and the application of activation heat. Synthetic pozzolans (byproducts) are materials that have not been considered as the main objective in which production processes. Byproducts with or without specific processes can cause the production of pozzolan. Between these two groups more attention is paid to natural pozzolans; one reason of which might be environmental protection. Different types of synthetic pozzolans include: furnace slag, fly ash, brass shell ash and microsilis (7).

3. **Pozzolanic reaction**

It is in fact a mineral chemical reaction that occurs in Portland cement containing pozzolan. This reaction includes a type of acid-alkali reaction in which calcium hydroxide (Ca (OH) 2) and silicic acid (H4SiO4, or Si (OH)4) react with each other and produce calcium silicate hydrate (CaH2SiO4•2 H2O) which is known in cement industry as CSH. During the hydration two cement compounds containing Tri-calcium silicate (C3S) and di-calcium silicate (C2S) (C, S) present silica oxide and calcium oxide, calcium silicate hydrate CSH and hydroxide (Ca (OH) 2) are released (8). The general form of this reaction is as follows (8):

2(3CaO-SiO2) + 6H2O→ 3CaO.2SiO2 .3H2O + 3Ca (OH) 2

2(2CaO.SiO2) + 4H2O→ 3CaO.2SiO2 .3H2O + Ca (OH) 2

3CaO.Al2O3 + 31H2O + 3CASO4→ 3CaO. Al2O3 .3CaSO4 .31 H2O

4CaO.Al2O3.Fe2O3 + 10H2O + 2Ca (OH) 2 → 6CaO. Al2O3. Fe2O3. 12 H2O

$Ca(OH)_2 + H_4SiO_4 \rightarrow Ca^{2+} + H_2SiO_4^{2-} + 2\ H_2O \rightarrow CaH_2SiO_4 \cdot 2\ H_2O$

The reaction is shown as an abbreviation as follows:

CH + SH → CSH

Figure 1 shows the pozzolanic reaction and on fact pozzolanic reaction converts CH with less density and larger pores into denser CSH with smaller pores.

(A)

(B)

Figure 1. The geometric representation of pozzolan-Portland cement paste (A) and well hydrated Portland cement glue (b)

In the above figure A: presents H, CSH: represents CH and C: represents the capillary voids or empty spaces [9]

4. **Silica fume**

Silica fume is a type of very high purity SiO2 industrial pozzolan used to improve properties of various concretes and produce strong concretes. It has been available to the engineers over a decade.

This matter can be used to improve strength against freezing in RCC. RCC quality is directly related to the degree of compaction and the dry density can be considered as a measure of density [10]

5. Fly ash

Fly ashes include very fine ashes produced by collecting the tiny particles emitted by coal burning in thermal power plants. Due to sudden temperature change of coal, minerals in molten coal form small molten drops most of which are converted to glass particles during the cold snap11]. Fly ash can be used as mineral filler in the mixtures with less cement paste, to increase performance and RCC compression. The high amount of fine grains in RCC increases mechanical resistance and improves surface texture. In order to increase the amount of fine particles fly ash can also replace part of the used sand. The use of fly ash in RCC is an effective solution to provide fine particles required for full density [12].

6. Zeolite

Prior to 1950 the researchers sought to create natural and geochemical minerals to produce zeolite and thought that the formation of zeolites requires a temperature of about 200 to 400 ° C and tens of atmospheric pressure. But in 1957 the chemists were able to produce zeolite crystals at low temperatures (100 ° C) at industrial scales (13).

7. Slag cement concrete

Slag cement concrete is the by product (secondary) in the process of steel making. There are different types of slag in iron and steel industry which is the result of is steel making process including: Iron slag by-product of tall furnaces, steelmaking slag, electric arc furnace slag, open circuit steel furnaces and the converter slag process known as LD2. Steel slag is a nonmetallic composite which contain calcium silicates, calcium ferrites and iron, aluminum, manganese, calcium and magnesium oxides as byproducts of steel. Long furnace slag is a nonmetallic combination that has silicates, calcium Alumina silicates and other alkali elements produced as molten along with iron (14).

8. Profile of materials and mix design

8.1. The mixing ratio of materials and specimens' construction methods

In order to produce RCC specimens in this study the common mixture ratios in Spain are used that are presented in Table (1)

Sand With Size 10 to 20 Mm	209	Kg/M^3
Sand With Size 0 to 10 Mm	1472	Kg/M^3
Sand With Size 0 to 5 Mm	214	Kg/M^3
Pozzolan	80	Kg/M^3
Cement	155	Kg/M^3
Water	99	Kg/M^3

8.2. Aggregates

Aggregates used in this study are the natural, washed and graded and the graded sand grain size used are presented in Table 2 in detail.

Sieve Designation	Cumulative Percentage Retained	Percentage retained	Weight in $1m^3$
3.4 inch	100	0	0
1.2 inch	80	20	379
3.8 inch	66	14	265.3
4	50	16	303.2
8	40	10	189.5
16	32	8	151.6
30	25	7	132.65
50	20	5	948.75
100	16	4	75.8
200	8	8	151.6
	0	8	151.6

Fineness modulus of sand FM = 4.17

8.3. Cement

In this study in order to produce the RCC specimens Portland Type 1 cement is used.

8.4. Water

The water used to prepare RCC mixtures was drinking water.

8.5. Applied pozzolans

8.5.1. BFS

The prepared BFS is a byproduct of Esfahan Steel Company

8.5.2. Zeolite

Zeolite used in this study was clinoptilolite extracted from the mine located 30 kilometers north of Semnan. According to ASTM C618 standard the sum of three oxides ($SiO_2 + Al_2O_3 + Fe_2O_3$) must be greater than 70 percent.

8.5.3. Silica fume

The physical and chemical properties of silica fume used to produce the specimens are industrial and the product of ferro-silicon Company- Iran.

8.5.4. Fly ash

The fly ash is extracted from exhaust gases of coal-fired furnaces that differs in terms of the natural coal and it is as the waste materials in thermal power plants.

The apparatus and method of manufacture

Electric mixer was used in preparing the mixtures and specimens were molded in metal castings with dimensions of 15 x 15 x 15 cm^3. To create concrete compression the standard hammer with 45 cm, 4.5 kg weight and the fall height of 45.7 was used. The molds were concreted at three layers and in each layer 150 beats were entered to the concrete surface and its thickness before condensation was 7 am.

Specimens of each mixture were made by keeping aggregates, water and total cement material constant (including cement and silica fume, zeolite, fly ash and BFS) and only changing the replacement percentage of silica fume, zeolite, fly ash and BFS by cement. For better mixing all aggregates and cement materials were placed in mixer and mixed for 3 minutes. The water was added and the mixer worked for 7 minutes. After the preparation of concrete and molding the surface of the specimens was covered by wet canvas for 24 hours and after opening mold they were transferred to the treatment tank and removed from the water tank after 27 days to perform the tests.

The names of mix design in Table 3 are as follows:

P(Portland cement): Concrete contains Portland cement type 2

Z (Zeolite): represents the natural pozzolan zeolite and the following number presents the percent of Pozzolan replacing cement.

SF(Silica fume): presents silica fume pozzolan and the following number presents the percent of Pozzolan replacing cement.

FA(Fly Ash) indicates fly ash pozzolan and the following number presents the percent of Pozzolan replacing cement.

IS (Iron slag): presents BFS pozzolan and the following number presents the percent of Pozzolan replacing cement.

Example 1: PZ0.5 design is the design in which % of zeolite is used as a cement replacement

Name of design	Name Pzvlan	% By weight of the cement
P (Portland Cement)	Cement type 2	---
P Z0.5 (Zeolite)	Zeolite	5%
P Z0.1 (Zeolite)	Zeolite	10%
P Z0.15 (Zeolite)	Zeolite	15%
SF 0.5 (Silica fume)	Silica fume	5%
SF 0.10 (Silica fume)	Silica fume	10%
SF 0.15 (Silica fume)	Silica fume	15%
FA 0.05 (Fly Ash)	Fly ash	5%
FA0.1 (Fly Ash)	Fly ash	10%
FA0.15 (Fly Ash)	Fly ash	15%
Iron slag)) IS0.05	BFS	5%
Iron slag)) IS0.10	BFS	10%
Iron slag)) IS0.15	BFS	15%

11 - The results

In Figure 1, the compressive strength of pure specimen without pozzolan materials within 28 days is presented. The strength of 28-day specimen is 24.1 Pa.

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Figure 1. Strength of 28-day concrete without pozzolan

Figure 1 presents 5, 10 and 15 percent ratios of zeolite, fly ash, silica fume and BFS pozzolans in 28-day specimen.

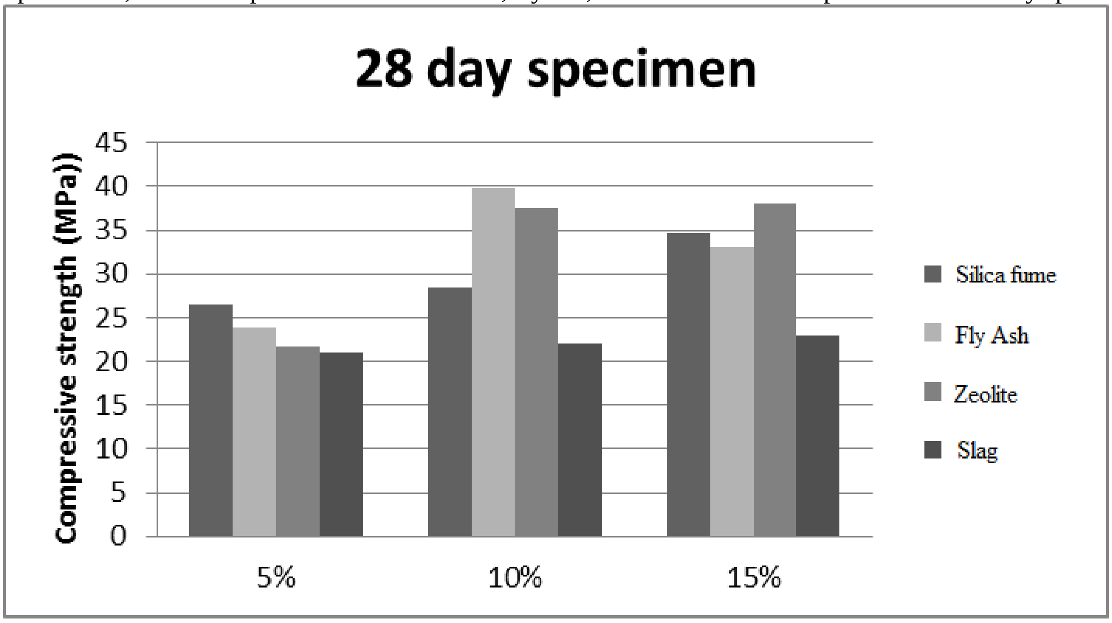

Figure 2: compressive strength with pozzolan ratio in 28-day specimen

The 28-day specimen results show that silica fume in the ratio of 15% had a better strength than 5 and 10% ones and also in zeolite with 15% had a better strength than 5 and 10% ones. However fly ash in the ratio of 10% had a better strength than 5 and 15% ones. In case of BSF it has presented lower strength compared to other pozzolans and slag strength is the same as the specimen without pozzolan.

In Figure 3, the compressive strength of pure specimen without pozzolan materials within 42 days. The strength of 42-day specimens is 28.3.

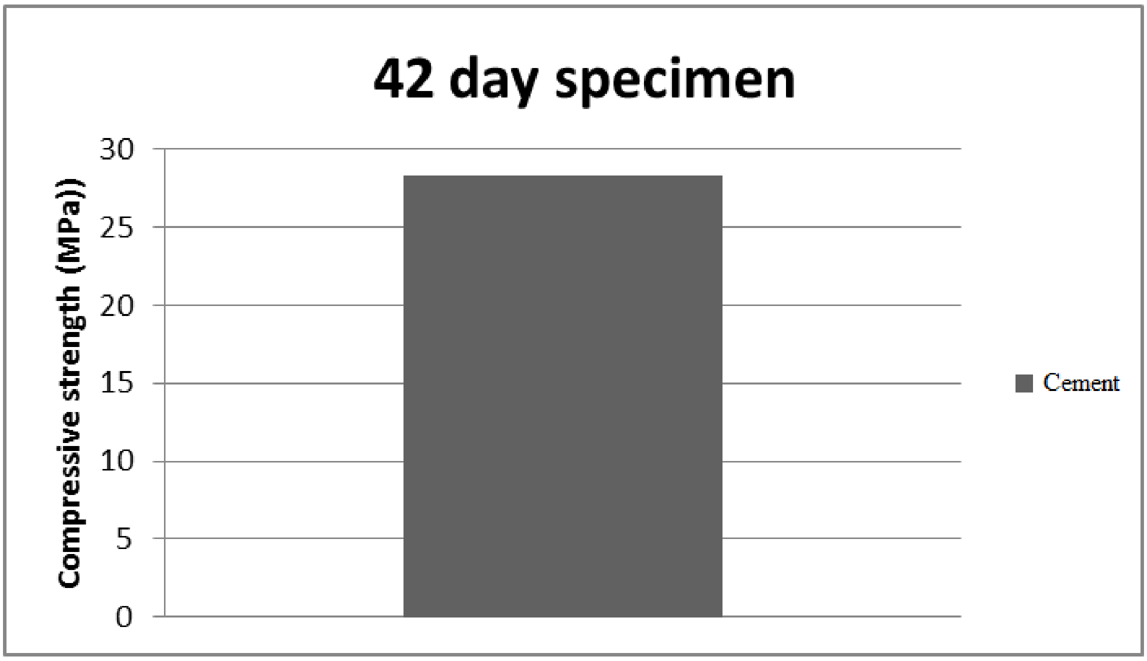

Figure 3: 42-day strength of concrete without pozzolan

Figure 2 presents 5, 10 and 15 percent ratios of zeolite, fly ash, silica fume and BFS pozzolans in 42-day specimen.

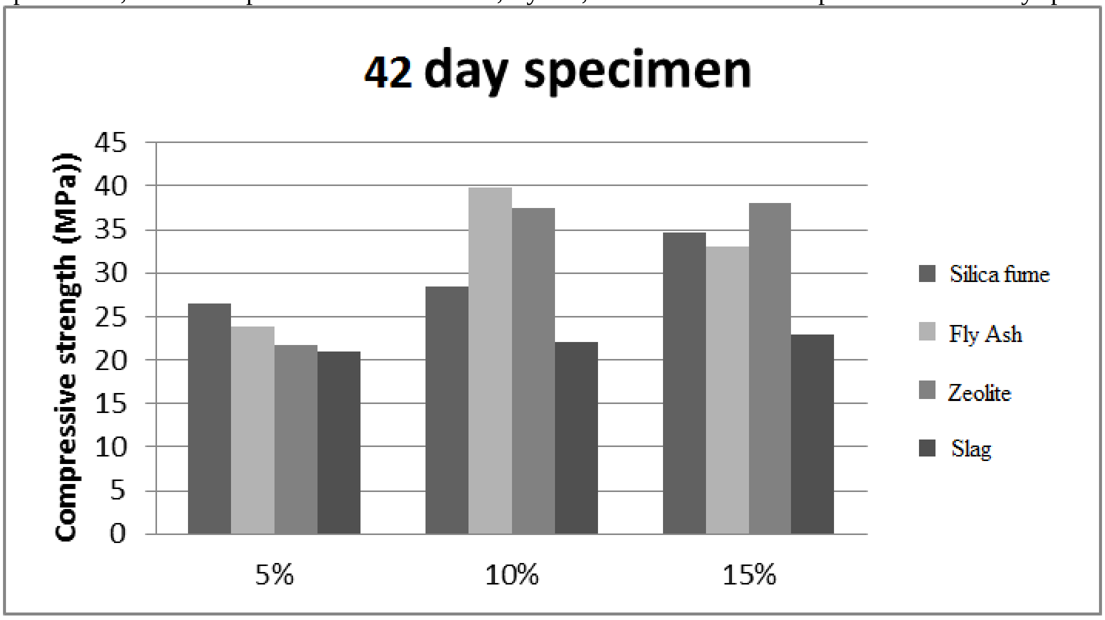

Figure 4: compressive strength with pozzolan ratio in 42-day specimen

The results of 42 day specimen indicate that silica fume unlike the 28 day specimen had a better strength at 10% ratio than 5 and 15% ones and also zeolite had a better strength at 15% ratio than 5 and 10% ones but there is no significant difference in terms of strength. However unlike the 28 day specimen the fly ash has better strength at 15% ratio than 5 and 15% ones in which the ratio of 10 and 15% is insignificant and presents the fixed long term effect of this pozzolan. In case of BFS similar to 28-day specimen, it presented lower strength compared to other pozzolans and slag strength is the same as the specimen without pozzolan.

According to the 28-day and 42-day specimens and the effect of pozzolan in increasing the strength of the concrete specimens, it can be argued that the presence of pozzolans fills the gaps and empty spaces between the aggregates and

5% pozzolan comparing 28 day versus 42 day specimens indicates that the 42 day specimen strength with 5% slag ash has increased by 10 MPa compared to 28 day specimen and also fly ash of 42 day compared to 28 day specimen presents 17.3 MPa increase and in zeolite the 42 day compared to 28 day specimen presents the significant increase of 34 MPa. However BFS of 42 day compared to 28 day specimen presents 3 MPa increase in strength. However at10% pozzolan comparing 28 day versus 42 day specimens indicates that the 42 day specimen strength with 10% slag ash has increased by 16 MPa compared to 28 day specimen; also fly ash of 42 day compared to 28 day specimen presents 16 MPa increase and in zeolite the 42 day compared to 28 day specimen presents the increase of 19 MPa. However BFS of 42 day compared to 28 day specimen presents 3 MPa increase in strength. However at15% pozzolan comparing 28 day versus 42 day specimens indicates that the 42 day specimen strength with 15% slag ash has increased by 6 MPa compared to 28 day specimen; also fly ash of 42 day compared to 28 day specimen presents 23 MPa increase and in zeolite the 42 day compared to 28 day specimen presents the increase of 19 MPa. However BFS of 42 day compared to 28 day specimen presents 2 MPa increase in strength. The results of comparison between 28 and 42 day specimens indicate that by increasing the life of concrete the strength of specimens with pozzolan is increased and the difference between the results are shown in Figure 5.

Since the study conducted by Azadi and and Abedi indicates that the amount of fly ash is about 21-31% of the cement material mass, that the added pozzolan percentages had a good effect in this study and has led to the increased strength. (15).

In Makhdoom study the effect of BFS in RCC dams has been studied and it has been the preplace for the slag in concrete which has reduced the strength and increased permeability and efficiency of the concrete which is due to the combination of lime in concrete with BFS (16).
Given the results of adding zeolite according to the results of Valipour et al. study, it can be concluded that the presence of zeolite (since its made of aluminum hydro silicates and some cation and alkali and alkaline earth metals) This crystalline silicate combination creates extensive and continuous chains that have reduced heat-removing of cement by hydration combination and have increased concrete strength (17). Hassani and Abedin Azadi using Silica fume, the rolling of RCC is improved and better density, specific weight and higher compressive strength is achieved. Therefore it can be said that silica fume has filled the pores between the particles and aggregates, strengthened silica gel and increased compressive strength significantly (15).

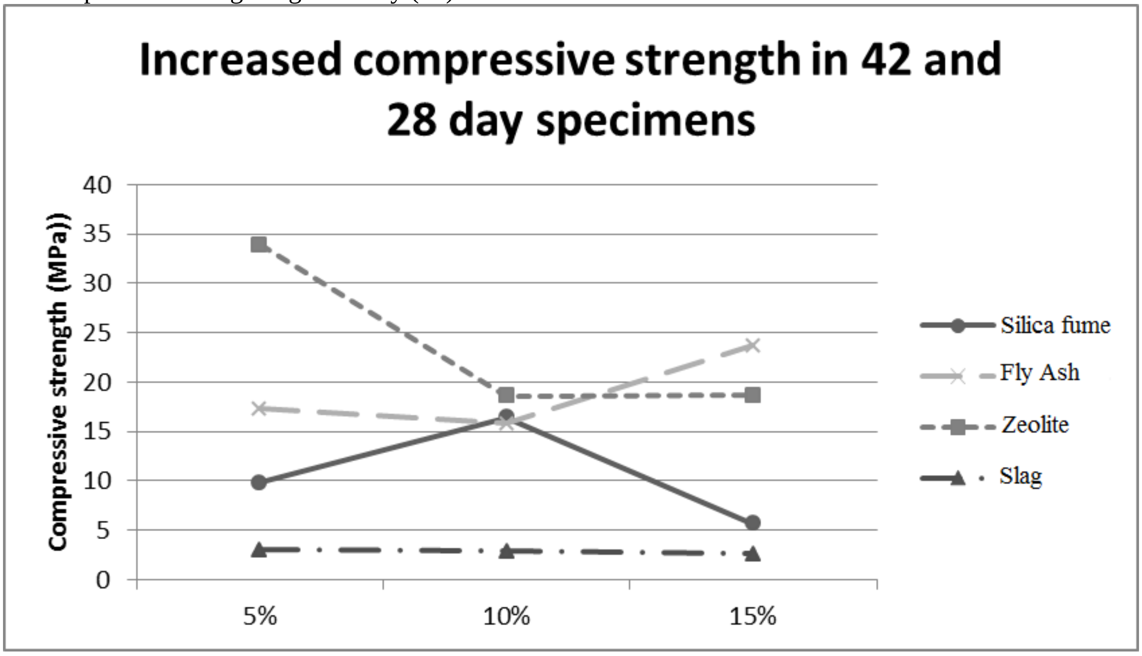

Figure 5: The compressive strength of 42 versus 28 day specimens

Cost evaluation

RCC can be used for any major activity in which concrete with low slump can be carried to, placed in and condensed. RCC is ideal for the conditions that a project should be implemented with the least cost this method of construction is a comparable method with other structural and pavement materials The most important advantages of this method include (18).

Costs: the history of using RCC versus regular concrete has shown that its cost of implementation for each cubic meter is much less than conventional concrete and the reduced cost ranges between 25-50%. The 25 to 50 percent reduction is due to applied material, the cement and the ease of implementation. Another reason that reduces cost is the reduced cost of RCC pavements. Rapid implementation: As mentioned earlier, this fast implementation method reduces the cost significantly compared to the conventional concrete methods. The reduced implementation time removes the implementation, supervision, potential costs of stopped equipment and costs associated with seasonal stops (19). Basically implementation by RCC in addition to (resolved) technical problems causes a major advantage known as being economic in dealing with time. RCC compaction by vibratory rollers provides engineers with a high advantage because it has low price while the fast implementation. On the other hand reducing the amount of cement in RCC will greatly help the economy (20). Portland cements are used as the adhesive material in RCC but different natural or synthetic pozzolans are suitable replacements for a part of cement. With the presence of pozzolans in RCC, the efficiency is increased, cement consumption is reduced and the machines are optimally used.

CONCLUSION

Portland cement is one of the key materials used to produce concrete. Since there is a need for construction all over the world, the industrialized and developing countries require building materials and therefore Portland cement is used increasingly. The production of Portland cement releases a large amount of carbon dioxide which plays an important role in global warming.

1. The results of 28 day specimens show that silica fume at 15% ratio present a better strength
2. Fly ash at 10% ratio presents a better strength than 5 and 15% ratios which is due to the percentage of pozzolan in cement.
3. In 28 day specimen the BFS has presented lower strength than the rest of pozzolans and this volcanic pozzolan is mixed with lime has reduced strength
4. Zeolite 28-day specimen ash at 15% ratio presents a better strength than 5 and 10% ratio. The alkali metal oxides existing in this pozzolan by cement hydration combination has reduced cement heat removing and increased concrete strength.
5. Pozzolan zeolite of 42 day compared to 28 day specimen presents the significant increase of 34 MPa.
6. BFS of 42 day compared to 28 day specimen presents 2 MPa increase in strength which has had a significant performance compared to other pozzolans.
7. Portland cement is often used as a binder in RCC but different natural or synthetic pozzolans will be a substitute replacement for a part of the cement.
8. Fly ash according to pozzolanicity has increased strength and when used as a part of cement, it will reduce the need of cement mixtures to water.
9. Pozzolans can be used as a filler mineral in mixtures with low cement paste, in order to increase the efficiency and density of RCC
10. Regarding the existence of pozzolan in filling the gap between the aggregates they increase strength and better performance during the compaction.

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