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WATER PERMEABILITY AND STRENGTH OF CONCRETE CONTAINING SILICA FUME, FLY ASH, SUPER POZZ, AND HIGH SLAG CEMENT

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ABSTRACT

In this study, effects of mineral admixtures on the water permeability and compressive strength of concretes containing silica fume (SF) and fly ash (FA), super pozz (SP) were experimentally investigated. Permeability of concrete was determined through DIN 1048 (Part 5). The research variables included cement type, ordinary Portland cement (OPC) or high slag cement (HSC), and mineral admixtures content were used as a partial cement replacement. They were incorporated into concrete at the levels of 5%, 10%, and15% for silica fume and 10%, 20%, 30% for fly ash, or super pozz by weight of cement. Water- cement ratio of 0.40 was used and tests were carried out at 28 days. From the tests, the lowest measured water permeability was for the 10% super pozz and 10% silica fume or 20% fly ash mixes. Although the highest compressive strengths of concretes determined was 10% silica fume mix for ordinary Portland cement and were reduced as the increase in the replacement ratios for other mineral admixtures than ordinary Portland cement concrete. The main objective of this research was to study the water permeability and compressive strength of concrete containing silica fume, fly ash, and super pozz and high slag cement to achieve the best concrete mixture have lowest permeability.

The results were compared to the control concrete ordinary Portland cement concrete without admixtures. The optimum cement replacement by FA, SP and SF in this experiment is 10%SP.

The knowledge on the strength and permeability of concrete containing silica fume and fly ash, super pozz and high slag cement could be beneficial on the utilization of these waste materials in concrete work, especially on the topic of durability.

Keywords: Permeability, Silica fume (SF), Fly ash (FA), Super pozz (SP), high slag cement (HSC).

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1 INTRODUCTION

It is known that the permeability controls deterioration of concrete in aggressive environment [1, 2], because the processes of such deterioration as carbonation, chloride attack and sulfates attack are governed by the fluid transportation in concrete. fillers and pozzolanic materials are introduced to improve the strength and other properties of concrete for necessary conditions.
Fly ash and Super pozz are produced from burning of powdered coal in power plants. Silica fume is also known as micro silica, volatilized silica, or condensed silica fume. It is a by-product from silicon metal and ferrosilicon alloy production. The material is a very fine powder with spherical particles about 100 times smaller in size than Portland cement or fly ash.
Slag is a by-product from the production of steel. During production liquid slag is rapidly quenched from a high temperature by immersion in water [3]. The slag is a glassy, granular, non-metallic product that consists "essentially of silicates and aluminosilicates of calcium and other bases" [4]. It is also known as granulated blast furnace slag (GBFS).
The aim of this research was to study the water permeability and compressive strength of concrete containing silica fume and fly ash; super pozz and high slag cement to achieve the best concrete mixture having lowest permeability. The results were compared to the control concrete ordinary Portland cement concrete without admixtures.
The knowledge on the strength and permeability of concrete containing silica fume and fly ash, super pozz and high slag cement could be beneficial on the utilization of these waste materials in concrete work, especially on the topic of durability.

2 EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Cement and Cement replacement materials

2.1.1.1 Ordinary Portland cement

Ordinary Portland cement used was provided from Tourah-factory. The approximate mineral composition of the used cement is shown in Table (1) [6].

Table (1) Typical Composition of Ordinary Portland Cement

constituents	C_3S	C_2S	C_3A	C_4AF	$C\bar{S}H_2$	Total
Percent %	50	25	12	8	3.5	98.5

2.1.1.2 High slag cement

Slag is a by-product from the production of steel. During production liquid slag is rapidly quenched from a high temperature by immersion in water [3]. The slag is a glassy, granular, non-metallic product that consists "essentially of calcium silicates

and calcium aluminosilicates and other bases" [4]. It is also known as granulated blast furnace slag (GBFS). Slag, in addition to pozzolanic properties, and unlike Class F fly ash and silica fume, also has cementitious properties. With regard to strength, there are three grades of slag: Grade 80, Grade 100, and Grade 120. Each number corresponds to a minimum 28-day compressive strength ratio of a mortar cube made with only Portland cement and a mortar cube made with 50% Portland cement and 50% slag. Because of cementitious properties, particles smaller than 10 μm contribute to early strength, while particles larger than 10 μm and smaller than 45 μm contribute to later strength. Since particles greater than 45 μm are difficult to hydrate, slag is mostly pulverized to particles with diameter less than 45 μm [3].
When used in concrete, slag provides the following benefits [9]:
- High ultimate strength with low early strength,
- High ratio of flexural to compressive strength,
- Resistant to sulfates and seawater,
- Improved alkali-silica reaction resistance,
- Low heat of hydration,
- Decreased porosity and permeability, and
- Better finish and lighter color.

Slag is also known for improved workability and lower water requirement [10]. Slag hydration is significantly influenced by temperature: hydration is accelerated at higher temperatures and retarded at lower ones, when compared to Portland cement hydration. This may lead to differences between the strength of concrete in the field and the laboratory specimens [3]. The chemical analysis and physical properties of slag in Table (2) [5].

Table (2) Chemical Analysis and Physical Properties of Slag

Analysis and properties	Mass %
SiO_2	39.0
Al_2O_3	8.7
Fe_2O_3	0.5
CaO	41.3
MgO	8.5
Na_2O	0.15
K_2O	0.21
SO_3	0.74
Loss on ignition (LOI)	0.52
Specific Surface Area (cm^2/g)	7000
Specific gravity	2.92

2.1.1.3 Fly ash

Fly ashes are by-products manufactured during combustion of powdered coal in power plants. A summary of the properties and chemical composition of different fly ashes was presented by Helmuth [6]. In general, depending on the chemical composition, fly ash can be classified as Class F or Class C. Class C fly ash has higher amount of CaO so it possesses more cementing characteristics and is less pozzolanic than Class F. ASTM 618 states that Class F fly ash is “normally produced from burning anthracite or bituminous coal”, while Class C fly ash is “normally produced from lignite and subbituminous coal” [8]. Class F fly ash is mostly composed of silicate glass containing aluminum, iron, and alkalies. The particles are in the form of solid spheres with sizes ranging from less than 1 µm to 100 µm, and an average diameter of 20 µm [3]. At least 70% of the chemical composition is made up of SiO_2, Al2O_3, and Fe_2O_3 [4]. The chemical analysis and physical properties of fly ash shown in Table (3).

The benefits for using fly ash in concrete include the following [4]:

• Improved workability,
• Lower heat of hydration,
• Lower cost concrete,
• Improved resistance to sulfate attack,
• Improved resistance to alkali-silica reaction,
• Higher long-term strength,
• Opportunity for higher strength concrete,
• Equal or increased freeze thaw durability,
• Lower shrinkage characteristics, and
• Lower porosity and improved impermeability.

Table (3) Chemical Analysis and Physical Properties of Fly Ash

Chemical Analysis Mass %	Mass %
Silica (SiO_2)	47.0-55.0
Aluminium (Al_2O_3)	25.0-35.0
Iron (Fe_2O_3)	3.0-4.0
Manganese (Mn_2O_3)	0.1-0.2
Calcium (CaO)	4.0-10.0
Magnesium (MgO)	1.0-2.5
Phosphorus (P_2O_5)	0.5-1.0
Potassium (K_2O)	0.5-1.0
Sodium (Na_2O)	0.2-0.8
Titanium (TiO_2)	1.0-0.5
Sulphur (SO_3)	0.1-0.5
Loss On Ignition (LOI)	0.5-2.0
Specific Surface Area(cm^2/g)	8500
Specific gravity	2.6

2.1.1.4 Super pozz

As can be seen in the chemical composition and physical characteristics listed in Table 4, Super-Pozz is an extremely fine, light colored powder composed primarily of amorphous calcium-silicates and aluminates. From its chemical analysis, Super-Pozz will meet the Class F fly ash requirement of BS 3892, but physically the product is unique with regards to its particle size distribution. The D99 value is 25 micron, the particle size below which 99% of the particles are to be found. Figure 1, illustrates the comparative particle size distribution analysis. The chemical analysis and physical properties of super pozz shown in Table (4)

Table 4. Chemical Analysis and Physical Properties of Super Pozz

Chemical Analysis Mass %	Mass %
SiO_2	53.5
Al_2O_3	34.3
CaO	4.4
Fe_2O_3	3.6
K_2O	0.8
MgO	1.0
Loss On Ignition (LOI)	< 1.0
Specific Surface Area (cm^2/g)	13000
Specific gravity	2.20

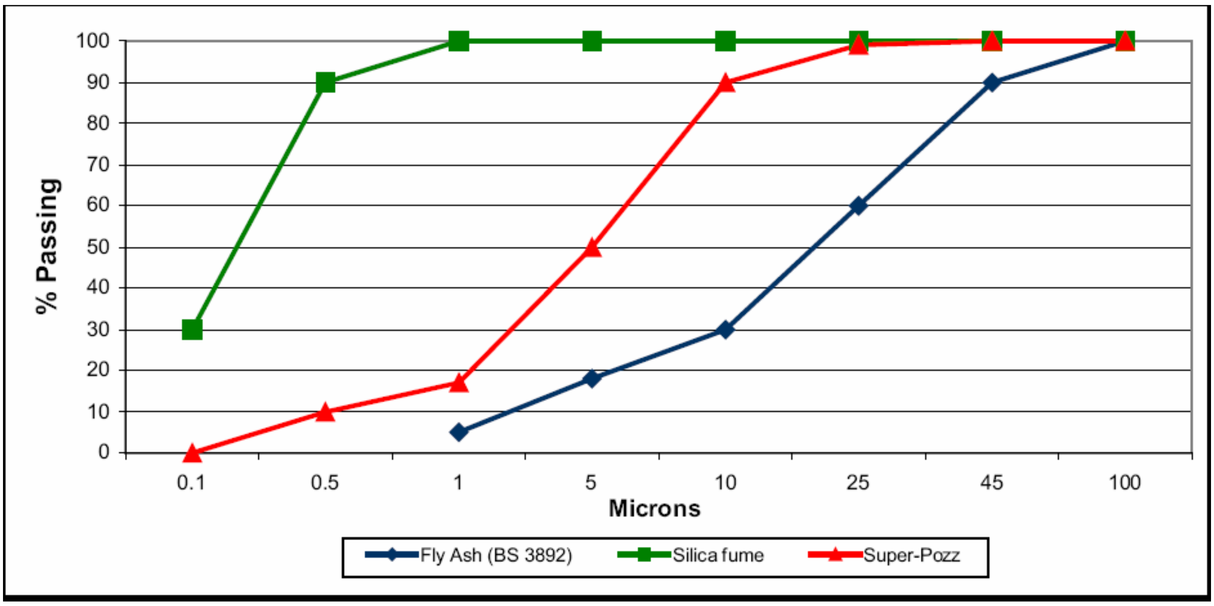

Figure 1: Particle Size Distribution

2.1.1.4 Silica fume

Silica fume is also known as micro silica, volatilized silica, or condensed silica fume. It is a by-product from silicon metal and ferrosilicon alloy production. The material is a very fine powder with spherical particles about 100 times smaller in size than Portland cement or fly ash. The diameters range from 0.02 to 0.5 µm with an average of 0.1 µm. Silica fume contains 85 to 95% noncrystalline silicon dioxide.
The first application of silica fume in the United States was conducted in Kentucky in 1982 [4]. The use of silica fume will make concrete with the following properties [5]:

- Low heat of hydration,
- Retarded alkali-aggregate reaction,
- Reduced freeze-thaw damage and water erosion,
- High strength,
- Increased sulfate resistance,
- Reduced permeability.

Silica fume is also known for creating problems in handling and cracking related to its small particle sizes and increased water requirement.
The chemical analysis and physical properties of Silica fume shown in Table (5).

Table (5) Chemical Analysis and Physical Properties of the Silica Fume

Analysis and properties	Mass %
SiO_2	90.2
Al_2O_3	1.7
Fe_2O_3	0.4
CaO	2.1
MgO	1.7
Na_2O	0.7
K_2O	0.7
SO_3	0.5
Loss on ignition (LOI)	2.5
Specific Surface Area (cm^2/g)	200000
Specific gravity	2.21

2.1.2 Aggregates

Natural sand with fineness modulus of 2.32 and specific gravity of 2.65 was used as fine aggregate. Crushed dolomite stone with nominal maximum size of 28 mm and specific gravity of 2.70 was used as coarse aggregate.
Sieve analysis test were carried out on the used Aggregates and results are listed in Table (6) and Table (7)

Table 6. Sieve analysis test results of sand

Sieve Size (mm)	Fine aggregate	
	% passing	% retained
9.5	100	0
4.75	98.6	1.4
2.36	96.52	3.48
1.18	90. 72	9.28
0.6	69.82	30.18
0.3	12.42	87.58
0.177	0	100

FM=2.32

Table 7. Sieve analysis test results of gravel

Sieve Size mm	coarse aggregate	
	% passing	% retained
38.1	100	0
28	95.57	4.43
19	48.83	51.17
14	13.43	86.57
9.5	1.13	98.87
4.75	0.13	99.87
2.36	0.03	99.97
1.18	0	100
0.6	0	100
0.3	0	100
0.177	0	100

2.1.3 Water

Clean drinking fresh water, free from impurities was used in the mixes. Water-cement ratio was 0.40 by weight.

2.2. Concrete mixtures

OPC was partially replaced by silica fume (SF) at 5%, 10%, 15% where as fly ash (FA) and super pozz (SP) replaced OPC at 10%, 20% and 30%, by weight of binder. The binder content of concrete was set as a constant of 400 kg/m^3 and mix proportions of concrete are presented in Tables (8, 9, and 10). The amounts of water and coarse aggregate in all concrete mixtures were constant.

Table (8) Mixture proportions for fly ash mixes

Materials (Kg/m^3)	Mixture Designation			
	100 % 0PC	10 % FA	20 % FA	30 % FA
Ordinary Portland cement	400	360	320	280
Coarse Aggregate	1212.34	1212.34	1212.34	1212.34
Fine Aggregate	681.94	675.6	669.3	662.9
Water	160	160	160	160
HRWR (L/m3)	8	8	8	8
Fly Ash	-	40	80	120
Calculated Unit Wt	2462	2456	2450	2443
w/c	0.4	0.4	0.4	0.4

Table (9) Mixture proportions for super pozz mixes

Materials (Kg/m^3)	Mixture Designation			
	100 % OPC	10 % SP	20 % SP	30% SP
Ordinary Portland cement	400	360	320	280
Coarse Aggregate	1212.34	1212.34	1212.34	1212.34
Fine Aggregate	681.94	673.7	665.5	657.2
Water	160	160	160	160
HRWR (L/m3)	8	8	8	8
Super-Pozz	-	40	80	120
Calculated Unit Wt	2462	2454	2445	2437
w/c	0.4	0.4	0.4	0.4

Table (10) Mixture proportions for silica fume mixes

Materials (Kg/m^3)	Mixture Designation			
	100 % HSC	**5% SF**	**10 % SF**	**15 % SF**
Ordinary Portland cement	400	380	360	340
Coarse Aggregate	1204.4	1212.34	1212.34	1212.34
Fine Aggregate	677.5	674.11	666.28	658.46
Water	160	160	160	160
HRWR (L/m3)	8	8	8	8
silica fume	-	20	40	60
Calculated Unit Wt	2450	2455	2447	2439
w/c	0.4	0.4	0.4	0.4

2.3. Testing

2.3.1. Water permeability

The Permeability of concrete was determined through DIN 1048 (Part 5). permeability test gives a measure of the resistance of concrete against the penetration of water exerting pressure. It shall normally be carried out when the age of the concrete is 28 to 35 days.

A concrete specimen shall be exposed either from above or below to a water pressure of 5 bar acting normal to the mould- filling direction Figures 2, 3. For a period of three days. This pressure shall be kept constant throughout the test. If water penetrates through to the underside of the specimen, the test may be terminated and the specimen rejected as failed. It shall be checked whether and when the unexposed specimen faces show signs of water permeation. Immediately after the pressure has been released, the specimen shall be removed and split down the centre, with the face which was exposed to water facing down. When the split faces show signs of drying (after about 5 to 10 minutes), the maximum depth of penetration in the direction of slab thickness, shall be measured, in mm, and the extent of water permeation established. The mean of the maximum depth of penetration obtained from three specimens thus tested shall be taken as the test result.

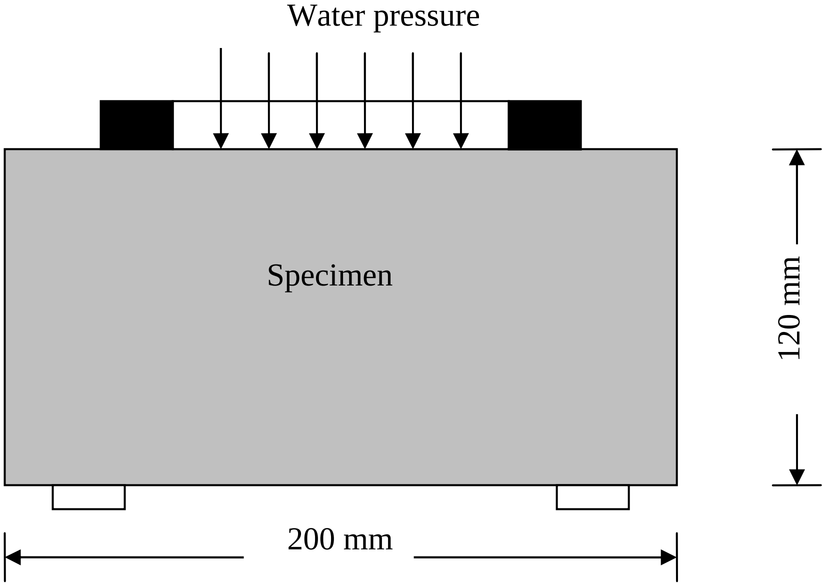

Figure 2: Testing water impermeability on sample
120 mm ×200 mm×200 mm

Figure 3: Apparatus of permeability test

2.3.2. Compressive strength

Concretes cubes of 150 mm were used to determine the compressive strength. The samples were demolded 24 h after casting and cured in water until the testing ages. The compressive strengths of concretes were determined at the ages of 28 days.

3. RESULTS AND DISCUSSION

3.1. Water permeability of concretes

The water permeability of concrete and the ratio of permeability are given in Table (11) and Figure 3. The ratio of permeability is defined as the permeability of concrete containing pozzolanic materials divided by the permeability of OPC concrete at the same age of testing. The mean of the maximum depth of water penetration of 20% FA concrete had lower an average reduction of 44% compared to the control mixture OPC.

The mixture containing blast furnace slag had an average reduction of 7 % when compared to the control mixture. Mixture 10%SF should have a lower value than of the OPC with reduction 66%. The fine particle sizes of the silica fume fills in the spaces between the cement particles and making the concrete much denser than mixtures without silica fume. The mixture containing 10%SP had lowest water permeability value compared to all mixtures.

3.2. Compressive strength

Compressive strengths of concretes are compared to OPC concrete in Table (11) and Figure 4. The compressive strength at 28 days of OPC concrete was 465 kg/cm^2. The concrete containing high slag cement had the compressive strength of 517 kg/cm^2 or 111% of the OPC. Compressive strengths of 10% FA, 20% FA, 30% FA concretes were 435, 414, 370 kg/cm^2 or 94%, 89%, 80% of the OPC concrete, respectively. At higher replacement ratio (30% FA), the strength of concrete lowest since the amount of Portland cement was greatly reduced. For series of SP concretes the compressive strengths were 486,422, and 386 kg/cm^{2}or 105%, 91% and 83% of the OPC concrete, for10% SP, 20% SP and 30%SP concretes, respectively. Again, increasing in replacement ratio of SP, the compressive strength of concrete was reduced, but was still slightly higher than that of FA concretes. For series of SF concretes the compressive strengths were 504,643, and 533 kg/cm^{2}or 108%, 133%and 115% of the OPC concrete, for 5% SF,10% SF and %15 SF concretes, respectively. %10 SF had higher compressive strengths because Silica fume is much finer than the Super-Pozz. As a result of the higher surface area the pozzolanic reaction proceeds rapidly and strength is quickly developed .

Table (11) Results of Compressive strength and max penetration water depth

Mixed	Compressive strength 28 days		Max penetration water depth	
	value(kg/cm^2)	% of control mix	Value (mm)	% of control mix
OPC (control mix)	**465**	**100**	**27**	**100**
HSC	517	111	25	93
10FA	435	94	23	85
20%FA	414	89	15	56
30%FA	370	80	28	104
10%SP	486	105	10	37
20%SP	422	91	22	82
30%SP	386	83	30	111
5 % SF	504	108	20	74
10%SF	643	138	12	44
15%SF	533	115	16	59

4. CONCLUSIONS

1. The optimum cement replacement by FA, SP and SF in this experiment is 10%SP.The higher replacement than this ratio results in the higher of permeability concrete and tends to give lower compressive strength.
2. SF concretes have higher compressive strength at all cement replacement levels Strength and tends to give lower permeability of concrete.
3. The permeability of SP, FA and SF concretes depends on the cement replacement ratios. In general, the permeability of concrete reduces with the increasing in the compressive strength and age of concrete.

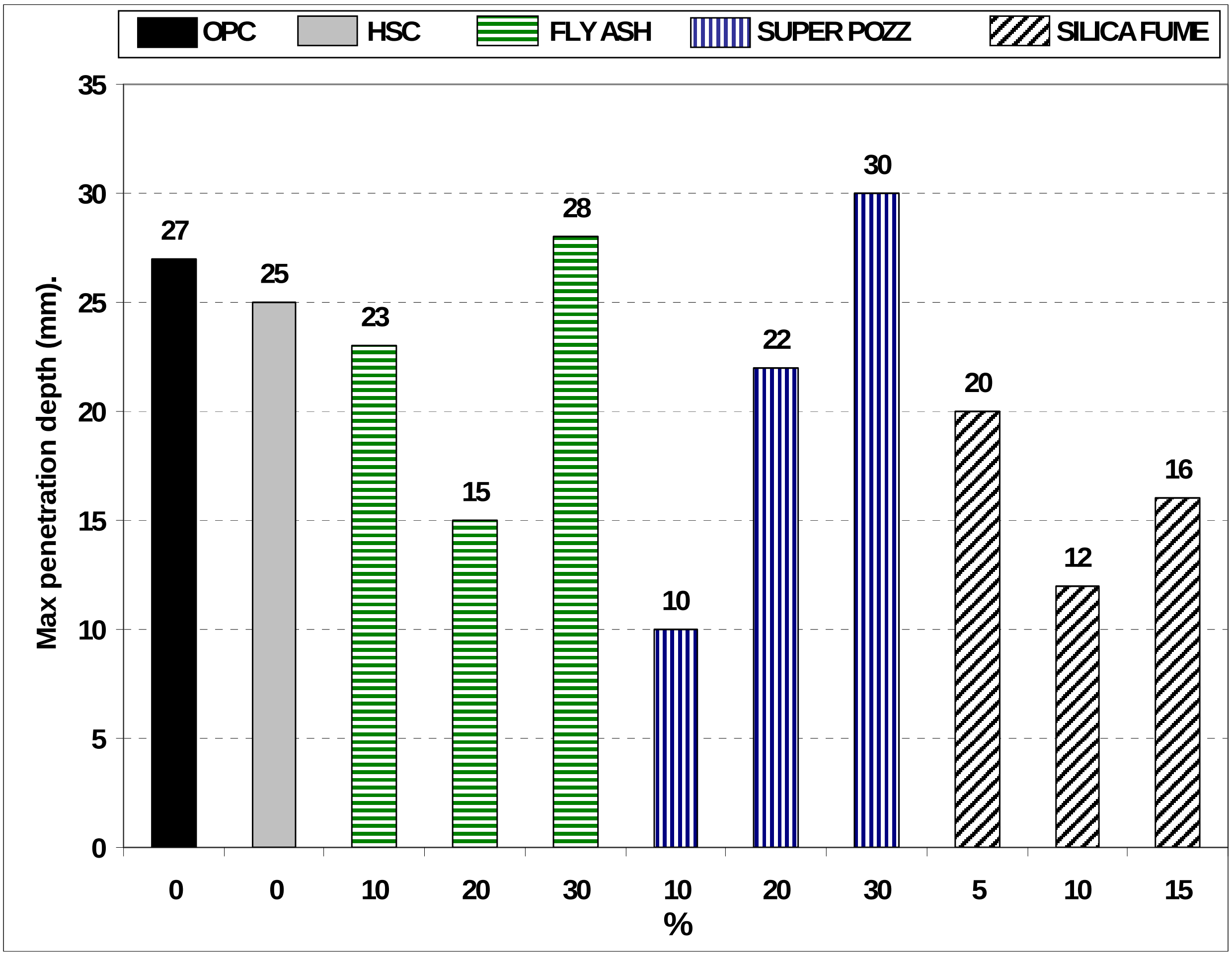

Figure 3: Results of maximum water penetration depth (mm)

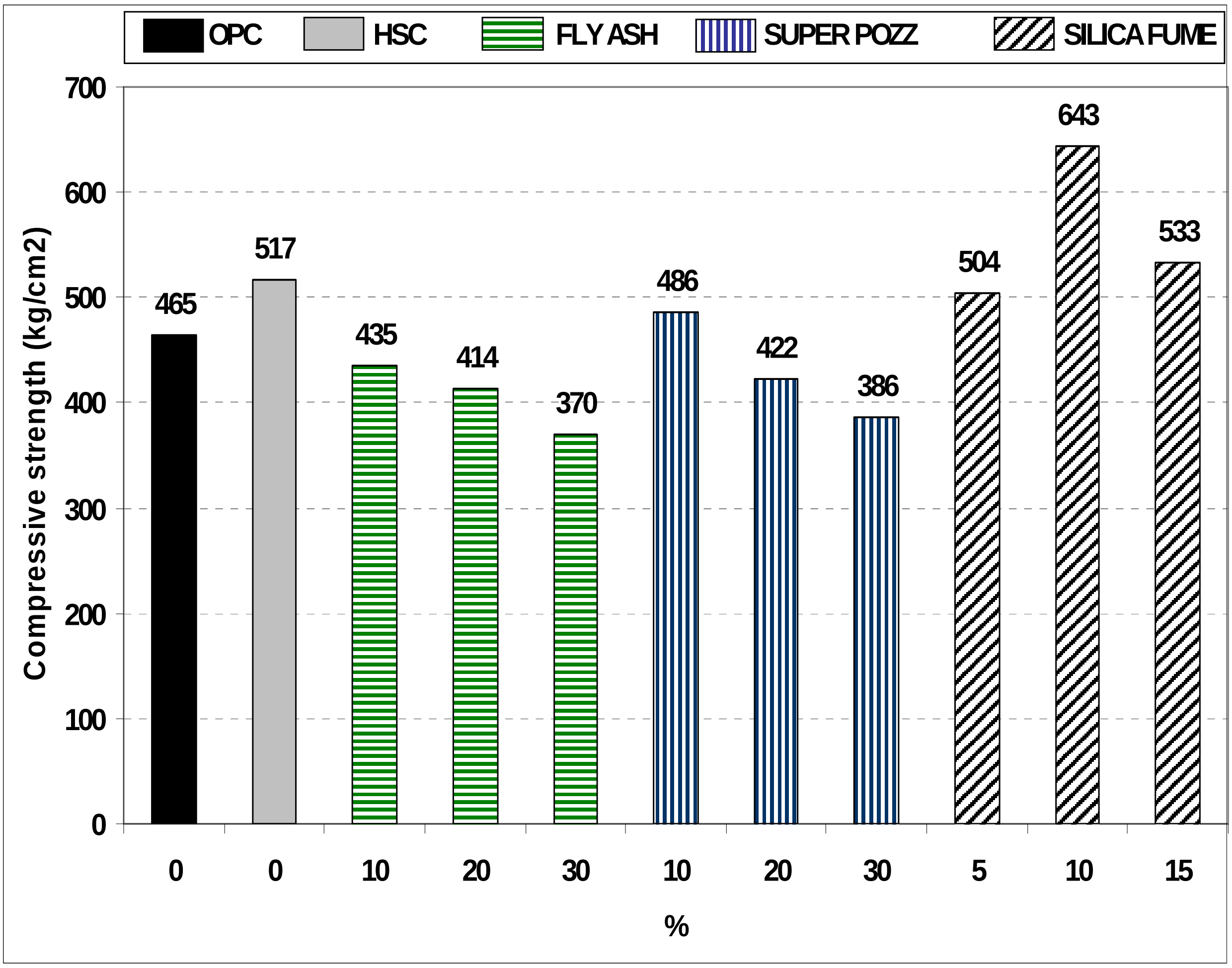

Figure 4: Results of Compressive strength (kg/cm^2)

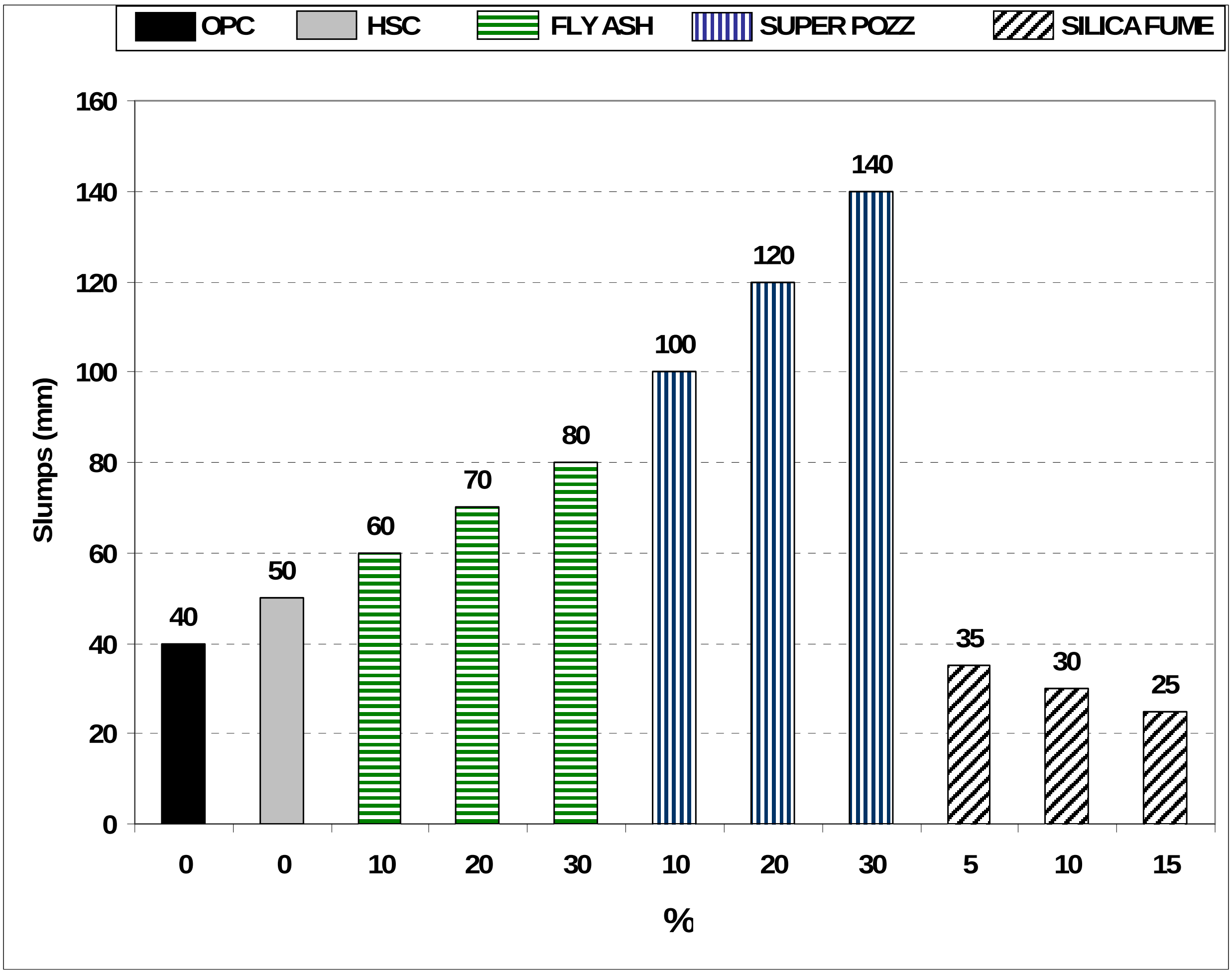

Figure 5: Results of slumps (mm)

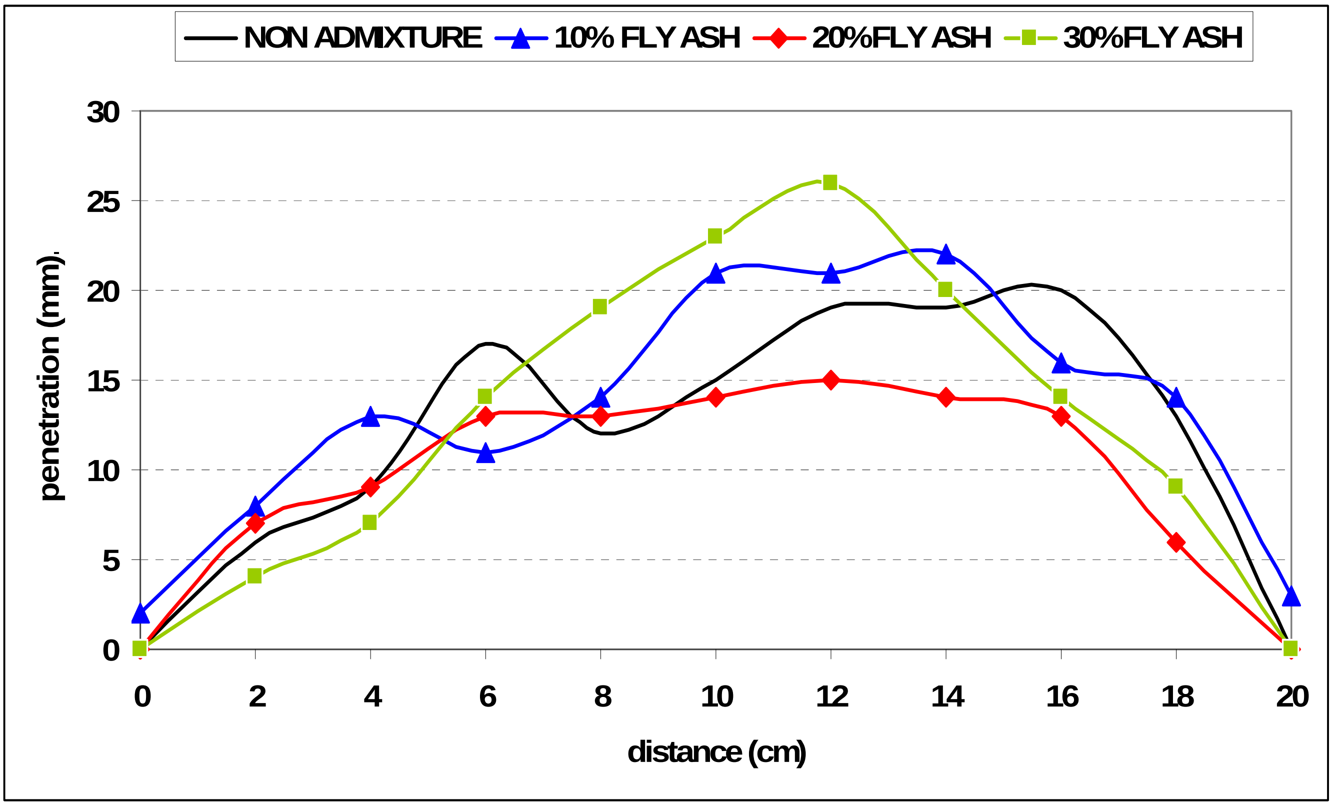

Figure (6) Average water penetration curves with different FLY ASH ratios.

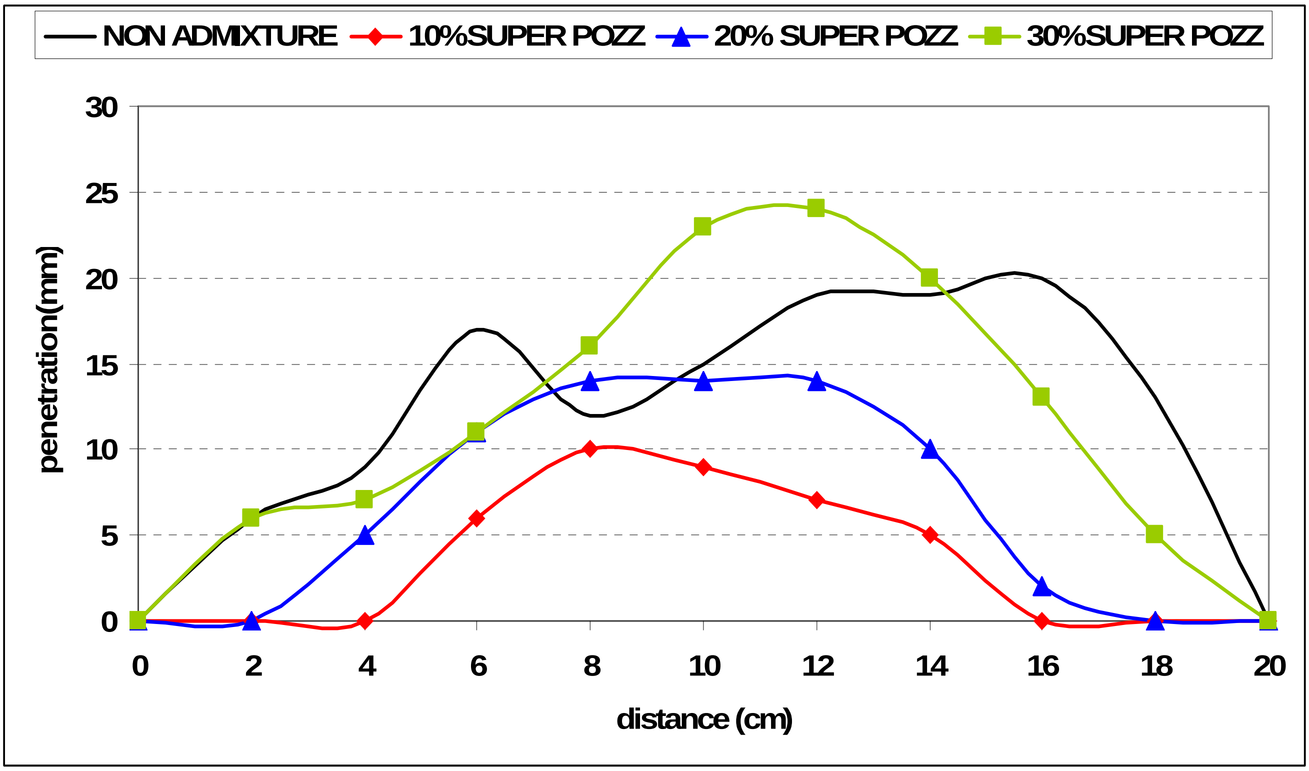

Figure (7) Average water penetration curves with different SUPER POZZ ratios.

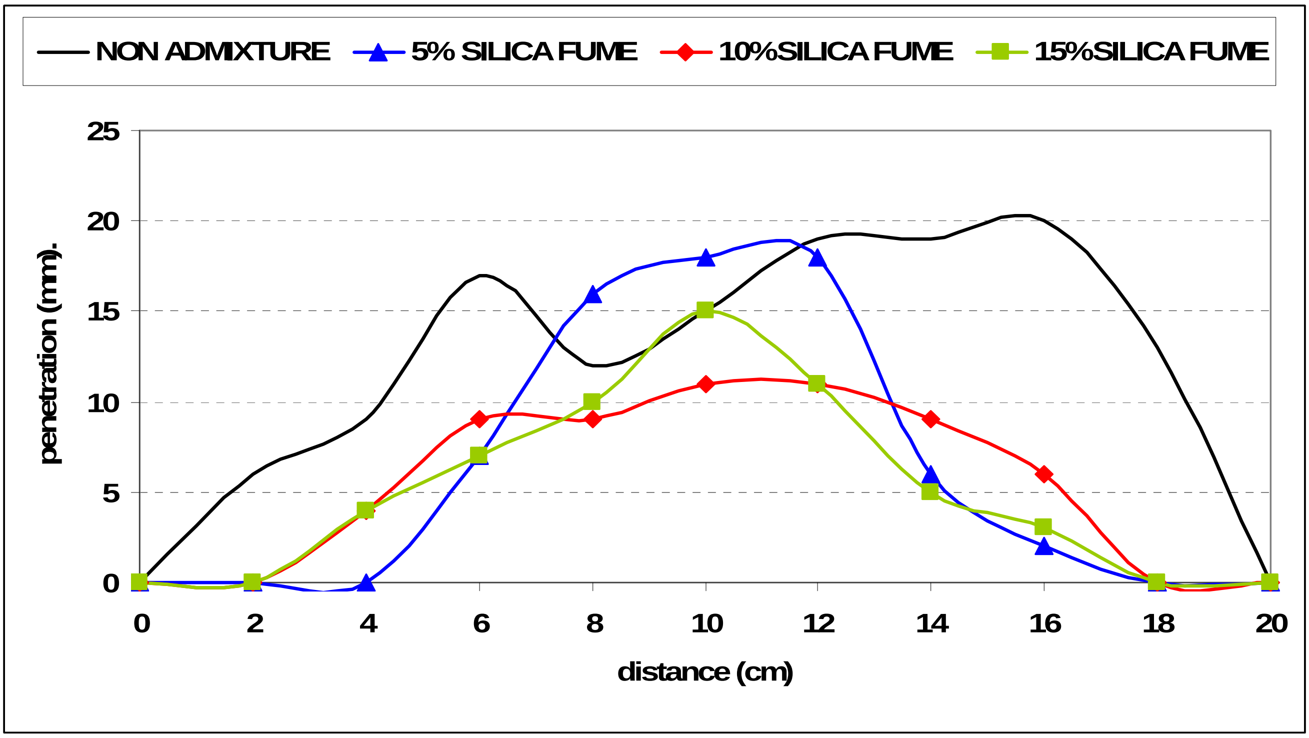

Figure (8) Average water penetration curves with different SILICA FUME ratios.

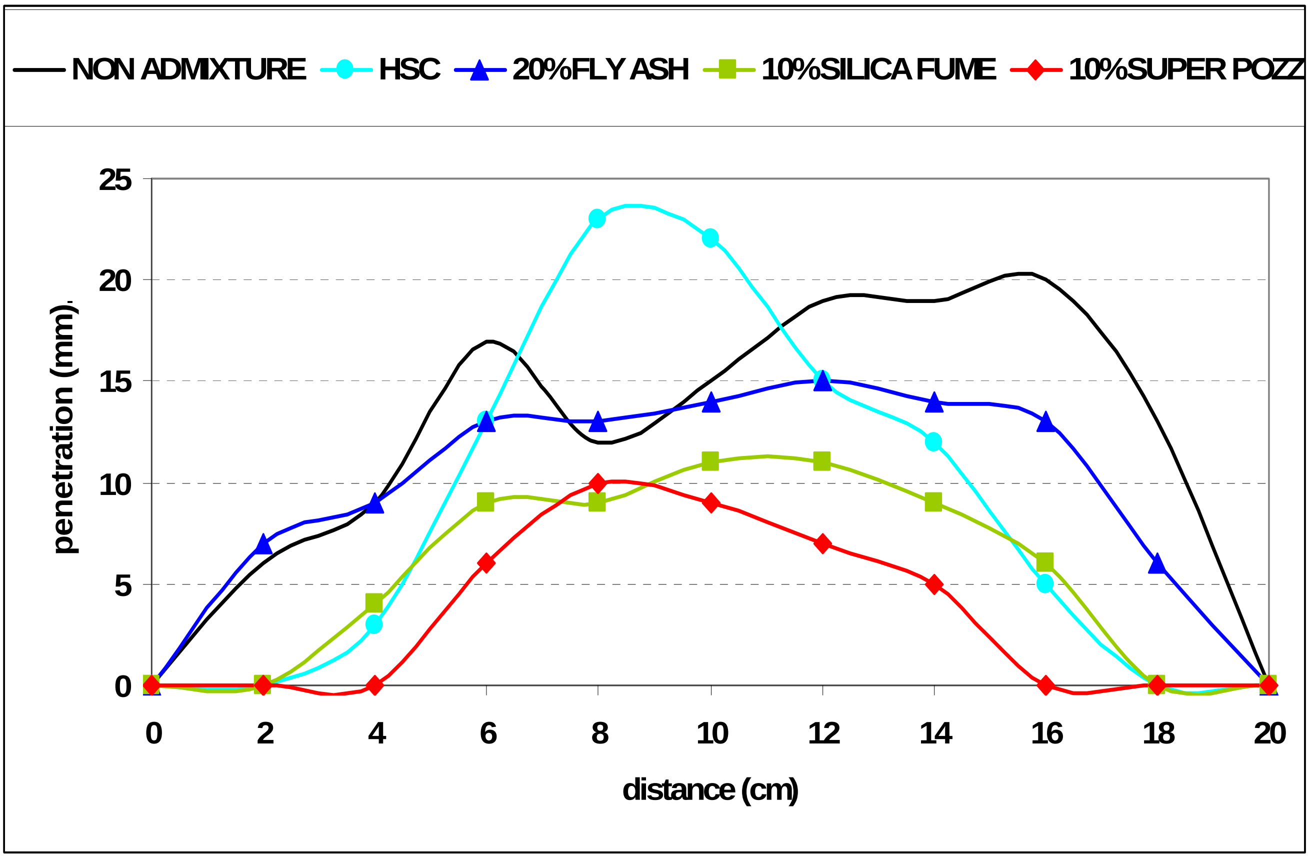

Figure (9) Comparison of the average water penetration curves with the best ratios of different admixture.

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