Indian Journal of Geo Marine Sciences
Vol. 48 (11), November 2019, pp. 1803-1812

Durability properties of fly ash and silica fume blended concrete for marine environment

Karthik Prabhu T*[1], Subramanian K[2], Jagadesh P[1], & Nagarajan V[3]

[1]Department of Civil Engineering, Coimbatore Institute of Technology, Coimbatore, Tamil Nadu, India.
[2]Civil Engineering, P.S.R. Engineering College, Sevalpatti, Sivakasi, Tamil Nadu, India.
[3]Department of Civil Engineering, Coimbatore Institute of Technology, Coimbatore, Tamil Nadu, India.
*[E-mail: ntkarthikprabhu@gmail.com]

Received 02 May 2018; revised 18 June 2018

The improvement in durability and strength by replacing the conventional components with supplementary materials in concrete is one of the recently focused areas in concrete technology. From the previous till the recent times serious efforts have been taken to improve the structural adequacy and durability characteristics of concrete so as to efficiently replace the usual conventional concrete. In this present research work, the mechanical and durability properties of the concrete blended with fly ash (FC) and silica fume (SC) are studied in detail. The partial replacement of cement with silica fume and fly ash in the concrete improves the overall property of the concrete, gives a way for the reuse of the supplementary material to be efficiently brought back giving a cleaner environment. The fly ash is used with the replacement percentages of 10, 15 and 20 of the cement whereas for silica fume the replacement percentages are 8, 10 and 12, respectively. Also the study is extended to combination mixes to test the strength and durability and it has been found that the increase in the percentage of the silica fume increases the strength reduces the workability and permeability to a high extent and the inclusion of the fly ash paves a way for the increase in the durability property. The effect of the cementitious material with FC and SC on the concrete is compared with the nominal concrete and also the suitability in the usage of marine environment is validated in accordance with the International codes.

[Keywords: Concrete; Durability; Fly ash; Relationship; Silica Fume]

Introduction

One of the developing areas in the construction industry is the effective usage of appropriate type of concrete based on application requirements of construction. It has been shown that the demand for the usage of the conventional concrete would increase drastically[1] since the recent trends is giving importance to the environmental concern and construction of the green building. Usage of supplementary material in the concrete is being presently focused, but there still remains a requirement for laboratory test to ensure the efficient performance of the supplementary blended concrete mix[2] and the efficiency of supplementary material used in this research is evaluated. The interface between the molecules in the concrete improves with the pozzolanic materials namely fly ash and silica fume[3]. Previous researchers have found that the inclusion of fly ash in the concrete as a replacement of cement improves the overall properties (strength and durability) of concrete[4]. It has proved that the concrete on the fly ash usage of cementitious materials decreases the permeability value of the mix as a whole and also increases the resistance of corrosion of the reinforced bar included in the concrete[5]. For the normal Pozzolanic Portland cement (PPC) (The PPC blended cements used in market is confirmed as per IS 1489 (Part-1):1991) 15 % to 25 % by mass of fly ash is usually replaced. Even though on increment of fly ash between 40 % and 60 %, many researchers have concluded that the fly ash blended concrete mix possess high resistant to alkali Silica reaction, increment in bond strength, reduces chloride ion penetration, sulphate attack and also good water repellent in permeability property[6]. The temperature rise in the concrete is controlled and lowered when the fly ash is included in the mix[7]. On the overall global scale on addition of a small quantity of fly ash in the cement concrete mix it nearly reduces 3 % – 8 % of the pollution[8]. The Silica fume is the by-product on the production of the silicon and alloys silica fume. In the high performance concrete the silica fume is typically usually replaced at replacement levels of 5–10 % for improving the property of strength and also increases the life span of the concrete as a whole. It reacts with calcium hydroxide to form C–S–H (Calcium

Silicate Hydrate), but also enhances the microstructure of the cement paste due to its fine nature particle size. Many studies describe the increase of the property of the concrete due to addition of silica fume[9]. The concrete structure service life is defined by chloride intrusion in the concrete affecting the reinforcement bars. Chlorides are well influenced in the marine environment which penetrates the concrete surface and affects the steel bars by corroding it. In concrete, the chloride ions consist of calcium chloro aluminate hydrates such as Friedel's or Kuzel's salt Friedel's Salt - $Ca_2Al (OH)_6 (Cl, OH) 2H_2O$: Kuzel's Salt – $3CaO\ Al_2O_3$ ½ $CaSO_4$ ½ $CaCl_2\ 11H_2O$ are absorbed by the Calcium Silicate Hydrate (CSH) present in the concrete. In addition to chlorides, sea water contains magnesium, sulfate and carbonate ions which reduces the life cycle of the marine reinforced concrete structures. These cause deterioration to the concrete structures in the coastal areas[10]. The objective of the present study in to find out suitable concrete for marine environmental conditions. The marine environment has more chloride amount which is harmful to normal concrete. The progress of chloride ion in concrete is discussed along with the use of new blended concrete.

Experimental Programme Materials for the preparation of blended concrete

Even though specifications are available for the mix design of the concrete, (the mix design is done as per ACI 211 and the characteristic compressive strength of concrete is 20 MPa), the need for laboratory tests for ensuring the anticipated performance of laboratory is required[11]. Class C Fly ash obtained from Neyveli Lignite Corporation Limited, Tamil Nadu, India, a state government owned power generating company was used for all the cement replacements in this project. The fly ash properties [specific gravity of fly ash is done as per IS 3812 (Part 1 &2) – 2003] are shown in Table 1, and the requirements as per ASTM C 618-93 are compared in Table 2. The fly ash inclusion in the concrete does not deviate too much in its properties when compared to the conventional concrete[12]

Elkem-Microsilica of Grade 920D used in the research work was purchased from Elkem India pvt ltd located in Navi Mumbai, India. It has been verified that the quality of silica fume is confined as specified by ASTM-C-1240 and AASHTO M 307 (use of silica fume as a mineral admixture in Hydraulic-Cement Concrete, Mortar, and Grout, AASHTO M 307, High-Reactivity Pozzolans for use in Hydraulic-Cement Concrete, Mortar, and Grout AASHTO M 321 and the Canadian Standards Association (CSA) Cementitious Materials Compendium Standard specification A3000-13). The properties of the silica fume are given in Table 3 and 4 respectively. The introduction of the silica fume in the concrete enhances the properties of the mix ie., mechanical and durability properties to a higher extent[13]

The cement of Grade 53 OPC was used in the research work conforming to IS 12269:2013. Coarse aggregates of 20 mm maximum size are used in the research work found suitable according to the Indian Standards, as per IS: 2386-1963. The properties of the OPC used for the research is shown in Table 5 along with comparison with the permissible limits according to IS 12269 – 2013.

Table — 1 Properties of Class C Fly Ash

Specific gravity	2.19
Ferric oxide (Fe_2O_3)	11.3 %
Magnesium oxide (MgO)	0.64 %
Titanium oxide (TiO_2)	1.4 %
Calcium oxide (CaO)	1.19 %
Silicon dioxide (SiO_2)	55.6 %
Sulphur trioxide (SO_3)	0.49 %
Aluminium oxide (Al_2O_3)	28.3 %
Loss on ignition	1.05 %

Table — 2 Requirements of Class C Fly Ash as per ASTM C 618-93

Property	Requirements (%)	Available (%)
$SiO_2 + Al_2O_3 + Fe_2O_3$ (minimum)	50	79
Loss of ignition (maximum)	6	3
Moisture content (maximum)	3	0.5
SO_3 (maximum)	5	0.8

Table — 3 Physical properties of silica fume

Properties	Values
Specific gravity	2.5
Surface area, (kg/m^2)	20,150
Bulk density, (kg/m^3)	578

Table — 4 Chemical properties of silica fume

Chemical properties	(%)
SiO_2	93.4
CaO	0.32
S	0.18
Na_2O	0.38
Fe_2O_3	0.60
K_20	0.76
MgO	0.82
C	0.81
Al_2O_3	0.63

The reason for the high consistency of cement is due to storage and environmental condition in laboratory, the quantity of water to be mixed with cement required is more in order to complete the reaction between cement and water. The fineness of cement is 11 % higher than the standard level which will also lead to more amount of water to initiate reaction between water and cement. More fineness means more the surface area; hence it requires more water for more surface area of cement particles The properties of the coarse aggregates are depicted in Table 6

Preparation of concrete

The durability studies for concrete are available only with American standards. Hence, in order to understand the effect of materials and exposure condition in India, it is necessary to do mix design as per American standards. The preparation of the concrete is shown in Tables 7 and 8 should be done in standard environment condition and necessary care should be taken for the specimen preparation for conducting the mechanical and durability tests [14]. The main usage of supplementary materials is to enhance the durability properties, strength of the concrete and also not compensating for the permeability loss[15].

Table 5 — Properties of cement (ACC cement 53 OPC grade)

S.No	Particulars	Result	Permissible Limits (As per IS 12269-2013)
1	Fineness of cement (m^2/kg)	248	Minimum of 225
2	Compressive strength of 3 mortar cubes (N/mm^2)		
	1. at 3 days	31	Should not be less than ‘27’
	2. at 7 days	43	Should not be less than ‘37’
	3. at 28 days	54	Should not be less than ‘53’
3	Soundness Le Chatelier method (mm)	1.7	Maximum 10
4	Initial setting time (min)	64	Minimum of 30
5	Final setting time (min)	289	Maximum of 600
6	Normal consistency (%)	37	

Table 6 — Physical properties of coarse aggregates

SlNo	Property	Result
1	Fineness modulus	6.81
2	Specific gravity	2.82
3	Water absorption %	0.96%
4	Crushing value, %	13.33%
5	Impact value, %	14.27%
6	Abrasion value, %	26.21%
7	Flakiness index, %	12.87%
8	Elongation index, %	11.62%

Casting and Curing-methods

The specimens for the durability tests namely rapid chloride penetration test, acid resistance test and abrasion resistance test cubes were casted according to ASTM C 39-2012 and for other durability tests namely water absorption and permeability specimens were casted in cylinders according to ASTM C779 / C779M, ASTM C 1585 -13 and ASTM C 1556- 11a-(2016) respectively. The grading of the aggregates does not have a high impact for the reduction in the properties of the concrete[16]. The materials used for casting the concrete were weighed in correct proportions and mixed by a concrete mixer machine for concreting and the vibrations were done by a vibrating needle. After 24 hours, the specimens were de-moulded and placed in curing tank for 28 days. The cement to the aggregate ratio is an important parameter and on decreasing the ratio it enhances the mechanical strength but has a reduction in permeability[17].

Test Procedures

More durability tests are required to determine the life cycle of the concrete specimens moreover, even the mechanical properties play a vital role in

Table 7 — Mix propotions

Materials	Proportions
Coarse aggregate (kg)	1508.25
Fine Aggregate (kg)	753.28
Cement (kg)	369.25
Water (lit)	195.25

Table 8 — Percentage replacement with Mix ID

Mix	Id
Nominal	NX
Fly Ash 10 %	FA
Fly Ash 15 %	FB
Fly Ash 20 %	FC
Silica Fume 08 %	SA
Silica Fume 10 %	SB
Silica Fume 12 %	SC
Fly Ash 10 %+ Silica Fume 08 %	F1S1
Fly Ash 10 %+ Silica Fume 10 %	F1S2
Fly Ash 10 %+ Silica Fume 12 %	F1S3
Fly Ash 15 %+ Silica Fume 08 %	F2S1
Fly Ash 15 %+ Silica Fume 10 %	F2S2
Fly Ash 15 %+ Silica Fume 12 %	F2S3
Fly Ash 20 %+ Silica Fume 08 %	F3S1
Fly Ash 20 %+ Silica Fume 10 %	F3S2
Fly Ash 20 %+ Silica Fume 12 %	F3S3

validating the mix property[18]. The most frequently used is ASTM C1202. This test is commonly referred to as the rapid chloride permeability test (RCPT). The RCPT is a measurement of the electrical charge that travels between two sides of a concrete specimen over a six-hour period. This charge is correlated to chloride ions travelling through the pore system. Lower values signify a higher resistance to chloride intrusion as shown in Table 9. The reduction in size of the aggregates causes a high compaction factor and decreases the chloride ion permeability [19].

Intensity of the current was monitored periodically (0, 30, 60, 120, 150, 180, 210, 240, 270, 300, 330, 360 minutes).

Using the trapezoidal rule suggested by ASTM C 1202 charges passed can be calculated.

$$Q = 900\ (I0 + 2\ I30 + 2\ I60 + \ldots\ldots + 2\ I330 + I360) \quad \ldots (1)$$

where,
Q = Charge passed (Coulombs)
I0 = Current (amperes) immediately after voltage is applied
It = Current at t min after voltage is applied

The concrete has high insulation values and low unit weight[20]. The acid resistance test was carried out by immersing 150 mm cubes in sulphuric acid and hydrochloric acid as shown in Figure 1. The concrete cubes specimens are oven dried after their 28th day curing for a temperature at 105 ^{o}C. Afterwards cooled at room temperature, and weights of the specimens were noted before immersing them into the acid solutions (M1). The cubes were observed and the cubes were continuously immersed in the acid solutions until the cubes began to lose the coarse aggregates. The direct exposure of the cubes was done in the concentration of 3 % and 7 % acid solution[28] [as per ASTM C1152 / C1152M - 04(2012)e1]. The cubes were taken out from the solutions and weighed (M2). The percentage of mass loss is calculated by using the equation

$$\text{Mass loss \%} = (M1 - M2 / M1) \times 100 \quad \ldots (2)$$

Table 9 — Chloride ion permeability based on charge passed

Charge passed (coulombs)	Chloride ion penetrability
> 4,000	High
2,000 - 4,000	Moderate
1,000 - 2,000	Low
100 - 1,000	Very low
< 100	Negligible

The water absorption test is done according to ASTM C 642-11 at the age of 28 days and the percentage of the water absorption should not exceed 20 %. For the water absorption test, small cylinders of size 100 mm x 200 mm is casted and kept in oven, maintained at a temperature of 100 ^{o}C to 110 ^{o}C for 24 h till dry and left to cool down in the range of of 20 ^{o}C to 25 ^{o}C. The dry weight is noted down initially (A). The specimens are immersed in water at 23 °C for 48 h. The specimens are then made to submerged in water for saturation and surface dried after taking out and weighed (B) as displayed in Figure 2.

The specimens are placed in auto clave and boiled for 5 hours and allowed to cool for 14 hours in room temperature and weighed (C). Finally, the specimens are immersed in water and weighed (D).

$$\text{Absorption after immersion} = \frac{(B-A)}{A} * 100 \quad \ldots (3)$$

$$\text{Absorption after immersion and boiling, \%} = \frac{(C-A)}{A} * 100. \quad \ldots (4)$$

$$\text{Volume of permeable pore space (voids), \%} = \frac{(C-A)}{(C-D)} * 100. \quad \ldots (5)$$

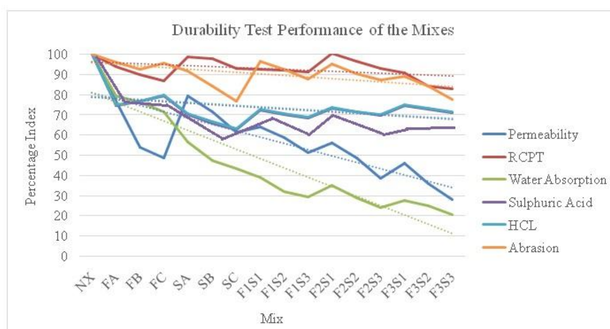

Fig 1 — Concrete - durability test performances of binary and tertiary replacement mixes

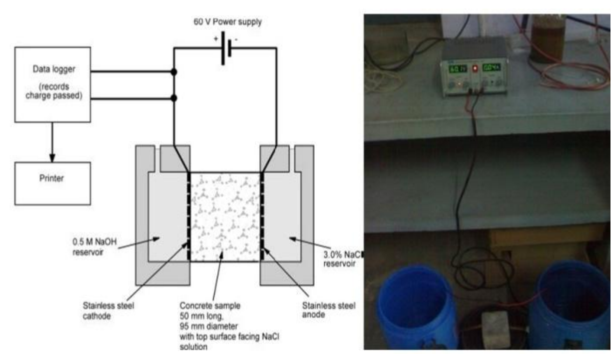

Fig 2 — Set up of the rapid chloride permeability test

The Abrasion resistance test was carried out as per ASTM C 418 by sand blasting technique. The Abrasion resistance is one of the most important tests for rigid pavement as a measure of durability. The deterioration of the concrete may occur by the movement of vehicles or load over the pavement surface by skidding, scraping or by abrasive process over the surface of the pavement. The abrasion resistance test was carried out on specimens of 70 mm x 70 mm x 35 mm by using abrasion testing machine. After 28 days curing of concrete, the specimens were taken and allowed to dry for about four hours, and the specimen thickness was measured accurately and kept in position on the abrasion testing machine. The machine was allowed to revolve for 300 revolutions; the speed of the machine was kept at 30 revolutions per minute (rpm). After completion of 300 revolutions, the specimen's thickness was measured. The average loss of the thickness was determined as shown in Figure 3.

Specimens used in the permeability test were 75 mm diameter and 75 mm length. The flexible sealing gum was used around the top perimeter of the sample to prevent water leakage along the sides of the specimen. The test was performed using several water heights as shown in Figure 4. The co-efficient of permeability (k) was determined by

$$K = (aL/At)\text{In}\,(h1/h2)\ . \qquad \text{... (6)}$$

where,
K= Co-efficient of permeability in cm/sec,
a= c/s area of stand pipe in cm^2,
L= Length of sample in cm,

Fig 3 — Specimens in the oven and in saturated conditions

Fig 4— Abrasion resistance test set up

A= c/s area of specimen in cm^2,
t= time in seconds from h1 to h2,
h1= initial water level in cm,
h2= final water level in cm.

Results and discussions

Durability tests

Rapid chloride penetration test (RCPT)

This experiment is to determine the resistance of concrete against the penetration of the chloride ions. The test is done by passing the charge through the samples which is a measure of electrical conductance. The blending of fly ash and silica fume in the concrete along with the various aggregate grading decreases the pore size and hence having a good repulsion of the chloride ion[21]. The value of the charge passed is recorded continuously for 6 h and readings were taken at the interval of every thirty minutes. By using the above equation (1) the total charge passed through the specimen is determined

The results of RCPT of specimen is taken at the age of 28 days. The RCPT tests were conducted for nominal mix for concrete and consequently the tests were done for the specimens whose components have been replaced by supplementary materials. The inclusion of the binary and tertiary mix decreases the void ratio and hence the permeability coefficient factor gets reduced considerably[22]. The specimens having the optimum value of strength and density are selected for conducting the RCPT tests.

The two factors which causes high conductivity are the age of the concrete and the particle size which are lesser than 38 µm[24]the physical properties of fly ash are included in Table 2. The increase in the fly ash shows a steady decrease in the charge conductivity. The conductivity is also a parameter to define the durability parameter of the concrete[25]. However, the replacement of two components in the sample does not create a considerable increase in the passing of charge, since the presence of silica fume and fly ash make the mix much resistance for the charge to pass due to the reduction of the permeability also the value of the charge passed stays behind the nominal mix as seen from Figure 5.

Saturated water absorption test

The concrete mix behaviour to the water absorption test is similar to that of the conventional concrete mix. But since the voids are of smaller diameter the capillary action of the concrete is reduced. Hence only small amount of water gets absorbed in the interior and exterior surface of the aggregates. The addition of the silica fume increases the bonding and decreases the voids and makes the specimen to be more water resistance against absorption. The addition of 10 % of the silica fume reduces the average saturated percentage of water absorption from 3.82 % to 2.16 %. On further increase of silica fume to 12 %, the average saturated water absorption gets even reduced to 1.9 % of the value of the nominal mix specimen.

On addition of fly ash the behaviour of the water absorption does not get varied notably[26]. The fly ash inclusion reduces the water absorption from 3.82 % to 3.04 % on 10 % replacement. Further increase of 5% of fly ash reduces the water absorption of the mix considerably as shown in Figure 6. The combination of two material replacements shows decrease in water absorption capability when compared to the nominal mix. Overall the water absorption percentage of optimum replacement mixes is found to be low than the nominal mix.

Fig 5— Permeability testing apparatus

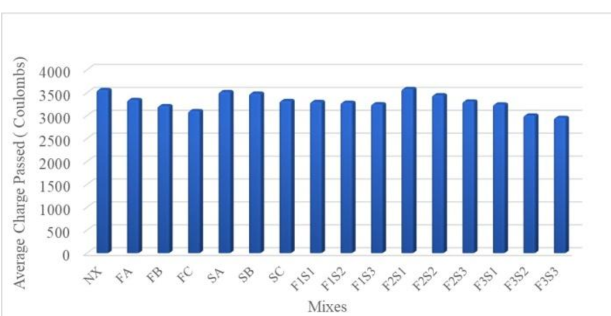

Fig 6 — Chloride ion permeability test for concrete

Acid resistance test

The cubes of 150 mm were taken after the age of 28 days. The loss of weight is measured in percentage for the optimum replaced mixes for concrete including the nominal mix for each type, respectively. For the acid resistance test three cubes of individual mix are immersed in the hydrochloric acid and also in sulphuric acid[27]. The weight loss in each is taken and the average weight loss is for concrete specimens.

It is observed from the Figure 7 and 8 that the loss of weight of the concrete mix is around 4 %. The replacement of cementitious material by 10 % and 12 % of silica fume has a reduction in the percentage of loss of weight. This shows that the silica fume creates a good bond between the particles and also a good resistance to the acid attack. The weight loss can be obtained upto 3 % for 12 % replacement of silica fume. Also, the addition of fly ash in 10 % to the cementitious material reduces the weight loss of

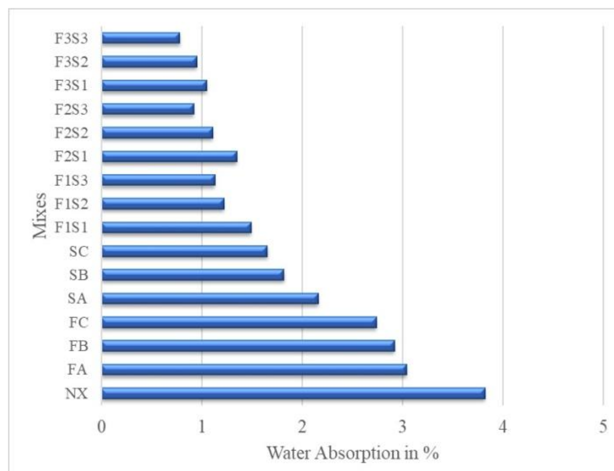

Fig 7 — Average saturated water absorption in percentage

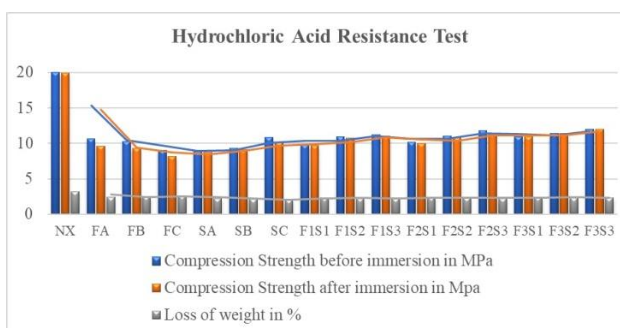

Fig 8 — Hydrochloric acid resistance test the specimen from 4 % of the nominal mix to 3 %. The fly ash which is a pozzolanic material creates a good repulsion to the chloride and sulphate molecules hence the addition of the fly ash to the concrete increases the durability against the attack of the acid[28]. The presence of silica fume and fly ash in the concrete mix resists the acid attack and this enhances the acid resistance of concrete specimens.

The compression test was carried out for the specimens immersed in the sulphuric acid at the age of 28 days[28]. The sulphuric acid has a little effect over the compression strength of the specimens. From the previous researches, it has been found that the compression strength of the specimens immersed in the sulphuric acid has a gain in strength over a long period of time as shown in Figure 9.

In the case of hydrochloric acid as seen in Figure 7, it has been found from the test that the hydrochloric acid has a mild affect over the specimens, when compared with the sulphuric acid immersed specimens. The loss of weight of the different mixes and their corresponding compression strength are shown in Figure 8. The presence of silica and fly ash retards the loss of weight of the specimens and induces a high resistance to the chloride ions attack

Abrasion resistance test

The tests result for concrete are given in Figure 10. The abrasion test is an important test regarding the pavement engineering[29]. The test samples are made from concrete as per ASTM C1747 / C1747M - 13

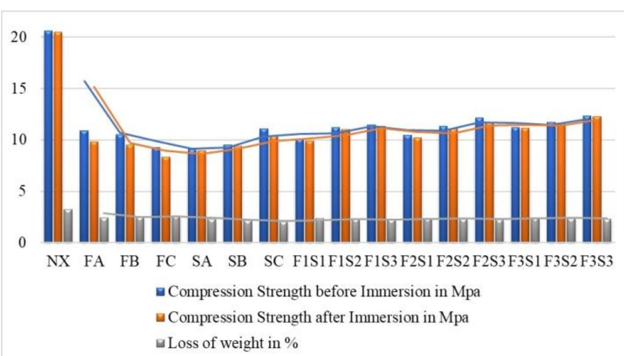

Fig 9 — Sulphuric Acid Resistance Test

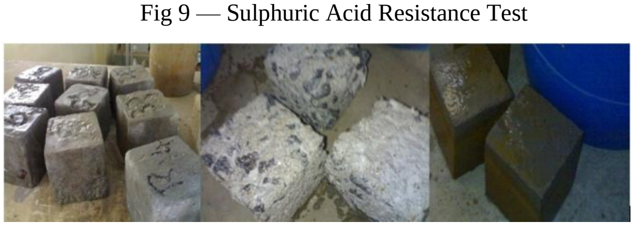

Fig 10 — Specimens before immersion and after immersion in the sulphuric acid and hydrochloric acid

For the case of concrete, the average loss of thickness is found to decrease when the increase in the silica replacement to that of the cementitious material, nearly 35 % increase in the abrasion is seen for the increase in 12 % of silica fume mix. The replacement of fly ash mix even though has good resistance against abrasion it does not have a high considerable decrease in the loss of thickness. The increase of the fly ash from10 % to 15 % shows decrease in the loss of thickness of the sample but after 15 % gradually the loss of thickness gets increased. It shows that beyond 15 % increase of the fly ash content has an impact of change in the abrasion value in the concrete as shown in Figure 10.

On two component replacements with silica fume and fly ash, the abrasion value nearly gets increased to 40 % of the abrasion value of the nominal mix. The replacement with fly ash and silica fume also shows a considerable reduction in the average loss of thickness value since the fly ash content is limited below 15 %. On two component replacement it can be seen that very high abrasion strength can be obtained as seen in Figure 10, because the silica fume offers a permissible abrasion resistance value as per ASTM C1747 / C1747M - 13. Since fly ash is also added in optimum quantity namely 15 % the mix gives a good result against abrasion.

Permeability test

Permeable pavements with a base and sub base that allow the movement of storm water through the surface. From the combined porosity profile and the analysis of the scanned image showed that on the surface of the pavement the most clogging can be seen[30]. In addition to reducing runoff, this effectively traps suspended solids and filters pollutants from the water. Permeability test is done with the cylinder 75 mmx 75 mm at the age of 28th day. The result briefs us about the permeability capacity for different mixes.

Good permeability was achieved for normal mix with 0.39 cm/sec. Gradual decrement of permeability was seen in the increment of fly ash. The permeability value is not affected by the presence for fly ash in the concrete up to the 50 % of the cement replacement while above 50 % of the cement replacement the nature of the concrete specimen gets slowed down causing the permeability to drop down.

The good infiltration rate also depends upon the soil structure of the area where the pavement is to be constructed[31]. The result as shown in Figure 11 proves

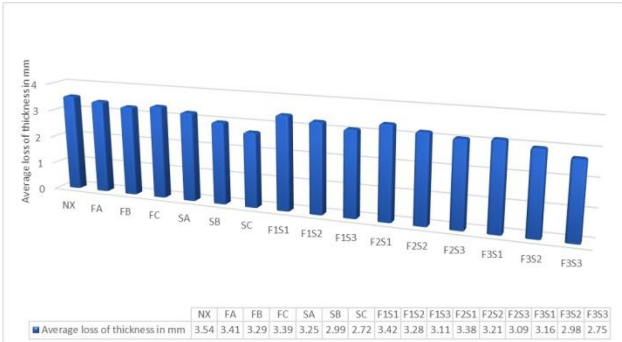

Fig 11 — Abrasion Resistance Test

Fig 12 — Permeability test comparison of all mixes

that if the permeability increases then the strength automatically decreases.

Suitability for marine construction

It has been seen from the results that the RCPT values which is the main suitability check for marine environment for concrete can be observed that by comparing the nominal mix with the replacement mixes. Since the sample is of concrete, the passing of the charge is relatively low when compared to the conventional mix. The pavement in the marine environment is highly affected by the environment factors and thus for has high chance of charge discharges[23]. The addition of silica fume increases silicon di oxide which reacts with calcium in cement and hydrogen from water to form calcium silicate hydrate which decreases the void content and increases the bonding. Hence the addition of silica fume decreases the average charge passing through the specimen, when the percentage of silica fume gets increased further the charge gets reduced. On addition of fly ash and silica fume in the mix the average charge passing gets reduced when compared with the nominal mix. Also, other durability properties are well within the permissible limit stating the use of the silica fume and fly ash blended concrete in the marine environment to be of high suitability.

Conclusion

The durability tests were conducted for the concrete mixes of control mix as well as single and double replacement mixes by using silica fume and fly ash, respectively. The results show sufficient increase in the durability property of the concrete when replaced with the supplementary materials and the following observations were made from the experiment results as shown in Figure 12

- For the rapid chloride penetration test the F3S3 posses the highest durability value when compared with all the mixes; nearly 20 % increase in resistance to chloride ions when compared with the nominal mix, the reason behind the increase in the value is due to the highest density obtained by replacing the silica fume and fly ash to a high extent causing the reduction in the penetration of chloride ions.
- The water absorption is found to decrease to a high extent when silica fume and fly ash is added to the mix. Even though the presence of fly ash in the mix reduces the water absorption percentage but to a minimum extent.
- The combination of the fly ash and the silica fumes in the mix causes more water repellent character to the mix and can be decreased nearly from 40 % to 50 % when compared to the nominal mix.
- Loss of weight of all the mixes subjected to acid attack does not have a much significance difference in their value at nearly around 5 % is the variation for all the mixes. However, the compression test values done on the cubes before and after immersion test results depicts that F1S3 and F3S3 mixes have no change in their compressive strength values due to the presence of high content of silica fume supplements the strength lost by adding the fly ash.
- The silica fume in the mix nearly enhances 30 % of the strength in the concrete mix
- SC mix containing silica fume of 12 % has the highest abrasion resistance value, when compared with all the mixes of 35 % more when compared to the nominal mix
- The concrete has generally less abrasion resistance due to the absence of fine aggregates. The addition of fly ash in the mix neither increase the abrasion resistance nor have a considerable reduction in the abrasion resistance value the deviation of the abrasion resistance is seen to vary

from 10 % to 35 % in overall replacement mix when compared with nominal mix.

- On replacement of fly ash and silica fume the permeability value decreases to a considerable amount. For the higher percentage replacement mixes the permeability value is found to decrease rapidly as the pores are getting reduced in the replacement concrete mixes
- For fly ash replacement from 10 % to 20 % the permeability value decreases from 30 % to 50 %. The F3S3 mix has the least permeability value of 70 % reduction when compared to the nominal mix due to decrease in the void ratio to a higher extent

Acknowledgement

The authors wish to acknowledge the help and support of Structural Engineering Laboratory Technician and usage of DST-FIST sponsored Universal Testing Machine of 3000 kN Capacity.

References

1 Dale P. Bentz, "Virtual Pervious Concrete: Microstructure, Percolation, and Permeability", *ACI Mat. J.*, 105(3), (2008), 297-301.

2 Xiang Shu, Baoshan Huang, HaoWu, Qiao Dong and Edwin G.Burdette "Performance comparison of laboratory and field produced pervious concrete mixtures", *J of Construction and Building Materials*, No. 8, (2011) 3187-3192

3 YeQing, Zhang Zenan, Kong Deyu and Chen Rongshen "Influence of nano-SiO2 addition on properties of hardened cement paste as compared with silica fume", *J. Const. Building Mat.*, 21(3), (2007) 539-545.

4 Prinya Chindaprasirt and Theerawat Sinsiri "Effect of fly ash fineness on compressive strength and pore size of blended cement paste", *J. Cement Conc. Comp.*, 24(4), (2005) 425-428.

5 Tae-HyunHa, Srinivasan Muralidharan, Jeong-HyoBae, Yoon-Cheol Ha, Hyun-GooLee, Kyung-WhaPark and Dae-KyeongKim "Accelerated short-term techniques to evaluate the corrosion performance of steel in fly ash blended concrete", *J. Build. Environ.*, 42(1), (2007) 78-85.

6 Edward G.Moffatt, Michael D.A.Thomas and Andrew Fahim "Performance of high-volume fly ash concrete in marine environment", *J. Cement Concrete Res.*, 102(2017) 127-135.

7 Cengiz Duran Atiş, "Heat evolution of high-volume fly ash concrete", *J. Cement conc res.*, 32(5), (2002) 751-756. https://doi.org/10.1016/S0008-8846(01)00755-4

8 Taylor-Lange, Sarah C, Stewart, Jane G, Juenger, Maria C G, Siegel and Jeffrey A. "The contribution of fly ash toward indoor radon pollution from concrete", *J. Build. Environ.*, 56(10), (2012) 276-282.

9 Muller A C A, Scrivener K L, Skibsted J, Gajewicz A M and McDonald P J "Influence of silica fume on the microstructure of cement pastes: New insights from 1H NMR relaxometry", *J. Cement Conc. Res.*, 74, (2015) 116-125

10 Villar-Cocina, E., Frias, M., Valencia Morales., Savastano, H., Study of the pozzolanic reaction kinetics in sugar cane bagasse–clay ash/calcium hydroxide system: kinetic parameters and pozzolanic activity, *Advances Cement Res.*, 21 (2009) 23–30

11 Xiang Shu, Baoshan Huang, HaoWu, Qiao Dong and Edwin G.Burdette "Performance comparison of laboratory and field produced pervious concrete mixtures", *J. Const. Build. Mat.*, 5(8), (2011) 3187-3192

12 TawatchaiTho-in,VanchaiSata, Prinya Chindaprasirt, and Chai Jaturapitakkul, "Pervious high-calcium fly ash geopolymer concrete", *J. Const. Build. Mat.*, 30, (2012) 366-371

13 JingYang and Guoliang Jiang,"Experimental study on properties of pervious concrete pavement materials", *J Cement Conc. Res.*, 33, No. 3, (2003) 381-386

14 Bradley Putman J and Andrew Neptune I, "Comparison of test specimen preparation techniques for pervious concrete pavements", *J. Const. Build. Mat.*, 25(8), (2011) 3480-3485

15 Baoshan Huang, Hao Wu, Xiang Shu and Edwin G. Burdette "Laboratoryevaluation of permeability and strength of polymer-modified pervious concrete", *J. Const. Build. Mat.*, 24, No. 5, (2010) 818-823

16 L. K. Crouch, P.E.; Jordan Pitt; and Ryan Hewitt, "Aggregate Effects on Pervious Portland Cement Concrete Static Modulus of Elasticity", *J. Mat. Civil Engg.*, 19, No. 5. (2007) 889-1561

17 An Cheng, Hui-Mi Hsu, Sao-Jeng Chao, and Kae-Long Lin, 'Experimental Study on Properties of Pervious Concrete Made with Recycled Aggregate', *Intl. J. Pave. Res. Technol.*, 4(2), (2011) 104-110

18 Chen yu, Wang ke-jin and Liang di 'Mechanical properties of pervious cement concrete', *J. Cent. South Univ*. 19 (2012) 3329−3334.

19 J Ramezanianpour A A and Malhotra V M, "Effect of curing on the compressive strength, resistance to chloride-ion penetration and porosity of concretes incorporating slag, fly ash or silica fume", *J. Cement Conc. Compos.*, 17(2), (1995) 125-133

20 Malhotra, V.M., No-Fines Concrete – Its Properties and Applications, *ACI J.*, November, 73(11), (1976) 628-644.

21 Marolf A,Neithalath N, Sell E, Wegner K, Weiss J, Olek J, 'The influence of aggregate size and gradation on acoustic absorption of enhanced porosity concrete', *ACI Mat. J.*, 101(1), (2004) 82–91.

22 VanchaiSata, AmpolWongsa and Prinya Chindaprasirt "Properties of pervious geopolymer concrete using recycled aggregates", *J. Cons. Build. Mat*., 42, (2013) 33-39

23 Betty Rushton, "Infiltration opportunities in parking lot designs reduce runoff and pollution", *Proc. of eventh Biennial Stormwater Research & Watershed Management Conference, Southwest Florida Water Management District, 2379 Broad St., Brooksville, FL* on May 22-23, (2002) 146-155

24 Masoud Kayhanian, Dane Anderson, John Harvey T, David Jones and Balasingam Muhunthan,"Permeability measurement and scan imaging to assess clogging of pervious concrete pavements in parking lots", *J. Environ. Management*, 95(1), (2012) 114-123

25 Kevern J, Wang T K and Schaefer V R "Effect of Coarse Aggregate on the Freeze-Thaw Durability of Pervious Concrete", *J. Mat. Civil Engg.*, 22, No 5 (2010) 469-475

26 Evangelista L and J.de Britob,"Mechanical behaviour of concrete made with fine recycled concrete aggregates", *J. Cement Conc. Composites*, 29 (5), (2007). 397-401.

27 Monteny J,Vincke E, Beeldens A, N De Belie, Taerwea J, Van Gemert D and Verstraete W, "Chemical, microbiological, and in situ test methods for biogenic sulfuric acid corrosion of concrete", *J. Cement Conc Res*, 30 (4), (2000) 623-634.

28 CaijunShi and Stegemann J A,"Acid corrosion resistance of different cementing materials", *J. Cement Conc. Res.*, 30(5), (2000) 803-808. https://doi.org/ 10.1016/ S0008-8846(00)00234-9

29 Hao Wu, Baoshan Huang, Xiang Shu and Qiao Dong, "Laboratory Evaluation of Abrasion Resistance of Portland Cement Pervious Concrete", *J. Mat. Civil Engg.*, 23(5), (2011) 697-702

30 S.O. Ajamu, A.A. Jimoh, J.R. Oluremi,'Evaluation of The Structural Performance of Pervious Concrete in Construction', *Intl. J. Engg. Technol.*, 2(5), (2012) 829-836

31 Bradley J.Putman and Andrew I.Neptune, "Comparison of test specimen preparation techniques for pervious concrete pavements", *J Cons. Build Mat.*, 25, No. 8. (2011) 3480-3485