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STRENGTH AND DURABILITY PROPERTIES OF HIGH PERFORMANCE CONCRETE WITH MANUFACTURED SAND

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ABSTRACT

The modernization of the construction sector led to the development of innovative materials in the last few decades. One such development is High Performance Concrete (HPC) and the HPC shall be produced by using silica fume. Another prime factor of concern is illegal sand mining which leads to the depletion of Natural Sand (N- Sand). Manufactured Sand (M-Sand) produced by the crushing of hard granite has been identified as a good substitute for natural sand. The main objective of this study is to check the strength and durability characteristics of HPC using M-Sand along with 5% silica fume. The natural sand was replaced by M-Sand on proportion of 0%, 20%, 40%, 60%, 80% and 100%. The compressive strength, flexural strength, splitting tensile and modulus of elasticity were studied. Similarly the durability properties like sorptivity and Rapid Chloride Permeability test were also conducted. The results indicated that a marginal increase in strength and durability properties of high performance concrete by addition of manufactured sand as a complete replacement of natural sand.

Keywords: high performance concrete, manufactured sand, natural sand, strength and durability.

INTRODUCTION

Concrete is a mixture of hydraulic cement, aggregates and water with or without admixtures, fibres or other cementations materials. Currently India has taken a major initiative on developing the infrastructures such as express highways, power projects and industrial structures, etc. In order to meet the requirements of globalization, in the construction of buildings and other structures the quality of concrete plays the rightful role and need for high performance concrete is vital. Since the boom of the construction sector, there has been a rapid depletion of natural resources mainly river sand [1]. Continuous extraction of natural sand from river beds leads to many environmental problems like bank slides, loss of vegetation on the banks of rivers, exposing the intake well of water supply schemes, disturbance to aquatic life , affecting agriculture due to lowering the underground water table etc. In order to balance this situation many alternative materials have been identified as a substitute for river sand [2, 3]. Some alternatives materials such as quarry rock dust, bottom ash, copper slag and foundry sand are used in concrete and mortar mixtures as a partial or full replacement of natural sand [4-7].

Amongst these materials, M-Sand presents to be a viable solution for the replacement of river sand [8, 9]. M-Sand is a crushed aggregate produced from hard granite stone which is rough, flaky shaped with sharp edges, washed and graded with consistency to be used as a substitute of river sand. The mechanical and durability properties of concrete incorporating M-sand is enhanced due to its filler content and interlocking effect between the particles [10-12]. On the contrary, the angular shape of the M-Sand particles tends to reduce the workability which can be improved by the use of water reducers and mineral admixtures [13, 14].

High Performance Concrete in general contains high powder content and mineral admixtures like GGBFS, fly ash, Met kaolin, Silica fume etc. The strength and durability properties of HPC are mainly affected by the use of these mineral admixtures mainly due to their filler effect and Pozzolonic reaction [15, 16]. Silica fume is a by product resulting from the manufacture of silicon and ferrosilicon alloys. Compared with other supplementary cementations materials the peculiar characteristics that make silica fume a very reactive pozzolona are its high SiO_2 content, its amorphous state and its extreme fineness improves strength and durability properties [17, 18].The replacement of cement by silica fume in the range of 5-10% with a smaller dosage of super plasticizer improve the workability and strength of concrete [19-21]. The researchers found that at 5-10% replacement of cement by silica fume with a smaller dosage of super plasticizer improve the workability and strength of concrete. In contrast, strength increases with silica fume addition but optimum replacement level was not constant and depends on water cementations ratio of the mix [22-25]. The addition of silica fume reduces the permeability of both cement paste and concretes, reduces the size of pores and porosities, resistance to aggressive environments. The inclusion of silica fume significantly increased the autogenously shrinkage of concrete due to the refinement of pore size distribution [26, 27].

Taking into consideration of the above mentioned points, this research work poses to use the manufactured sand as a replacement of natural sand in varying percentages (0%, 20%, 40%, 60%, 80% and 100%) which would be efficient in conserving the natural resources if adopted in the construction sector throughout the country and world. The cement was replaced by 5% of silica fume with the addition of super plasticizer equal to 1.5% by weight of binder (cement & silica fume).

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EXPERIMENTAL WORK

Materials

Cement

Ordinary Portland cement of 53 Grade was used and the specific gravity of cement was found to be 3.15. The physical and chemical properties of cement are presented in Table-1.

Silica fume

Silica fume was collected from ELKEN South Asia Pvt. Ltd. Mumbai, was named Elkem - Micro silica 920 D conforming to ASTM C1240 (1998) [28]. It is available in dry dignified form. The physical and chemical properties of cement and silica fume are also presented in Table-1.

Table-1. Physical and chemical properties of cement and silica fume.

Properties	Cement	Silica fume
Physical properties		
Specific gravity	3.15	2.2
Surface area, m^2/kg	320	20,000
Size, micron	-	0.1
Bulk density, kg/m	-	576
Initial setting Time (min)	45	-
Final setting Time(min)	375	-
Chemical properties, percentage		
SiO_2	90-96	20-25
Al_2O_3	0.5-0.8	4-8
MgO	0.5-1.5	0.1-3
Fe_2O_3	0.2-0.8	0.5-0.6
CaO	0.1-0.5	60-65
Na_2O	0.2-0.7	0.1-0.5
K_2O	0.4-1	0.4-1.3
Loss of Ignition	0.7-2.5	0.1-7.5

Fine aggregate

Natural Sand: Locally available natural sand was used.

Manufactured Sand: M- Sand was used as partial replacement of fine aggregate. It was collected from I Blue Minerals Pvt. Ltd. Karur, India. M-sand is manufactured by the use of crushing stone in a central crushing plant by making use of VSI (Vertical Shaft Impact) crusher. The unique design of the VSI crusher produces sand particles that are similar in shape to the natural sand. The plant contains Air Filter system and washing jets for sieving the manufactured sand particles and restricting the percentage of microfines passing through 150 micron below 10%.The sieve analysis results for N- Sand and M-Sand are presented in Table-2 along with IS 383-1970 (2002)[29] guidelines. The physical properties of Natural and M-Sand are presented in Table-3.

Table-2. Details of sieve analysis for river sand and M-sand.

Sieve size	N -Sand % passing	M-Sand % passing	IS Grading limits for Zone II
4.75mm	97	99.2	90-100
2.36mm	92.2	93.6	75-100
1.18mm	77	56.6	55-90
600μm	52.2	38.6	35-59
300 μm	10.6	18.4	8-30
150 μm	2	7.4	0-10
	Conforming to grading Zone II of IS 383		

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Table-3. Physical properties of river sand and M-sand.

Property	N-Sand	M-Sand
Fineness modulus	2.69	2.86
Bulk density(kg/m^3)	1726	1748
Specific gravity	2.63	2.65

The particle size distribution curve for various proportions of N-Sand and M-Sandis presented in Figure-1. The Scanning Electron Microscopy (SEM) image of M-sand shown in Figure-2 indicated angular shape and size distribution of the particles. The EDAX image of M-Sand presented in Figure-3 showed the chemical composition and also confirmed that Silica is the predominant compound similar to N-Sand particles.

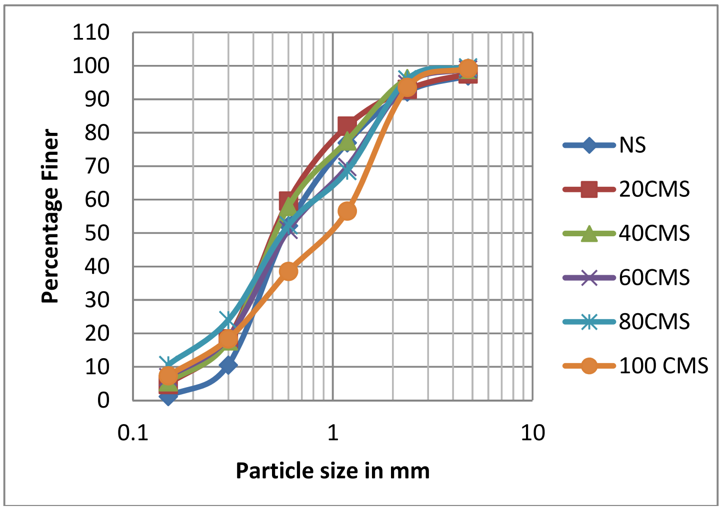

Figure-1. Particle distribution curve for N-Sand and M-Sand.

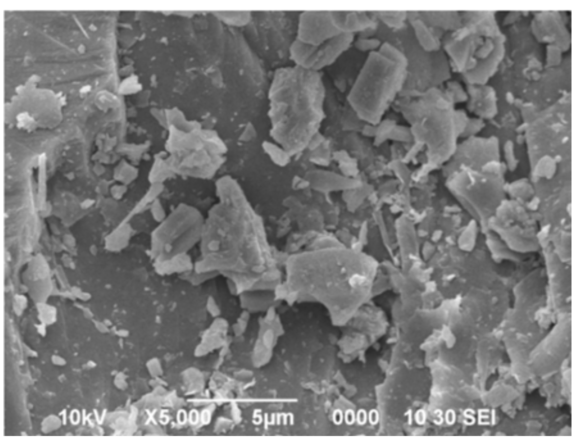

Figure-2. SEM image of M- Sand.

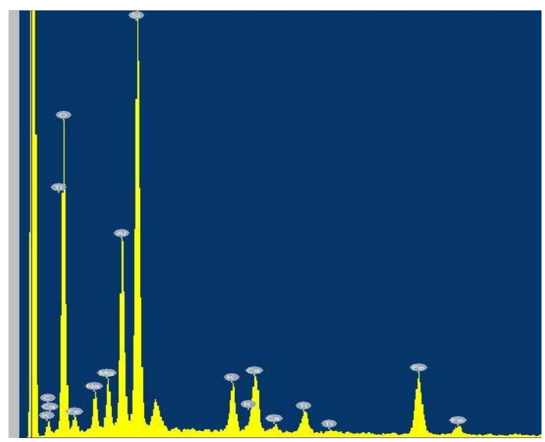

Figure-3. EDAX Image of M- Sand.

Coarse aggregate

Crushed, angular, graded coarse aggregates of nominal maximum size 12.5mm were used in the investigation. The specific gravity and the water absorption of the aggregates were 2.81 & and 0.6%, respectively. The bulk density of coarse aggregate was 1550 kg/m^3.

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Super plasticizer

In order to improve the workability of high-performance concrete, super plasticizer in the form of poly-carboxylic ether based superplasticizer (Glenium B233) was used as chemical admixture. The product has specific gravity of 1.09 and solid contents not less than 30% by weight.

Water

Fresh potable water, free from acid and organic substance, was used for mixing the concrete.

Mixture proportions and casting of specimen

A control concrete mixture (M-1) was designed as per as per the guidelines specified in ACI 211.4R-08 - "Guide for selecting proportions for high strength concrete with portland cement and other cementations materials"(2008) [30] to have 28 day compressive strength of 60 MPa. Five more concrete mixtures (M-2, M-3, M-4, M-5 and M-6) were made by replacement of N-Sand with M- Sand. Replacement percentages were 20, 40, 60, 80 and 100. The mix proportion chosen for this study is given in Table-4 with 5% silica fume replacement.

Table-4. Concrete mix proportions, with and without M-Sand.

Mix Identity	M-1	M-2	M-3	M-4	M-5	M-6
Cement(kg/m^3)	517.75	517.75	517.75	517.75	517.75	517.75
Silica fume (kg/m^3)	27.25	27.25	27.25	27.25	27.25	27.25
Natural Sand (kg/m^3)	605	484	363	242	121	0
M-Sand (%)	0	20	40	60	80	100
M-Sand(kg/m^3)	0	121	242	363	484	605
Coarse Aggregate(kg/m^3)	1137	1137	1137	1137	1137	1137
Water(kg/m^3)	175	175	175	175	175	175
W/B Ratio	0.32	0.32	0.32	0.32	0.32	0.32
SP Dosage (%)	1.5	1.5	1.5	1.5	1.5	1.5
SP(l/m^3)	8.175	8.175	8.175	8.175	8.175	8.175

Mix design and sample preparation

The quantities of cement, natural sand /M-Sand, coarse aggregate and silica fume, for each proportion were measured and homogeneous mixing of the above was achieved by means of pan mixer. The fresh concrete was casted and it was compacted by table vibrator. The water to binder ratio was kept as 0.32 and the dosage of super plasticizer was 1.5% by weight of binder (Cement + Silica fume). All freshly cast specimens were left in the moulds for 24 hours before being remoulding. The remoulded specimens were cured in water until the required test date. To determine the compressive strength, twelve cubes (150 mm X 150 mm X150 mm) were cast for each mix and three samples were tested after 3,7,14 and 28-days of curing. Three 150 mm diameter X300 mm long cylinders were prepared for each mix in order to determine the 28- day split tensile strength of concrete. Also, to determine the flexural strength for each mix, three 100 mm X100 mm X500 mm prisms were cast and tested after 28-days of curing. Two (150 mm X150 mm X150 mm) cubes were prepared and tested after 28-days in order to assess the durability of the HPC using Sorptivity test. Two (150 mm diameter X 300 mm) cylinders were cast for Rapid Chloride Penetration Test (RCPT).

Testing procedure

After curing, the following tests were carried out on the concrete specimens:

Compressive strength test was conducted at the age of 3,7,14 and 28-day in accordance with IS 1881: Part 116(1983) [31] using a loading rate of 140 kg/cm^2 per minute till the specimens fails. Test was conducted using AIMIL Compression Testing Machine (CTM) of capacity 2000KN. Split tensile strength of concrete was carried out conforming to IS: 516(1959) [32], cylinders were tested using above machine. Flexural strength of concrete was carried out conforming to IS: 516(1959) [32], beams were tested using Flexure Testing Machine (FTM) of capacity 100KN.The sorptivity test measures capillary suction of concrete when it comes in contact with water. The test was conducted on 150mm cube specimens in accordance with the ASTM C 1585 (2006) [33]. Two specimens were cured under water for 28 days and tested at 28 days and 90 days of age. The specimens were oven dried until constant weight and then put in contact with water in one surface and sealing the other surfaces. Mass gain due to sorption was measured at definite intervals for the first six hours. The sorptivity S is the slope of the best-fit line to the plot of absorption against square root of time.

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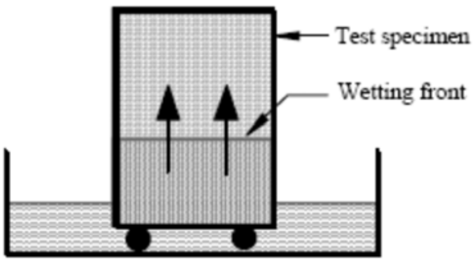

Figure-4. Set up for sorptivity

The rapid chloride permeability test was conducted to assess the concrete equality as per ASTM C 1202 (1997) [34]. A potential difference of 60 V DC was maintained across the specimen. One of the surfaces was in contact in a sodium chloride solution (NaCl) and the other with a sodium hydroxide solution (NaOH). The total charge passing through 30 minutes interval for the duration of six hours was measured, indicating the degree of resistance of the specimen to chloride ion penetration.

The total charge passed during this period was calculated by

Q = $900 (I_0 + 2 I_{30} + 2 I_{60} + \ldots\ldots\ldots + 2 I_{330} + I_{360})$

where,

Q = charge passed (coulombs)
I_0 = current (amperes) immediately after voltage is applied, and
It = current (amperes) at't' minutes after voltage is applied.

Figure-5. RCPT Test setup.

RESULTS AND DISCUSSIONS

Compressive strength

Compressive strength results of concrete mixtures with and without manufactured sand at the age of 3, 7, 14 and 28 days are shown in Figure-6. It could be observed that a concrete mixture made with manufactured sand (20 - 100%) shows higher compressive strength than control concrete at all ages. Compressive strength of control mix was 43.22 N/mm^2 at 7 days. From the results, it was found that 7days compressive strength increased by 14.13%, for the mix M-6 (100% M Sand) than control mix M-1 (0% M-Sand) and the 28 days compressive strength increased by 8.22%, than control mix M-1.

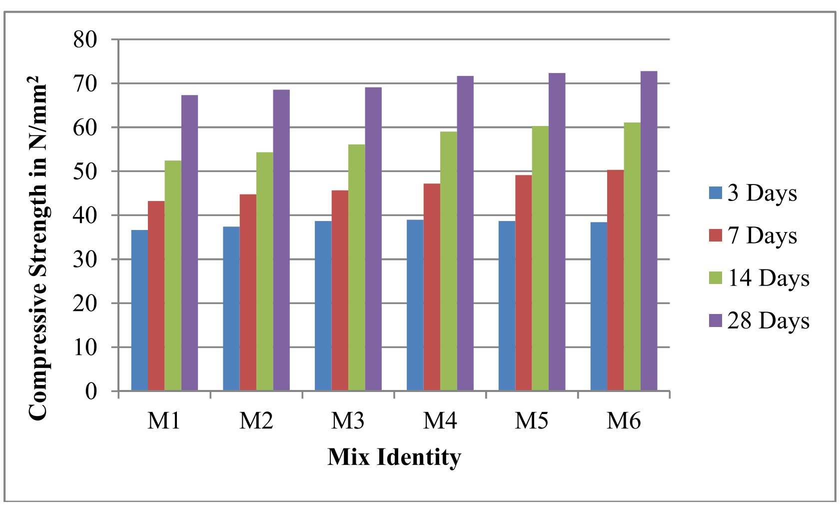

Figure-6. Compressive strength of concrete.

The compressive strength of concrete increased with the increase in manufactured sand and the maximum strength was obtained for 100% manufactured sand. This is the main reason for the increase in strength since it is attributed by the formation of water cement gel in matrix due to the excellent bonding of coarse and fine aggregates. The presence of high fines in M Sand increases the water demand. However, the M Sand fines contribute to an

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increase in paste volume which is strengthened by the incorporation of silica fume and Super plasticizer. The addition of silica fume strengthens the weak interfacial transition zone by strengthening the bond between the cement paste and aggregate leading to the formation of a more dense and homogenous microstructure of the transition zone. The study concluded that the concrete with manufactured sand had lower early strengths at w/c of 0.32 and that the strengths of mixtures were higher than the control specimens when replaced with 100% manufactured sand when combined with 5% silica fume and super plasticizer. The above observations are supported by the work of other researchers who studied the influence of manufactured sand as fine aggregate on the strength of high-performance concrete. Similar observations were made by Elavenil *et al* (2013) and Balapgol *et al* (2002) found that there is an increase in compressive strength by use of manufactured sand about 5 to 10% compared to natural sand for M 40 grade concrete [11, 35].

Split tensile strength and flexural strength

The split tensile and flexural strength results are presented in Figure-7. The split tensile strength is increasing with the increasing percentage of M-Sand. The split tensile strength is observed as 4.56 N/mm^2 for 0% M-Sand with 5 % silica fume and 5.62 N/mm^2 for the same percentage of silica fume and 100% M-Sand. There is an increase in split tensile strength by over 16% by using M-Sand. Previous researchers reported that the splitting tensile strength increased with inclusion of crushed stone aggregate in concrete due to better binding effect of manufactured sand and silica fume with the available cement paste and aggregate[37, 38].

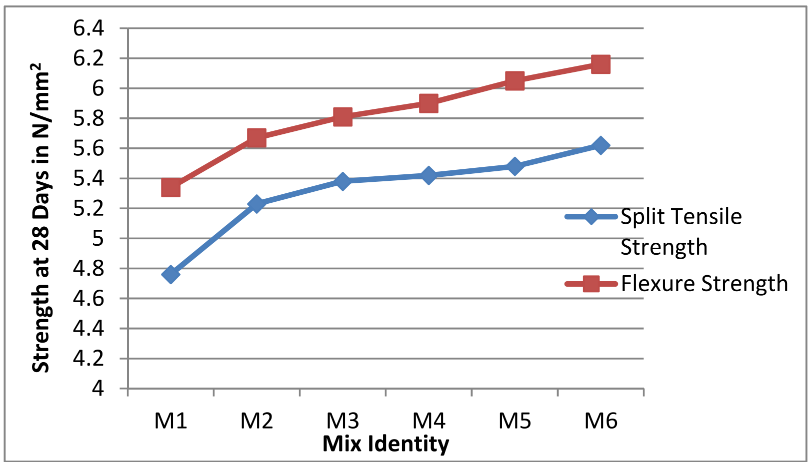

Figure-7. Split tensile and flexure strength of concrete.

The flexural strength of Mix M1 (0% MS) to M6 (100%MS) specimens was varied from 5.34MPa to 6.16 MPa. The increase in flexural strength can be explained by the fact that the presence of M-Sand and silica fume results in a much denser matrix. The increase in the denseness of the matrix possibly provides as much improvement in bond between the aggregate and cement paste. The maximum percentage increase in flexural strength is observed as 14% with 100% M-Sand. For similar beam size, the flexural strength results obtained for manufactured sand based normal strength concrete presented by various researchers. They concluded that the flexural strength of concrete with crushed sand was marginally increased about 1 to 5% as compared to natural sand [9]. The increase in the split tensile strength and flexure strength of HPC specimens with manufactured sand are increased due to the filling effect of the fine particles of manufactured sand in the micro-voids of concrete as discussed earlier [35, 36].

Modulus of elasticity

Modulus of elasticity was investigated at the age of 28 days, and test results are shown in Figure-8. It is evident that, Modulus of elasticity of control concrete mixture (M-1) without M-Sand was 32.3GPa. The increase in Modulus of Elasticity is 3.8%, 4.3%, 4.6%, 5% and 7.3% for M-2, M-3, M-4, M-5and M-6 respectively than control concrete mix (M-1). According to Guney *et al.* (2010) concrete exhibited similar modulus of elasticity as that of control concrete mixture at 100% replacement of natural sand with manufactured sand [39].

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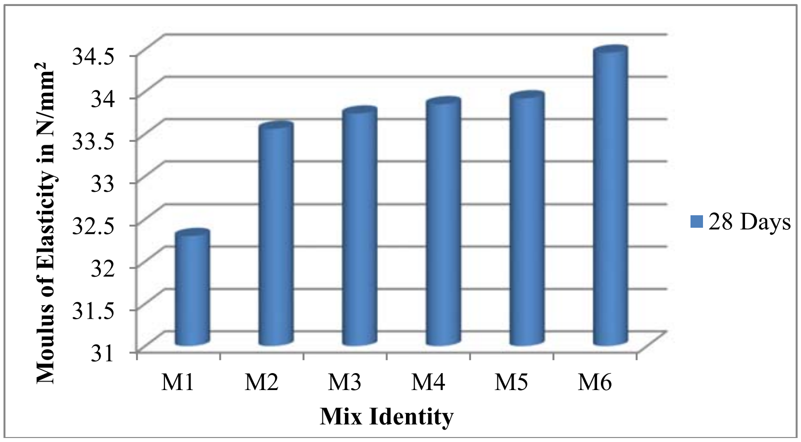

Figure-8. Modulus of elasticity of concrete.

Sorptivity

The sorptivity test results are shown in Figure-9. It can be seen that, the manufactured sand high performance concrete exhibits lower sorptivity values compared to N-Sand concrete in presence of silica fume. The sorptivity decreased with the increase of M-Sand content. The sorptivity value of natural sand concrete was 14 X 10^{-6} ($m/s^{0.5}$) and manufactured sand was 6.06 X 10^{-6}($m/s^{0.5}$), it was 56% lower than the N-Sand concrete at 28 days. After 90 days, sorptivity dropped by 53% of the control concrete, value of10.5 X 10^{-6}($m/s^{0.5}$) N-Sand Concrete and 4.86 X 10^{-6} ($m/s^{0.5}$) for M-Sand Concrete.

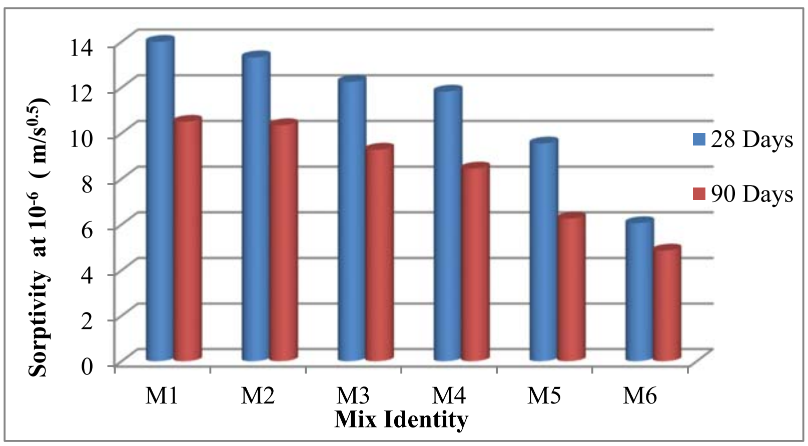

Figure-9. Effect of M-sand on sorptivity.

Manufactured sand addition seems to affect in a positive way the water absorption of concrete. It is noteworthy that the sorptivity coefficient evaluates the presence of larger capillary pores which may be formed by the increased w/c ratio of the concrete. And the results have shown significant reduction of capillary suction due to inclusion of manufactured sand. Similar results were reported by Ganesan *et al*, [40]. The sorptivity valve of rice husk ash high performance concretes varies from 5.33 to 11.0510^{-6} ($m/s^{0.5}$).

Mix	Sorptivity at 10-6 (m/s0.5)	
	28 Days	90 Days
M1	14	10.5
M2	13.32	10.35
M3	12.25	9.28
M4	11.82	8.45
M5	9.55	6.26
M6	6.06	4.86

Rapid chloride permeability test

The permeability of concrete to the penetration of chloride ions is an important parameter influencing the durability properties. The presence of chloride ion in concrete adversely affects the concrete as well as reinforcement. The ingression of these chlorine ions leads the expansion of concrete by 2 to 2.5 times than that caused by the penetration of water. This test is conducted to evaluate the resistance of concrete to chloride ion penetration as shown in Figure-10.

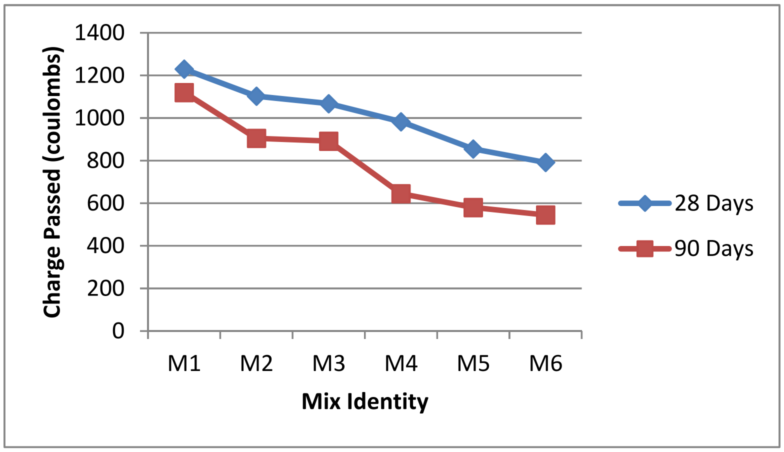

Figure-10. Effect of M-sand on chloride ion permeability.

From the results, it can be seen that the charge passed to concrete decreases with the increase of manufactured sand at the age of 28 and 90 days. All the values obtained were between 100 and 1000 and hence the chloride ion permeability is very low as per the code. The important observation is that, addition of M-sand in concrete up to 30% of the fine aggregates will definitely help to reduce the pores of the concrete and makes it more impermeable (makes concrete less permeable to chloride ions). At the age of 28 days up to 40% replacement of M-Sand by N-Sand achieved low level of chloride ion penetration. For other replacements (60%, 80% and 100%) it achieved very Low level of chloride ion penetration. At 90 days of age, all replacement levels manufactured sand in high performance concretes show every low level of chloride ion penetration in contrast to the low level of the corresponding control concretes at the same age. This results revealed that the decrease in chloride ion penetration is due to the less pores in manufactured sand High Performance Concrete. Similar results were reported by Shanmugavadivu *et al*, (2012). They found that the Chloride ion penetration is lower in manufactured sand concrete compared to concrete made with natural sand for M20 grade Concrete [41].

CONCLUSIONS

The tests were performed to determine the strength and durability properties of High Performance Concrete mixes and the following conclusions could be drawn.

- From the mechanical properties (compressive, split tensile, flexural and Modulus of Elasticity) there is an increase in strength properties for high performance concrete with 5% silica fume and 100% manufactured sand.
- Inclusion of M - Sand decreased the value of Sorptivity and chloride ion penetration in high performance concrete, which indicates that concrete, has become denser and impermeable.
- Industrial by products silica fume and manufactured sand can be advantageously used in producing High Performance concrete.
- Manufactured Sand can be suitably used in making structural grade concrete by replaced 100% with natural sand.

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