

# Performance Characteristics of Blended Cement

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**Abstract:** Recent developments in civil engineering such as high-rise buildings and long-span bridges for which higher compressive strength concrete was the need of time. Currently, high-performance concrete is used in massive volumes due to its technical and economic advantages. This study focuses on the strength performance of concrete with metakaolin, silica fume and its blend. Cement replacements by 5%, 10%, 15%, 20% with metakaolin, silica fume and its blend were studied. Concrete tests were conducted on the concrete samples at the specific ages. The comparison was made on the compressive strength performance of metakaolin, silica fume concrete and also its durability to acid resistance.

**Keywords:** Blended cement, silica fume, metakaolin, compressive strength, durability

## I. INTRODUCTION

With a fast population growth and a higher demand for housing and infrastructure, accompanied by recent developments in civil engineering, such as high-rise buildings and long-span bridges, higher compressive strength concrete was the need of time. High performance concrete was proposed and widely studied at the end of the last century. Currently, high-performance concrete is used in massive volumes due to its technical and economic advantages. Such materials are characterized by improved mechanical and durability properties resulting from the use of chemical and mineral admixtures as well as specialized production processes. Pozzolanic additives are the materials or admixtures that can improve concrete properties such as concrete strength, durability and impermeability. They are used either as partial substitutes of Portland cement or as an addition. The main component of pozzolanic additives is usually active  $\text{SiO}_2$  in the amorphous phase. Pozzolanic reaction is a simple acid-based reaction between calcium hydroxide ( $\text{Ca}(\text{OH})_2$ ) and silicium acid ( $\text{H}_4\text{SiO}_4$ ). The current pozzolans in use are such as fly ash, silica fume and slag. This study focuses on the strength performance of concrete with metakaolin, silica fume and its blend. A strength characteristic is important because it is related to several other important properties which are more difficult to measure directly. Cement replacements by 5%, 10%, 15%, 20% with metakaolin, silica fume and its blend were studied. Concrete tests were conducted on the concrete samples at the specific ages. All the strength tests are limited to the ages of 28 days. The cubes were also being tested to know their durability behavior.

## II. CEMENT REPLACING MATERIALS USED FOR INVESTIGATION

### A. Silica Fume

Silica fume, also referred to as microsilica or condensed silica fume, is a byproduct material that is used as a pozzolana. This byproduct is a result of the reduction of high-purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume rises as an oxidized vapor from the 2000°C (3630°F) furnaces. When it cools it condenses and is collected in huge cloth bags. The condensed silica fume is then processed to remove impurities and to control particle size. Condensed silica fume is essentially silicon dioxide (usually more than 85%) in noncrystalline (amorphous) form. Since it is an airborne material like fly ash, it has a spherical shape. It is extremely fine with particles less than 1  $\mu\text{m}$  in diameter and with an average diameter of about 0.1  $\mu\text{m}$ , about 100 times smaller than average cement particles. The relative density of silica fume is generally in the range of 2.20 to 2.5. Portland cement has a relative density of about 3.15. The bulk density (uncompacted unit weight) of silica fume varies from 130 to 430  $\text{kg/m}^3$  (8 to 27  $\text{lb/ft}^3$ ). Silica fume is sold in powder form but is more commonly available in a liquid. Silica fume is used in amounts between 5% and 10% by mass of the total cementitious material. It is used in applications

where a high degree of impermeability is needed and in high strength concrete. With the addition of silica fume, the slump loss with time is proportionally increased in concrete mix. Due to the high surface area of silica fume particles in the concrete mix, workability and consistency of concrete decrease.

*I) Effect of silica fume on strength, on chemical, on durability:* Increase in compressive strength by using silica fume also results an increase in the tensile and flexural strength. Increased tensile strength causes a possible reduction in slab thickness while maintaining high compressive strengths. Hence, it reduces the overall slab weight and cost. Research has shown that addition of silica fume decreases efflorescence due to the refined pore structure and increased consumption of the calcium hydroxide. The addition of untreated silica fume to steel reinforced concrete enhances the corrosion resistance of the reinforcing steel. Silica fume decreases bleeding significantly. The durability of silica fume concrete to freeze thaw is normally satisfactory at silica fume content of less than 20%. The addition of silica fume to mortar enhances the freeze-thaw durability in spite of the poor air void system. The permeability of chloride ions in concrete reduces by the addition of untreated silica fume.

#### B. Metakaolin

Kaolinite is the clay minerals which provide the plasticity of the raw material and change during firing to produce a permanent material. Kaolin is a phyllosilicate, consisting of alternate layers of silica and alumina in tetrahedral and octahedral coordination. Kaolinite is the mineralogical term for hydrated aluminum disilicate,  $Al_2Si_2O_5(OH)_4$ , the primary constituent of kaolin (40-70%). Other minerals comprising kaolin include quartz, muscovite-like micas, and rutile.

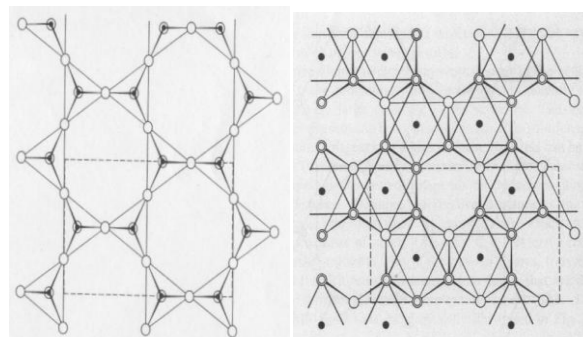


Fig.1 Atomic arrangements of (a)  $Si_2O_5$  and (b)  $AlO(OH)_2$

Metakaolin is usually produced by thermal treatment, *i.e.*, calcination of kaolin clays within a definite temperature range. The main process important for production high reactivity pozzolana from kaolin clay is calcination. The heating process drives off water from the mineral kaolinite ( $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ ), the main constituent of kaolin clay, and collapses the material structure, resulting in an amorphous aluminosilicate ( $Al_2O_3 \cdot 2SiO_2$ ), metakaolinite.

*I) Effect of metakaolin on workability:* Workability of concrete decreases as percentage of metakaolin or silica fume increases from 5% to 11% at intervals of 2% by replacement in OPC. By adding 10% activated flyash in both the mixes of silica fume and metakaoline workability is improved.

*II) Effect of metakaolin on strength:* Calcium hydroxide accounts for up to 25% of the hydrated Portland cement, and calcium hydroxide does not contribute to the concrete's strength or durability. Metakaolin combines with the calcium hydroxide to produce additional cementing compounds, the material responsible for holding concrete together. Less calcium hydroxide and more cementing compounds means stronger concrete. Metakaolin, because it is very fine and highly reactive, gives fresh concrete a creamy, nonsticky texture that makes finishing easier. Metakaolin aggressively consumes calcium hydroxide.

**III. TESTS AND EXPERIMENTAL WORK DONE**

Other than the two pozzolanic materials the materials used were, Cement, Aggregates – fine and coarse, Water as per the mix design. Tests on each of the above materials were conducted and there results were obtained as given,

*A. Tests on Cement*

1. Fineness test
2. Standard Consistency
3. Initial and Final setting time

Table. I. Physical Characteristics of Cement

Sr. No.	Property	Result	Permissible limit as per IS:12269
1.	Normal consistency	36 %	-----
2.	Initial setting time	200min	>30 min
3.	Final setting time	500min	< 600 min
4.	Fineness modulus	98% passes through 90 micron sieve	-----

Ordinary Portland cement of 53 grade conforming to IS: 12269 – 1987 being used for the experimental investigation. The specific gravity of cement is 3.10

*B. Tests on Aggregates*

1. Aggregate impact value
2. Aggregate Crushing Value
3. Shape Test
4. Specific Gravity
5. Moisture content of aggregates
6. Los Angeles Abrasion Value

Table.II. Physical property of fine aggregate, coarse aggregate

Sr. No.	Property	Fine Aggregate	Coarse Aggregate
1	Fineness Modulus	94% finer than 4.75mm	12.5mm , 20mm
2	Specific Gravity	2.50	2.68
3	Crushing Value	NA	16.5
4	Impact Value	NA	5.6
5	Abrasion Value	NA	23.16

Table.III. Physical and chemical characteristics of materials used

Physical property	OPC	Silica fume	Metakaolin
Specific gravity	3.1	2.2	2.54
Mean grain size (µm)	22.5	0.15	2.54
Specific area cm <sup>2</sup> /gm	3250	150000-300000	150000-180000
Colour	Grayish	White	Pinkish
Chemical property	OPC	Silica fume	Metakaolin

Silicon dioxide (SiO <sub>2</sub> )	20.25	85	60-65
Calcium oxide (CaO)	63.61	0.2-0.8	0.2-0.8
Magnesium oxide (MgO)	4.56	0.2-0.8	0.2-0.8
Sodium oxide (Na <sub>2</sub> O)	0.08	0.5-1.2	0.5-1.2
Potassium oxide (K <sub>2</sub> O)	0.51		
Loss on ignition	3.12	<6.0	<1.4

In this study, the early age properties of fresh concrete and mechanical performance and durability of hardened concrete were examined. All tests were conducted using the following sample groups:

1. Ordinary cement paste or concrete,
2. Concrete substituted with 10% MK by mass.
3. Concrete substituted with 10% silica fume by mass.
4. Concrete substituted with 5% silica fume by mass and 5% MK by mass.
5. Concrete substituted with 5% silica fume by mass and 10% MK by mass.
6. Concrete substituted with 5% silica fume by mass and 15% MK by mass.
7. Concrete substituted with 5% silica fume by mass and 20% MK by mass

#### IV.RESULT AND DISCUSSION

Results of fresh and hardened concrete with partial replacement of silica fume and metakaolin in combination are discussed in comparison with those of normal concrete. For the above combinations of concrete mixes three cubes were being casted each for varying curing days of 3,7,28 days. Tests for the same being conducted under compressive testing machine of capacity 2000KN

Table. IV. Compressive & tensile strength of the cubes casted.

Replacement levels(%)		Compressive Strength (MPa)			Split Tensile test results
SF	MK	3 days	7 days	28 days	
0	0	30.88	36.77	42.33	4.157
0	10	29.77	32.67	41.56	3.289
10	0	29.64	32.11	39.11	4.67
5	5	26.97	31.20	46.22	2.55
5	10	26.67	34.89	47.56	4.16
5	15	29.67	35.36	52.11	3.86
5	20	26.03	33.46	41.67	3.67

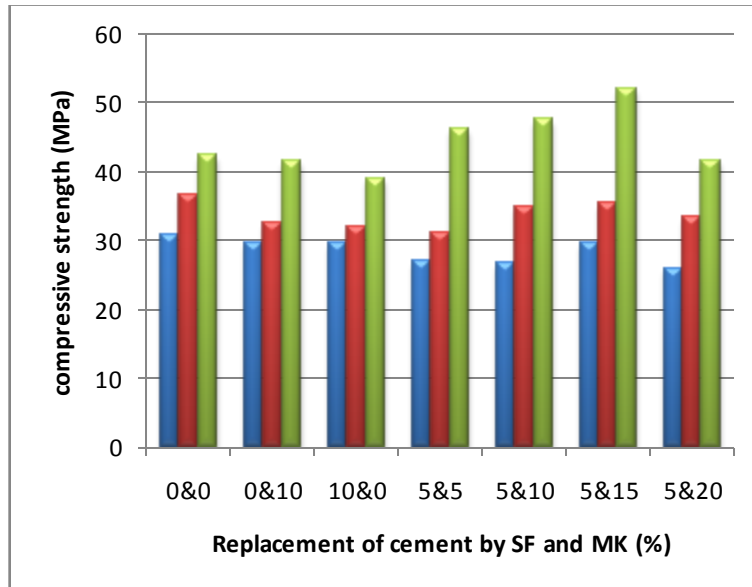


Fig.2. Graph on effect on compressive strength as per curing days on various % of cement replacement

*A. Experimental Investigation for Durability concepts regarding Acid Attack on Concrete*

The materials used for this purpose is as listed above in and tested as per the code provisions made in the above clauses. Even the mixes and mix proportion made according to the requirement is also mentioned in the above clause. BIS code procedure as per IS: 10262-1982 was followed for finding the mix proportions of all the concrete specimens. Water binder ratio was considered as 0.4 to the optimum.

*B. Testing methods for durability assessment:*

*I. Mass loss:*

Table V. Effect of acid solution on concrete by loss of mass

Mix Designation	Concrete Grade	Loss of mass of concrete due to acidic reaction (%)
OPC	M40	7.085
OPC+10%MK	M40	4.439
OPC+10%SF	M40	4.302
5%SF+5%MK	M40	4.152
5%SF+10%MK	M40	3.529
5%SF+15%MK	M40	3.931
5%SF+20%MK	M40	4.439

1. The OPC mix suffered the most deterioration in terms of mass loss when immersed in 5% HCl solutions. The mass loss at 30 days cured M40 grade PCC specimens was 7.085% reaches the 10% loss level within two weeks of immersion period in 5% H<sub>2</sub>SO<sub>4</sub>. During the curing period, level of mass loss increases and it shows that the hydration process of cementitious materials was not fully completed within 28 days curing.
2. The development of blended concrete with upto 20% MK replacement level reduces the mass losses considerably. The mass loss of specimens was approximately reduces 30%–40% mass loss of PCC when immersed in 5% HCl

solutions. The minimum mass loss was observed in 5%SF+10%MK concrete only. The M40 grade specimens were shown only less than 10% mass loss within the observation period of 4 weeks.

- The results show that the resistance against the acid attack increased when cement replaced by SF and MK and the main reason for the increased acid resistance of blended concrete investigated was the formation of dense hardened cement paste and aggregate interface with low porosities.
- The formation of unstable ettringite causes the concrete matrix to be more porous and susceptible to the acid attack through the capillary pores.

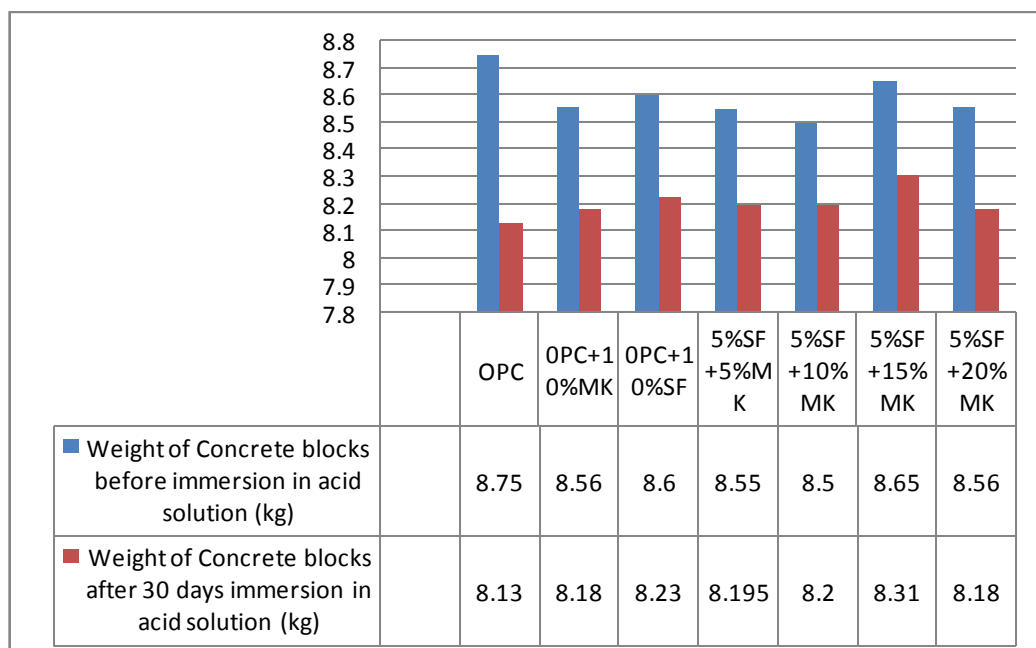


Fig. 3. Graph on loss of mass in acid solution

II. *Strength deterioration factor (SDF):*

Table VI. Effect of acid solution on concrete by strength loss

Mix Designation	Concrete Grade	Loss of compressive strength of concrete due to acidic reaction (%)
OPC	M40	23.36
OPC+10%MK	M40	13.90
OPC+10%SF	M40	10.20
5%SF+5%MK	M40	21.16
5%SF+10%MK	M40	7.48
5%SF+15%MK	M40	15.56
5%SF+20%MK	M40	18.93

- The reduction of compressive strength due to acid attack was expressed in the form of strength deterioration factor (SDF). Figures above show the SDF at 30 days cured specimens of M40 grade concrete immersed in 5% HCl solution.
- The PCC specimens are severely affected the acid attack and hence the SDF values of PCC specimens were more than 23%. The rate of change SDF for PCC specimen was observed as rapid change up to 4 weeks of immersion period. The SDF for 5% HCl were shown in figures above.

3. Meantime the minimum SDF value of 7.48% was observed in 28 days cured M40 grade concrete after the immersion period of 4 weeks. The addition of SF and MK in concrete specimens consumes  $\text{Ca}(\text{OH})_2$  and develop the secondary hydration products (C-S-H gel) which reduces the micro pores of concrete and makes dense concrete mass.
4. The ternary blended concrete specimens are less affected than that of the binary and control concrete mixes immersed in 5% HCl solutions. The presence of SF offered the resistance against permeability during early ages and the MK contents prevents the entry of acidic solutions during the latter ages. The ternary blended combination increases the impermeability of concrete in the higher order and hence the observed SDF values were very less than that of the other mixes.

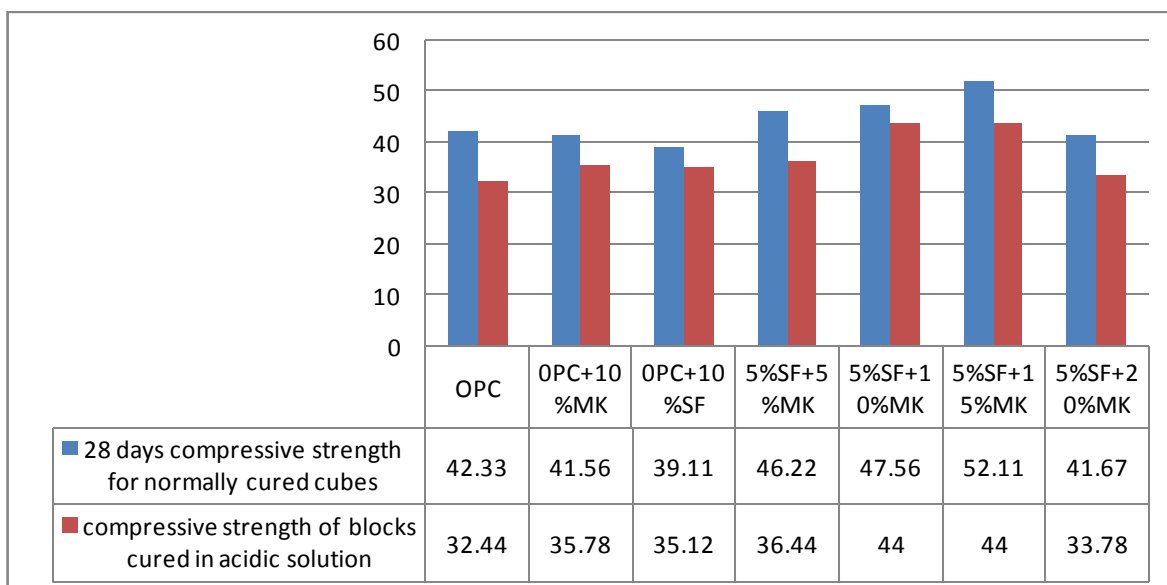


Fig. 4. Graph on Strength deterioration of concrete in acid solution

### V.CONCLUSION

1. From above graphs the conventional curing for 28 days has shown that the optimum results are obtained at replacement of cement by 5% SF and 15% MK by weight of cement achieves highest strength.
2. Regarding split tensile strength still PCC holds good results but it is seen that at metakaolin replacement tensile strength can be improved.
3. Silica fume being finer holds good results against permeability and had shown good consistency results.
4. The PCC specimens of M40 grade concrete were severely deteriorated after immersion in 5% HCl solutions up to 4 weeks.
5. The mass loss within the concrete was the maximum for OPC condition where as moderate for the binary and least for the ternary conditions.
6. Thus as the acid concentration was being maintained throughout the immersion period of 4 weeks in HCl solution still it shows appropriate mass loss and strength deterioration.
7. Even during strength deterioration the most drastically affected was the OPC cubes where as the least affected were the ternary cubes.
8. Thus it proves that when cement is blended with certain pozzolanic materials it gives better results against durability and is safer than the normal cement concrete.

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