

# Experimental Investigation on Partial Replacement of Cement with Metakaoline, Fly Ash and Silica Fume in Concrete

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**Abstract.** The process of construction begins some thousand years ago and the monuments that we are seeing are the proof for that. The materials that are being used in the construction some thousand years ago are not the same which are being used nowadays. The construction materials get modified and new inventions are taking place due to the continuous research. The scope of this project is to make building materials sustainable and to make them eco-friendly. In the olden days lime was used as a mortar and now it's being replaced by cement. But still research is going on to make better binding materials to make construction reliable. As an initiative, in our project we are going to partially replace cement with metakaoline, fly ash and silica fume simultaneously. We are going to replace cement with each additive in the order of 5%, 7.5%, 10%, 12.5%, and 15%. Therefore, the summation of replacement of all additives will be in the order of 15%, 22.5%, 30%, 37.5%, 45%. The concrete specimens are casted based on the replacement ratios along with the conventional concrete specimens. The specimens are subjected to the various laboratory tests and it was found that a 10% replacement of cement with additive materials to be optimum.

## Introduction

The main constituent of construction is concrete. Cement used in concrete is ordinary Portland cement which emits carbon dioxide that causes pollution to the environment. Reduction in the usage of OPC in concrete gains a greatest advantage in the environment. As the nation is focusing more on the infrastructure development the usage of cement in the structure is increasing tremendously. So we are in need of finding an alternative resource that can replace cement and also which does not harm the environment. In this research work we are going to replace the OPC with metakaolin, silica fume and fly ash in different percentage in order to find the optimum percentage of the replacement. The metakaoline is used for greater binder in concrete.

## Material Investigation

The materials which are to be used in the research are subjected to basic material test and the results are furnished in the Table 1.



*Table 1 – Preliminary test results of aggregates*

Fine aggregate [4]		
S.no	Properties	Results
1.	Specific gravity	2.60
2.	Bulk density	1469 kg/ m <sup>3</sup>
3.	Fineness modulus	3.16
4.	Water absorption	0.25 %
Coarse aggregate [4]		
1.	Specific gravity	2.7
2	Water absorption	0.15%
3	Bulk density	1579 kg/ m <sup>3</sup>
4	Fineness modulus	4.71
Cement [5]		
1	Specific gravity	3.12
2	Fineness modulus	2.86
3	Soundness of cement	2 mm
4	Initial setting time	45 min
5	Final setting time	10 hours
Metakaoline [2]		
1	Specific gravity	3.4
2	Bulk density	1523 kg/m <sup>3</sup>
3	Fineness modulus	2.78
4	Water absorption	0.26 %
Fly ash [8]		
1	Specific gravity	2.18
2	Bulk density	1235 kg/m <sup>3</sup>
3	Fineness modulus	2.72
4	Water absorption	0.265 %
Silica fume [8]		
1	Specific gravity	2.3
2	Bulk density	320 kg/m <sup>3</sup>
3	Water absorption	0.245 %

**Mix design:**

M20 grade concrete is used for the research. Following the IS codes the mix design has been arrived and the quantity calculation for different % of replacement are shown in Table 2. [6, 9]

Cement: FA : CA : W/C  
 1 : 1.62 : 2.68 : 0.5

*Table 2 – Mix proportions for various % of replacement*

<b>Mix (%)</b>	<b>Cement (Kg)</b>	<b>Metakaolin (Kg)</b>	<b>Silica fume (kg)</b>	<b>Fly ash (kg)</b>	<b>Fine aggregate (kg)</b>	<b>Coarse aggregate (kg)</b>
Control	13.16	-	-	-	24.25	48.50
15%	11.21	0.65	0.65	0.65	24.25	48.50
22.5 %	10.19	0.99	0.99	0.99	24.25	48.50
30 %	9.2	1.32	1.32	1.32	24.25	48.50
37.5 %	8.21	1.65	1.65	1.65	24.25	48.50
45 %	8.32	1.97	1.97	1.97	24.25	48.50

During the concrete mix the water content is increased based on water absorption of the additive materials

**Experimental Investigation**

Mixing was done in a laboratory by hand mixing. Fig.1 and Fig.2 shows the hand mixing of concrete.



*Fig.1 Mixing*



*Fig.2 – Casting*

**Slump Cone Test**

Table 3 represents the slump value of various mixes.

Table 3 – slump cone test results

Grade of concrete	Mix	Slump value
M20 GRADE	CC	85
	M1	74
	M2	78
	M3	80
	M4	81
	M5	77

**Acid Test Results**

**Test Result of HCL**

Table 4 represents the test results of acid test. From the test results the concrete containing fly ash and other materials were found to exhibit resistance more than the zero percentage replacement specimens. Fig.3 shows the graphical representation of test results of acid test.

Table 4 – Test result of HCL

S.No	% of replacement	Loss in weight (grams)
1	Control	280
2	15%	211
3	22.5 %	170
4	30 %	162
5	37.5 %	247
6	45 %	253

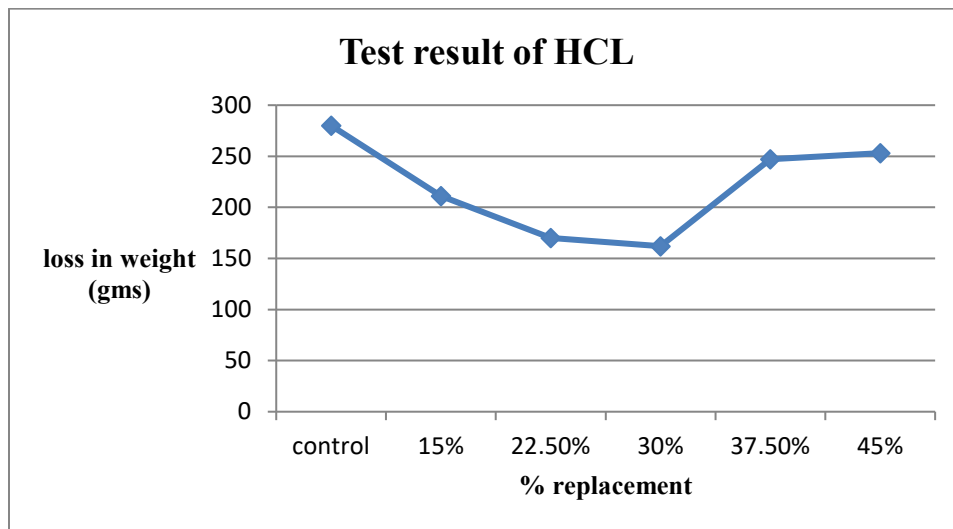


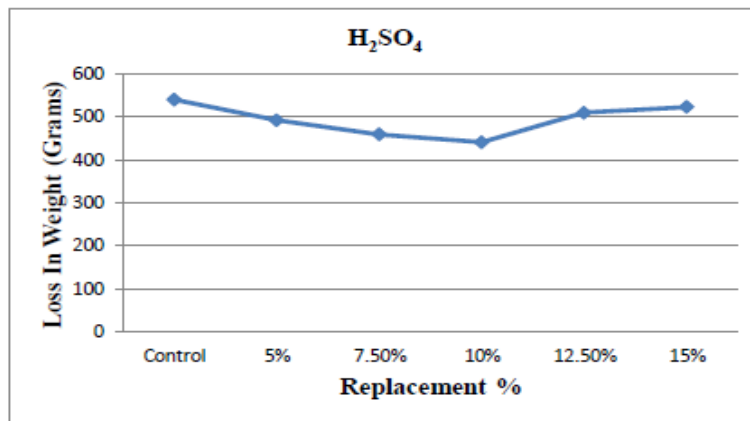
Fig.3 – Graphical representation of test results of Acid test (HCL)

**Test Result of H<sub>2</sub>SO<sub>4</sub>**

Table 5 shows the test results of sulphuric acid test. From the table, the replaced cement concrete shows higher resistance than that of normal cement concrete up to 37.5%. And the resistance of 45% is higher but it is less than normal cement concrete. The graphical representation of the results of the sulphuric acid test is shown in figure 4.

*Table 5 - Test results of sulphuric acid test*

S.No	% of replacement	Loss in weight (grams)
1	Control	540
2	15%	492
3	22.5 %	459
4	30 %	441
5	37.5 %	510
6	45 %	523



*Fig.4 – Graphical representation of sulphuric acid test*

**Mechanical Properties**

**Compressive Strength Test Results**

Once the curing period ends the concrete are subjected to hardened concrete test. As a first step the concrete is subjected to compressive strength test and are tabulated in Table 6. Fig.5 represents the graphical representation of test results of compressive strength test. [5, 7, 9]

*Table 6 - Compressive Strength Value (28days)*

Mix	Compressive strength (N/mm <sup>2</sup> )
Control	25.76
15%	26.25
22.5 %	26.88
30 %	27.41
37.5 %	24.32
45 %	19.28

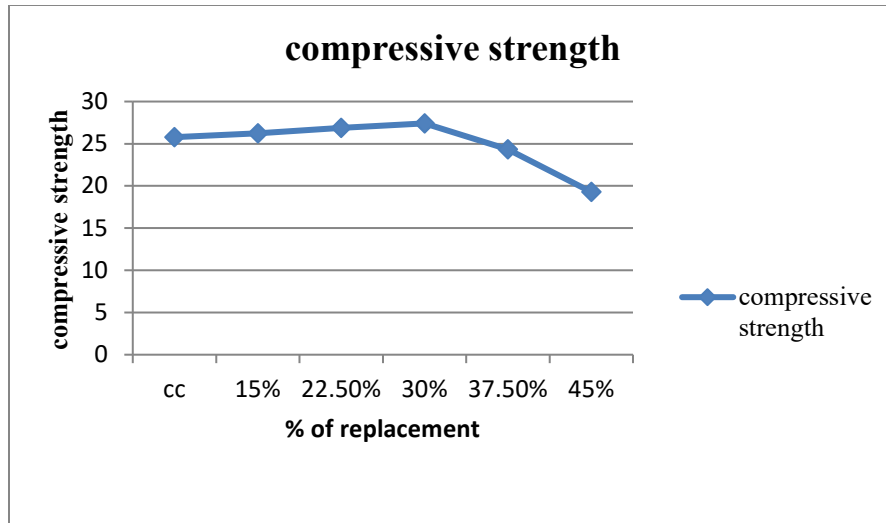


Fig.5 –compressive strength results after 28 days

### Split Tensile Strength Test Result

Split tensile strength test was conducted in universal testing machine and test results are listed in Table 7. Fig.6 shows the split tensile strength test. Fig.7 shows the graphical representation of split tensile strength test results. [5, 7, 9]

Table 7 - split tensile strength test (28 days)

Mix	Split tensile strength (N/mm <sup>2</sup> )
Control	2.28
15%	2.30
22.5 %	2.33
30 %	2.35
37.5 %	2.21
45 %	1.97



Fig.6 - split tensile strength test

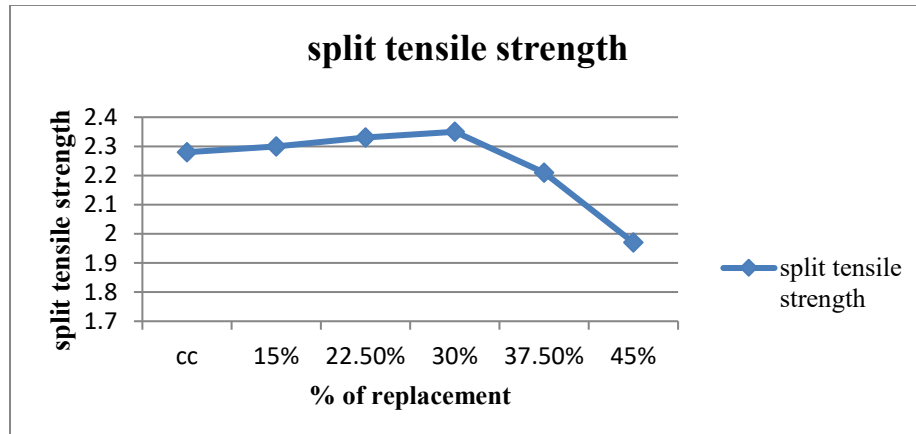


Fig.7 – Split tensile strength test result – Graphical representation

**Modulus of Elasticity Test Results**

Table 8 shows the test results of modulus of elasticity test. Fig.8 shows the experimental set up of modulus of elasticity test. [5]

Table 8 - Modulus of Elasticity test results

Mix	Young’s Modulus (N/mm2)
Control	22360
15%	22516
22.5 %	23000
30 %	23162
37.5 %	22986
45 %	22788



Fig.8 – Modulus of elasticity test set up

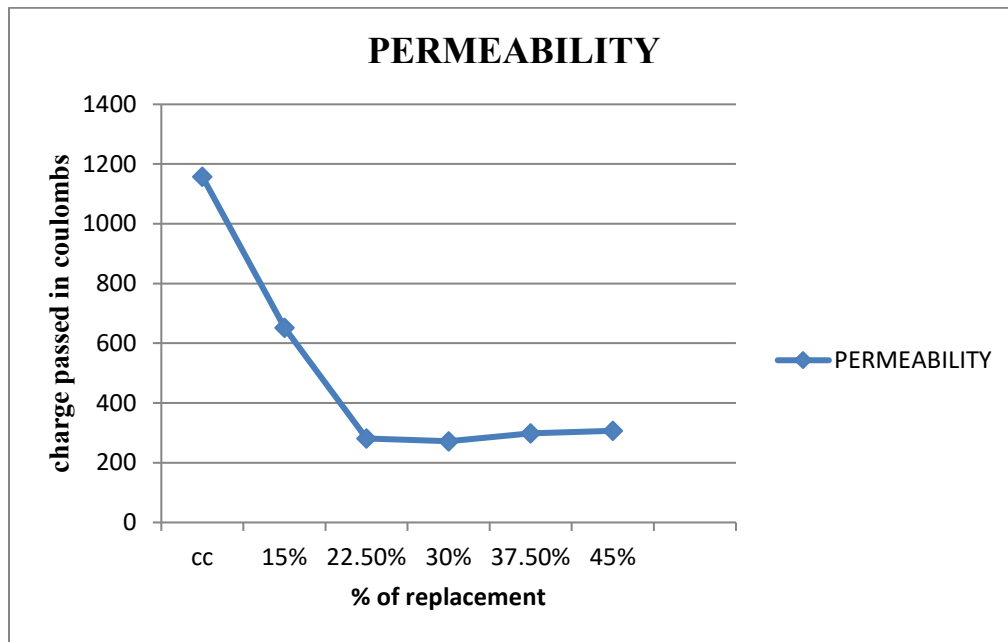
**Permeability Test Results**

Permeability test was carried out and the test results have been furnished in the Table 9. Fig.9 shows the graphical representation of test results of permeability test. [8 ,9]

*Table 9 - Charge Passed In RCPT*

Grade of concrete	% of replacement of metakaolin, silica	Charge passed (coulomb)	Chloride permeability as per ASTM C1202
M20	Control	1158	High
M20	15%	652	moderate
M20	22.5 %	281	Very low
M20	30 %	272	Very low
M20	37.5 %	298	low
M20	45 %	307	low

The rapid chloride ion permeability measured at 28 day is illustrated. We can see that the total charge passed through the cement replaced concrete decreases when the percentage of additives increases.



*Fig.9 – permeability test results*

**Results & Discussions**

1. From the acid test it has been observed that the loss in weight is more for the conventional concrete and for the 37.5% and 45% replacement of cement with additives when compared to the 15%, 22.5% and 30% replacement of cement with additives. The reason behind this is, as the alkaline content is low it neutralizes the acid and thereby the loss in weight is less



for the lower replacement percentage when compared to the higher replacement percentage of additives. [12]

2. From the compressive strength test we can find that the strength is increasing for the concrete with the replacement of cement by additives in the range of 15%, 22.5% and 30%. It is because the voids have been filled by the additive materials. Therefore the strength gets increased when the grain size of the additive materials is well graded with aggregate.
3. On further adding the additive materials in the range of 37.5% and 45% the strength decreases since the grain size of the additive materials become uniformly graded which leads to the decrease in strength. [1, 10]
4. From split tensile strength test it has been found that the strength gets increased upto 30% replacement of cement with additives. On mixing with water, the additives develop a homogenous layer with the aggregates because it acts as filler materials as well as binding materials [1, 3, 6]. Hence it gives better split tensile strength than the conventional concrete. If the percentage of replacement is being increased the minor cracks in the concrete gets developed which leads to the failure of the concrete or in other words reduction in the tensile strength. [11]
5. Modulus of elasticity will be greater for the concrete which is having well graded aggregates. The well graded aggregates in concrete can be achieved due to the addition of additives which reduces the voids present in the concrete. Therefore the replacement of cement with 30% of additives will results in better modulus of elasticity values as the voids in the concrete is being filled by the additives. On increasing the percentage of replacement the well graded aggregates will change into uniformly graded aggregates which leads to increase in voids thereby the modulus of elasticity values gets decreased.
6. From RCPT test we can found that the permeability is low for the 30% replacement of cement with additives. Grain size of additives is less when compared to aggregates thereby we are getting the low permeability. On partially replacing the cement with additives the voids present in the concrete is getting reduced. On increasing the percentage of additives the permeability gets increased due to the uniform grain size. [3, 10, 11]

## Conclusion

The following conclusions were arrived from the research

1. The basic test results were conducted on the materials from which the material properties were found out which is used in the mix design calculation.
2. Various test has been conducted on the hardened concrete and it has been found that 30% replacement of cement with additives is optimum
3. From acid test it has been found that the loss in weight of the 30% replaced concrete is less when compared to conventional concrete. So it becomes dense concrete.
4. Form compressive strength test it has been found that the 30% replaced concrete has 6% more strength than the conventional concrete.
5. From split tensile strength test it has been found that the 30% replaced concrete has 3% more strength than the conventional concrete.
6. On conducting RCPT test we can found that the permeability for the 30% replacement of cement with additives shows better result when compared to all other percentage of replacement.
7. From the above results we can conclude that the 30% replacement of cement with additives shows better permeability, durability and strength properties. So we can replace cement

with metakaolin, silica fume and fly ash up to 30% without affecting durability and strength properties of the concrete.

8. Finally we suggest that this concrete can be utilized as a sustainable construction material.[11,12]

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