A STUDY ON REPLACEMENT OF CEMENT WITH PAPER SLUDGE AND SILICA FUME IN M30 & M40 GRADE CONCRETE

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Abstract: **Cement manufacturing industry is one of the carbon dioxide emitting sources besides deformation and burning of fossil fuels and concrete industry is one of the largest consumers of natural virgin materials. Concrete is strength and tough material but it is porous material also which interacts with the surrounding environment. In order to address environmental effects associated with cement manufacturing and constantly depleting natural resources, there is a need to develop alternative binders to make concrete industry sustainable.**

***IndexTerms* -. Paper Sludge, Silica Fume,Concrete**

CHAPTER-1 INTRODUCTION

1.1 GENERAL

Concrete is strength and tough material but it is porous material also which interacts with the surrounding environment is rapid increase in construction activities leads to active shortage of conventional construction materials such as cement, fine aggregate, coarse aggregate. Concrete has attained the status of a major building material in all the branches of modern construction. It is very difficult to point out another material of construction which is a variable as concrete and which is the best material choice is for strength and durability.

1.2 PAPER MILL SLUDGE

Paper making industries generally produces a large amount of solid waste. Over 300 million tons of industrial wastes are being produced per annum by chemical and agricultural process are available in India. These materials possess problems of disposal along with health hazards and aesthetic problem. The paper fibers will be recycled only a limited number of times before they become too short or weak to make high quality of paper. It means that the broken, low- quality paper fibers are separated out to become like waste sludge. But Paper sludge behaves like cement because of silica and magnesium properties which improve the setting of the concrete. And the quantity of sludge varies from mill to mill.

1.2.1 Applications of paper mill sludge

- To provide an economical concrete.
  - It should be easily adopted in field.
  - Using the wastes in useful manner.
  - Light weight comparably with conventional concrete.
  - Paper mill sludge is the cheaper substitute to OPC.

1.2.2 Limitations of paper mill sludge

- Availability
- Handling problems during constructions

1.3 SILICA FUME

Silica fume is a byproduct of producing silicon metal or ferrosilicon alloys. One of the most beneficial uses for silica fume is in concrete. Because of its chemical and physical properties, it is a very reactive pozzolan. Concrete containing silica fume can have very high strength and can be very durable. Silica fume is available from suppliers of concrete admixtures and, when specified, is simply added during concrete production. Placing, finishing, and curing silica-fume concrete require special attention on the part of the concrete contractor.

1.3.1 Applications of Silica Fume

- Silica fume is a highly efficient polyurethane material, with considerable potential for use in a variety of fields including concrete and mortar
- Using silica fume in refractory produces better particle stacking and requires less water, with no loss of fluidity

1.3.2 Limitations of Silica Fume

- Silica fume concrete is too viscous and difficult to apply.it is not easy to wipe the surface
- Silica fume requires a high amount of water and needs to be used with a superplasticizer
- The price of silica fume is relatively high compared to cement and fly ash

CHAPTER-2 LITERATURE REVIEW

2.1 GENERAL

The main purpose of a literature review is to give us an idea about the work conducted world over in the field of study. In this chapter a brief review of literature about the study on paper mill sludge and silica fume in various construction materials is reported and discussed.

2.2 LITERATURE REVIEW

Dhiraj Agrawal, Pawan Hinge1, U. P. Waghe[1] In the present age the waste generated from industries is the huge concern for the environment, health, and cause for land filling. Recycling of such wastes and using them in construction materials appears to be viable solution is not only to the pollution problem but also an economical option in construction. In view of utilization of industrial waste is the construction material, the present paper reviews various waste materials at different levels in construction materials. Compressive test to find the strength of concrete and mortar incorporating different waste materials is reviewed and recommendations are suggested at the outcome of the study. The different waste materials tested are Quarry Dust, Rice Husk Ash, Crumb Rubber, Silica fume Ash , Paper Mill Sludge Ash, Class F-Fly ash , Pumice Fine Aggregate.

A.M. Md Nazar , N.F. Abasa , M.A. OthumanMydin [2] A revenue study of the conducted as a result of investigations into a use of paper mill sludge as a recycled materials and additives of concrete mixes for the use in construction projects. The study had been provided the assurance that of concrete produced had the correct mechanical strength of concrete. Concrete mixes containing paper mill sludge were prepared, and their basic strength characteristics such as the compressive strength, flexural strength, ultra pulse velocity and dynamic modulus elasticity were tested. Four concrete mixes, i.e. a control mix, and a 10%, 20%, and 30% mix of paper mill sludge as a cement replacement for the concrete were prepared with a DOE mix design by calculating the weight of cement, sand and aggregate. As a result, when the percentage of paper mill sludge in the concrete increased, the strength is decreased. Overall, a high correlation was the observed between density of concrete and strength of the concrete containing paper mill sludge. The best percentage of mix volume for paper mill sludge is 10 %, because it has a tendency to absorb water and its strength is long-time. A good relationship was observed between the density and strength of concrete mixes were containing paper mill sludge.

CHAPTER-3 SELECTION OF MATERIALS

3.1 INTRODUCTION

In developing the concrete mix for construction, it is important to select proper, ingredients, evaluate their properties and understand the interaction among different materials for optimum usage. The ingredients used for this investigation were cement, fine aggregate, coarse aggregate, water, paper mill sludge and silica fume.

3.2 CEMENT

Cement is a fine, grey powder. It is mixed with water and materials such as sand, pozzolanas to make mortar and concrete. The cement and water forms a paste that binds the other materials together. In this work cement is used in the ordinary Portland cement of 53 grade conforming to IS: 12269-1987.

Table 3.1: Properties of OPC (53 grade) cement

Physical properties of grade of cement	Results	Requirements as per IS:8112-1989
Specific gravity	3.15	3.10-3.15
Consistency	31.22%	30-35
Initial setting time	98min	30 minimum
Final setting time	260 min	600 maximum
Compressive strength N/mm2 at 28 days	53.14 N/mm^2	53 N/mm^2

3.3 AGGREGATE

Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. One of the most important factors for producing workable concrete is a good gradation of aggregate. Good grading implies that a sample fraction of aggregates in required proportion such that the sample contains minimum voids. Samples of the well graded aggregate

3.4 FINE AGGREGATE

The river sand and is being used in combination as fine aggregate conforming to zone-II according to IS: 383-1970 was used. The sand was sieved through a set of sieves 4.75 mm, 2.36 mm, 1.18 mm, 600µ, 300µ and 150µ. The river sand is wash and screen, to eliminate deleterious materials and over size particles. Sieve analysis and physical property test results are presented below:

3.7.2 Silica Fume

Silica fume is a byproduct in the carbothermic reduction of high-purity quartz with carbonaceous materials like coal, coke, wood-chips, in electric arc furnaces in the production of silicon and ferrosilicon alloys..

Table 3.4: Properties of paper mill sludge and Silica fume

Physical properties of replacement materials	Paper Mill Sludge	Silica Fume
Specific gravity	2.6	2.4

Initial setting time	110min	115min
Final setting time	275min	285min

Figure 1.2 silica fume

CHAPTER-4 TESTS CONDUCTED ON MATERIALS

4.1 TESTS ON CEMENT

4.1.1 Specific Gravity of Cement

The method used to calculate specific gravity of Cement is Le-chatlier's Flask method. In this Cement is tested by using Kerosene.

W_1 = weight of dry density bottle with cap is noted.
W_2 = weight of the density bottle with 1/3 cement filled.
W_3 = weight of density bottle with cement and kerosene filled
W_4 = weight of density bottle with kerosene up to top of cap

The specific gravity can be calculated by the formula

$$\text{Specific gravity (G)} = \frac{(W2 - W1)}{(W2-W1)-(W3-W4)}$$

Table 4.1: Specific gravity of cement

S.No	Observation	Weights(Kg)
1	W_1	0.35
2	W_2	0.76
3	W_3	1.40
4	W_4	1.13
Specific gravity of cement		3.15

Result: Specific gravity of cement= 3.15
Specific gravity of paper mill sludge= 2.6
Specific gravity of silica fume = 2.3

4.2.2 Sieve analysis of Fine Aggregate

Sieve analysis helpful in determining the particle size distribution of the aggregates gradation of fine aggregate. It is confirming to IS 2386 – 1963 part 1.

Table 4.3: Sieve analysis of Fine aggregate

S.NO	Sieve size	Weight retained (gm)	Cumulative weight retained (gm)	Cumulative % wt retained	% of passing
1	4.75mm	10	10	1.0	99
2	2.36mm	100	110	11.0	89
3	1.18mm	72	182	18.2	81.8
4	600 µ	362	544	54.4	45.6
5	300 µ	268	812	81.2	18.8
6	150 µ	132	944	94.4	5.6
7	Pan	56	1000	100	0
Total				260.2	

Fineness modulus of sand = (Total cumulative % wt retained)/100
= 260.2/100 =2.60
Result:
The sieve analysis of sand confirm to Zone II
Fineness modulus of sand= 2.60

CHAPTER-5 MIX DESIGN

5.1 GENERAL

Mix Design is the process of a selecting suitable ingredients of the concrete and determining their relative quantities for producing concrete of certain minimum properties of the strength, durability and consistency etc., as economically as possible. Two mix designs were done for M30, M40 grade concrete.

5.2 MIX DESIGN – M30

The steps involved in the design of concrete mix as per IS: 10262-2009 is a follows,

Stipulations for proportioning:

Grade designation : M30
Type of cement : OPC 53 grade confirming to IS 12269:1987
Maximum nominal size of aggregate : 20 mm
Exposure condition : Severe (for reinforced concrete)
Degree of supervision : Good
Minimum cement content : 320 Kg/m^3
Type of aggregate : Crushed angular aggregate
Maximum cement content : 450Kg/m^3
Workability : 25-50mm

Test data for Materials:

Cement used: OPC 53 grade confirming to IS 12269:1987
Specific gravity of cement: 3.15

Specific gravity of

- Coarse aggregate :2.8
- Fine aggregate :2.6

STEP-1: **Target mean strength for mix proportioning**

$f_t = f_{ck} + 1.65\ S$

$f_t = 30 + 1.65(5) = 38.25 N/mm^2$

f_t = Target average compressive strength at 28 days
f_{ck} = Character compressive strength at 28 days
S = Standard deviation (taken from Table1 of IS: 10262-2009)
S=5

STEP-2: Selection of Water-cement ration

From IS: 456-2000, Table 5 by taking severe exposure condition for M30 grade, the maximum water cement ratio is 0.45
W/C = 0.45

STEP-3: Selection of water content

From IS: 10262-2009, Table 2 depending upon the nominal size of aggregate (20mm), the maximum water content is 186 litres.

∴ Maximum water content per cubic meter of concrete for 20mm aggregate is 186 Kg (litres)

STEP-4: Calculation of cement content

The minimum cement content required for M30 as per IS:456-2000 of table is 320Kg/m^3 (Severe exposure condition)
W/C =0.45
186/C = 0.45
C = 413 kg
Hence we obtained cement content as 437 Kg
But , we are approximating this value of cement =380Kg
W/C = 0.45
W/380 = 0.45
W = 171 kg
380Kg/m^3 > 320Kg/m^3, hence, OK

STEP-5: Proportion of volume of coarse aggregate and fine aggregate content

∴ Volume of coarse aggregate =0.65
Volume of fine aggregate = 1-0.65 =0.35

STEP-6: Mix calculations

The mix calculations per unit volume of concrete shall be as follows:
(a) Volume of concrete = 1m^3
(b) Volume of cement = Mass of cement/specific gravity of cement ×1/1000
=380/3.15×1/1000

=0.120

(c) Volume of water =Mass of water /specific gravity of water ×1/1000

=171/1×1/1000

=0.171

(d) Volume of all in aggregate =1-(0.120+0.171)

=0.709

(e) Mass of coarse aggregate = Volume of all in aggregate × Volume of coarse aggregate × Specific gravity of coarse aggregate ×1000

=0.709×0.65×2.8×1000

=1290.38

(f) Mass of fine aggregate = Volume of all in aggregate× Volume of fine aggregate ×Specific gravity of fine aggregate ×1000

=0.709×0.35×2.6×1000

=645.19

380: 645.19: 1290.38

1: 1.697: 3.395

Cement: F.A: C.A

Table 5.1: Mix Proportion for M30

Cement Kg/m^3	Fine aggregate Kg/m^3	Coarse aggregate Kg/m^3	Water l/m^3
380	645.19	1290.38	186
1	**1.697**	**3.395**	**0.45**

CHAPTER -6

PREPARATION AND CASTING OF SPECIMENS

6.1 INTRODUCTIION

The casting specimens are designed M30, M40 mix as mentioned in table was used with various combinations of sludge and cement. The sludge as cement replaced materials as specified in table for the commercial the mix details are shown in table was used with combination of sludge as cement replaced material as specified

Table 6.1: Design mix proportion

Specimens	Cement	Fine aggregate	Coarse aggregate	W/C ratio	Mix Design
Cubes, Cylinders, Beams	380	645.19	1290.38	0.45	M30
Cubes, Cylinders, Beams	400	694.56	1273.608	0.38	M40

6.2 MIX COMBINATION:

The following mix combination has been carried out for this experimental investigation.

Table 6.2: Mix combination of cement with paper mill sludge for M30 and M40 grades

Mix composition	Cement (%)	Paper mill sludge (%)
Control mix (CM)	100	0
PST1	95	5
PST2	90	10
PST3	85	15

Table 6.3: Mix combination of cement with silica fume for M30 and M40 grades

Mix combination	Cement (%)	Silica fume (%)
Control mix (CM)	100	0
SFT1	95	5
SFT2	90	10
SFT3	85	15

6.3 MATERIAL QUANTITIES

Table 6.4: Mix proportion quantities of M30 grade & w/c=0.45

Mix	Cementitious material (Kg/m^3)		Coarse Aggregate (Kg/m^3)	Water (lt/m^3)
	Cement	Sludge		
Control Mix	380	0%	1290.38	171

PST1	361	5%	1290.38	171
PST2	342	10%	1290.38	171
PST 3	323	15%	1290.38	171

Table 6.5: Mix proportion quantities of M40 grade & w/c=0.38

Mix	Cementitious material (Kg/m^3)		Coarse Aggregate (Kg/m^3)	Water (lt/m^3)
	Cement	Silica Fume		
Control Mix	400	0%	1292.608	173
SFT1	380	5%	1293.608	173
SFT2	360	10%	1293.608	173
SFT 3	340	15%	1293.608	173

6.4 CASTING OF SPECIMENS

Casting of specimens are cubes, cylinders, beams.

Cubes:

- For each trail 6 cube specimens were casted for calculating 7 days and 28 days strengths. The dimensions of specimen for cube are of 150mm x 150mm x 150mm.

Fig 6.1 Casting of specimens

Cylinders:

- For each trail 6 cylinder specimens were casted for calculating 7 days and 28 days strengths. The dimensions of the cylindrical specimen are of Height 300mmand diameter 150mm.

Beams:

- For each trail 6 beam specimens were casted for calculating 7 days and 28 days strengths. The dimensions of the beam specimen are of 500mm x 100mm x 100mm.

Durability:

- For measuring the durability of concrete, cubes of size 100mm x 100mm x 100mm are casted.

Curing Of Specimens:

- Curing is most important process in concreting. Concrete strength increases with age of curing. The specimens should keep in curing tank for better improvement in strength. Generally curing is done by ponding curing tanks. The water used for concrete curing should be free from salinity, scrap, vegetation and chemicals. We need to change the water for every 7 days of curing. The specimens are tested for 7 days and 28 days curing.

CHAPTER-7 TESTS ON THE PROPERTIES OF CONCRETE

7.1 INTRODUCTION

The tests on conducted properties of concrete. The fresh and Hardened properties is the main in concrete testing. Slump cone workability test was conducted by the fresh concrete. The Hardened concrete specimens tests are compressive strength, flexural strength of concrete, split tensile strength of concrete and durability of concrete. . By taking out the specimens from the curing tank, the specimens were exposed to sun light for surface drying. After the drying process, the specimens are processed for testing. The specimens are tested for 7 days and 28 days strengths.

7.2 WORKABILITY TESTS OF FRESH CONCRETE

According to Cement Manufacture's Association India, a good concrete must has workability in the fresh state and also develop sufficient strength. The workability test for concrete is confirms to IS 1199 – 1959. It also mentioned that there are four factors that can be affect the workability, they are as below:

1. **Consistency:** The degree of consistency is depended on the nature of works and type of compaction.
2. **Water/ cement ratio or water control of a concrete:** water/cement ratio is the ratio of water in a mix to the weight of cement. The quality of water that required for a mix proportions, types and grading of aggregate.
3. **Grading of aggregate:** The smooth and rounded aggregate will produce a more workable concrete than the sharp angular aggregate.
4. **Cement Content:** The greater workability can be obtained with the higher cement content.

7.2.1Slump Test:

Slump test is used to determine the workability of fresh concrete. The test is simple and cheap. It is suitable to use in the laboratory and also at site. Although the test is simple. It also mentioned that a slump less than 25mm will indicate a very stiff concrete and a slump that more than 125mm will indicates a very runny concrete. Slump test will not indicate well for the concrete with very high workability and also very low workability. This is because a very high workability concrete will lose the shape by following and collapse, where a very low workability concrete will not collapse.

Fig 7.1 Slump Test

Slump cone method consist a cone of 300mm height, 200mm bottom diameter and 100mm top diameter. For doing slump test concrete is poured into the cone in 3 layers and tamped at 25 strokes for each layer with a tamping bar. After total compaction the cone will removed and height of cone will measured. The difference between the height of the mould and the average height of the top surface of the concrete.

CHAPTER -8 THE RESULTS AND DISCUSSIONS

8.1 INTRODUCTION

In this chapter deals with descriptive analysis and discussion about the compressive strength, flexural strength, split tensile strength and durability of concrete. The strength properties are calculating by replacing cement with paper mill sludge and Silica fume in different percentages are 5%, 10%, 15% in concrete. The detailed tabulations and graphs are presented as follows.

8.2 WORKABILITY OF CONCRETE

The workability of concrete is observed by the Slump Cone method. The range of slump was selected as 25-50mm.

Table 8.1: Slump obtained for M30 and M40 of paper mill sludge and silica fume

Mix	Slump (mm)	
	M30	M40
Control Mix	35	38
PST 1	32	35
PST 2	28	30
PST 3	25	27
SFT 1	30	32
SFT 2	27	28
SFT 3	25	26

8.4 FLEXURAL STRENGTH RESULTS:

Fig 8.6 **Flexural strength tests on beam**

- When cement is replaced with paper mill sludge of 5% an increased at compressive strength @ 7 days is observed to be 2.6% and @ 28 days is 4.2%
- At 10% replacement & beyond is increasein flexural strength is found to decrease.
- When cement is replaced with silica fume of 5% an increased at compressive strength @ 7 days is observed to be 25.41% and @ 28 days is 23.8%
- At 10% replacement & beyond is increasein flexural strength is found to decrease.

9.3 DETAILED PROCEDURE ADOPTED

- Cubes of size 100mm x 100mm x 100mm are casted for each trail of M30 and M40 grades.
- The specimens are placed in a undisturbed curing period of 28 days.
- After the completion of curing, cubes are taken out of water.
- Initial measurements are taken for each cube in terms of weight and dimensions.
- The initial weight and diagonal dimensions of each set of cubes were carefully taken.
- The prepared cubes are placed in acid curing for 28 days
- The solutions are prepared by taking 8 litres of water with 5% HCL and 5% H_2SO_4
- After the completion of acid curing period 7 days and 28 days the cubes are processed for Acid attack factor and Acid durability factor.

9.4 TESTS ON DURABILITY

The durability properties of concrete are examined with the help of Acid attack factor and Acid durability factor.

- Acid attack factor was calculated by the formula
  Acid attack factor = (loss in mm on 8 corners) / 4
- The acid durability factor was calculated by the formula
  Acid durability factor = S_r (N/M)

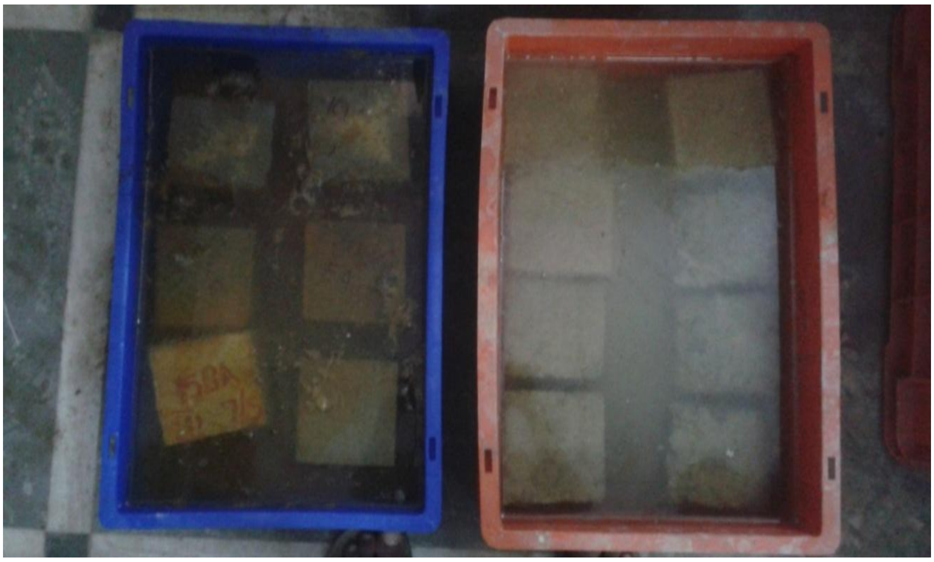


Table 9.1 Acid curing

9.5.2.2 For M40 Grade

Percentage wt loss of cubes in 5% HCL, 5% H_2SO_4 of paper mill sludge

Table 9.6: Weight loss % in HCL, % H_2SO_4 for M40 Grade of Paper Mill Sludge

Mix	Curing under 5% HCL		Curing under 5% H_2SO_4	
	% Wt loss after 7days	% Wt loss after 28days	% Wt loss after 7days	% Wt loss after 28days
PST 1(5%)	1.18	2.2	3.84	12
PST 2(10%)	1.21	2.6	4.20	11.6
PST 3(15%)	1.4	3.2	4.50	10.5

Percentage Wt loss of cubes in 5% HCL, 5% H_2SO_4 of Silica Fume

Table 9.7: Weight loss % in HCL, % in H_2SO_4 for M40 Grade of Silica Fume

Mix	Curing under 5% HCL		Curing under 5% H_2SO_4	
	% wt loss after 7days	% wt loss after 28days	% wt loss after 7days	% wt loss after 28days
SFT 1(5%)	1.15	3.2	4.0	11.1
SFT 2(10%)	1.19	3.8	4.25	12.2
SFT 3(15%)	1.21	4.0	4.6	13

- When cured under 5% HCL& H_2SO_4 for 7 & 28 days both paper mill sludge & silica fume mixers have shown in increase in weight loss.

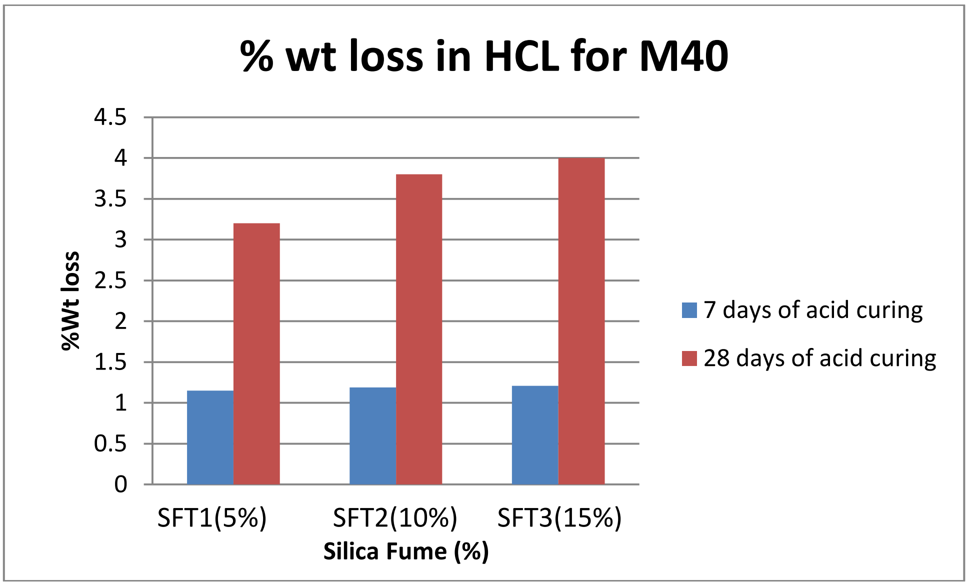
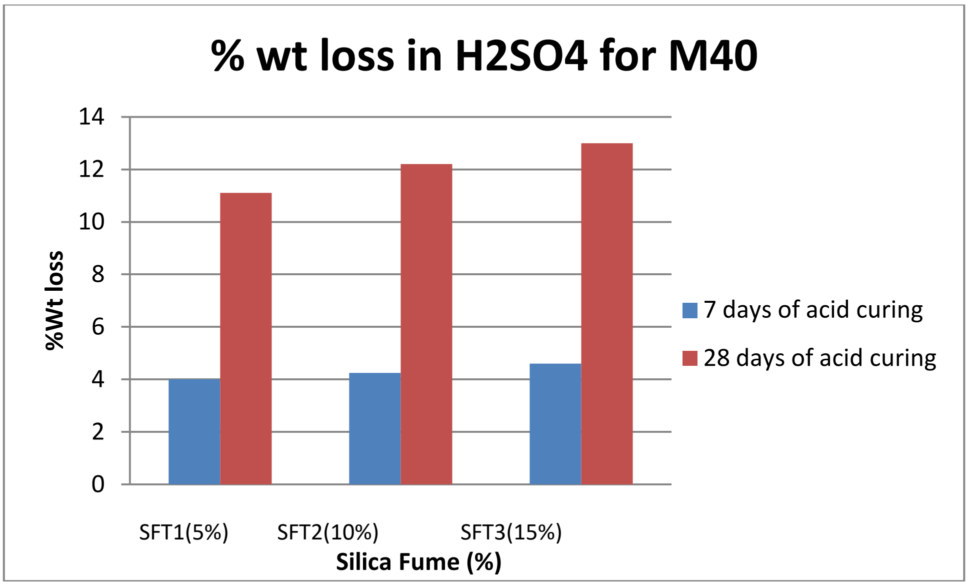


Fig 9.8 **Variation of** %Wt loss in HCL with Silica Fume of M40grade for 7&28 days



9.6.2 M40 Grade

The Acid attack factor values for M40 grade of paper mill sludge immersed in 5% HCL & 5% H_2SO_4 are tabulated as follows

Table 9.10: Acid attack factor for M40 Grade of Paper mill sludge immersed in 5% HCL & 5% H_2SO_4

Mix	Acid attack factor in 5% HCL		Acid attack factor in 5% H_2SO_4	
	7days	28days	7days	28days
PST 1(5%)	4	11.5	17.2	31.4
PST 2(10%)	4.5	12.3	18.5	32
PST 3(15%)	5.0	12.8	19.7	32.6

The Acid attack factor values for M40 grade of silica Fume immersed in 5% HCL & 5% H_2SO_4 are tabulated as follows

Table 9.11: Acid attack factor for M40 Grade of silica Fume immersed in 5% HCL & 5% H_2SO_4

Mix	Acid attack factor in 5% HCL		Acid attack factor in 5% H_2SO_4	
	7days	28days	7days	28day
SFT 1(5%)	4.8	12.3	18.1	32.5
SFT 2(10%)	5.4	13.2	18.7	33.2
SFT 3(15%)	5.9	13.8	19.3	34.6

- When the acid attack of paper mill sludge & silica fume immersed in 5 % HCL & H_2SO_4 in 7 & 28 days curing decreases in acid attack factor
- At 10% & beyond to decrease in acid attack factor is found increase .

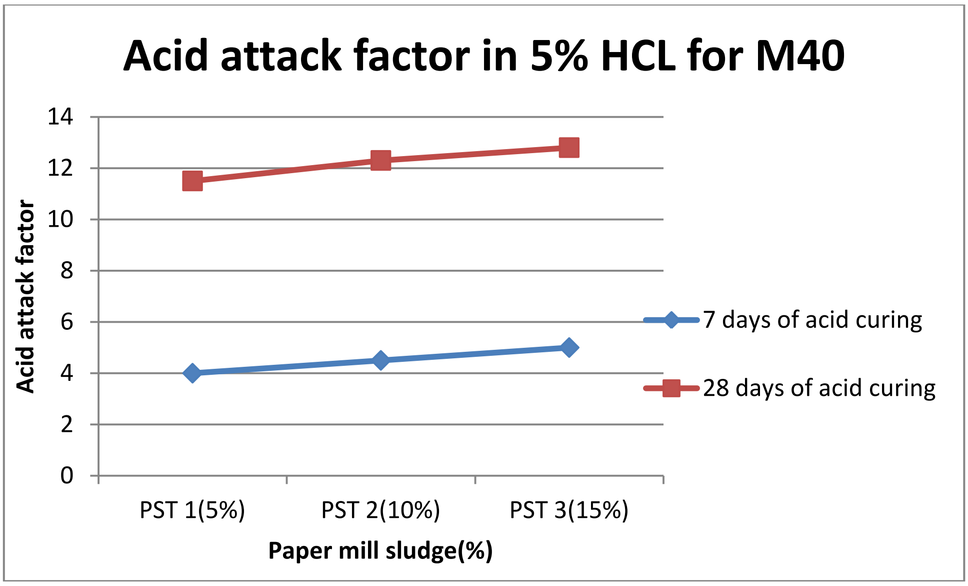


Fig 9.14 Variation of Acid attack factor in 5% HCL with Paper mill sludge of M40grade for 7&28 days

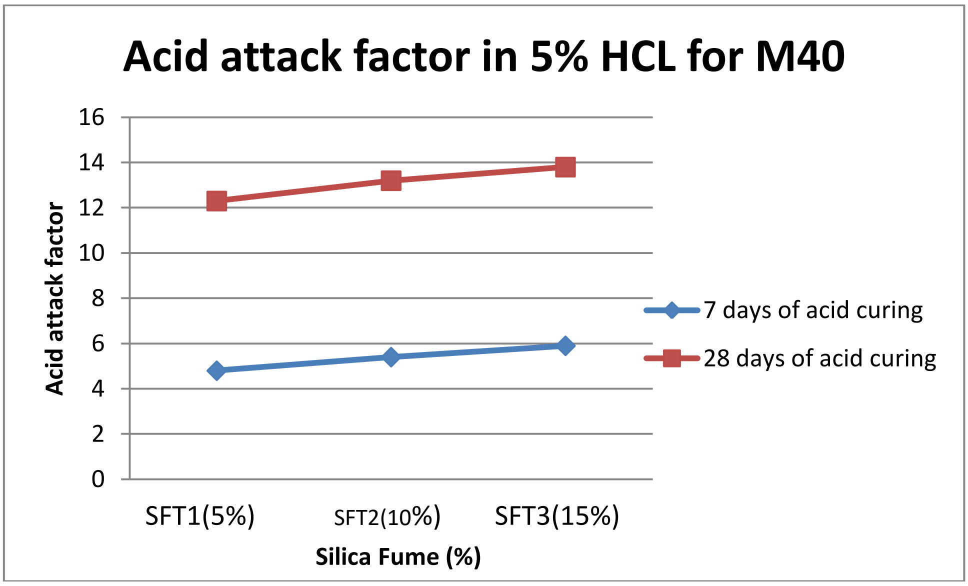


Fig 9.16 Variation of Acid attack factor in 5% HCL with Silica Fume of M40grade for 7&28 days

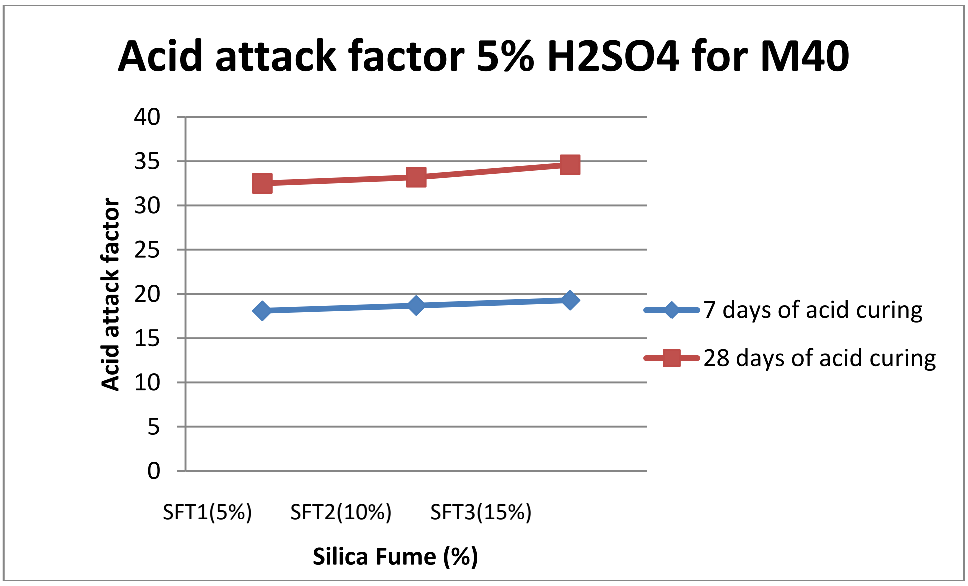


Fig 9.17Variation of Acid attack factor in 5% H_2SO_4 with Silica Fume of M40grade for 7&28 days

9.7 ACID DURABILITY FACTOR

Acid durability factor values for M40 grade of Silica Fume in 5%H_2SO_4 are described as follows

Table-9.19: Acid durability factor for M40 Grade of Silica Fume in 5% H_2SO_4

Mix	Acid Durability Factor (%) in 5% H_2SO_4							
	ADF for 7 Days				ADF for 28 Days			
	Compressive Strength after 7days of acid curing (Mpa)	% loss in strength	Relative strength S_r (%)	ADF	Compressive Strength after 28days of acid curing (Mpa)	% loss in strength	Relative strength S_r (%)	ADF
SFT 1(5%)	28.04	24.6	75.4	18.85	30.232	42	58	58
SFT 2(10%)	23.24	23.4	76.6	19.15	26.35	41.8	58.2	58.2
SFT 3(15%)	21.94	22.2	77.8	19.45	23.78	41	59	59

- When the paper mill sludge &silica fume compressive strength after 7 days & 28 days of acid curing at 5% increase .
- At 10% &beyond increase in compressive strength is found to decrease.

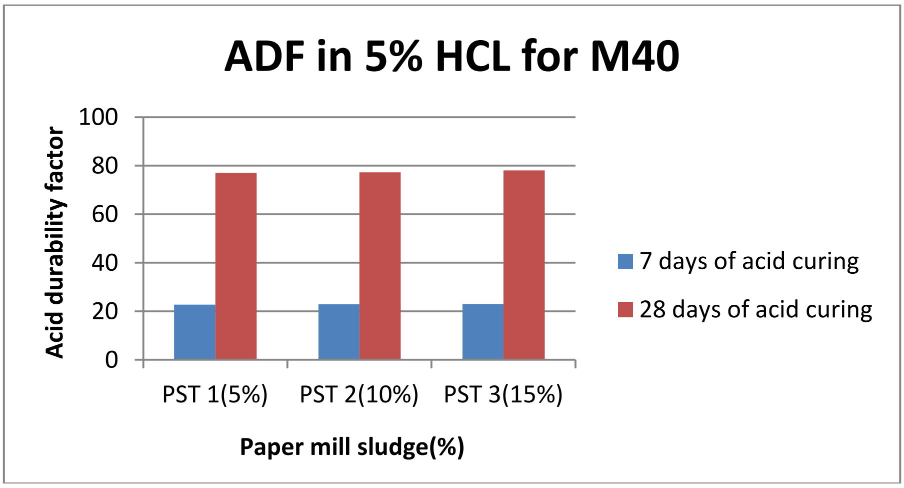


Fig 9.22 **Variation of** acid durability factorin HCL with Paper mill sludgeof M40grade for 7&28 days

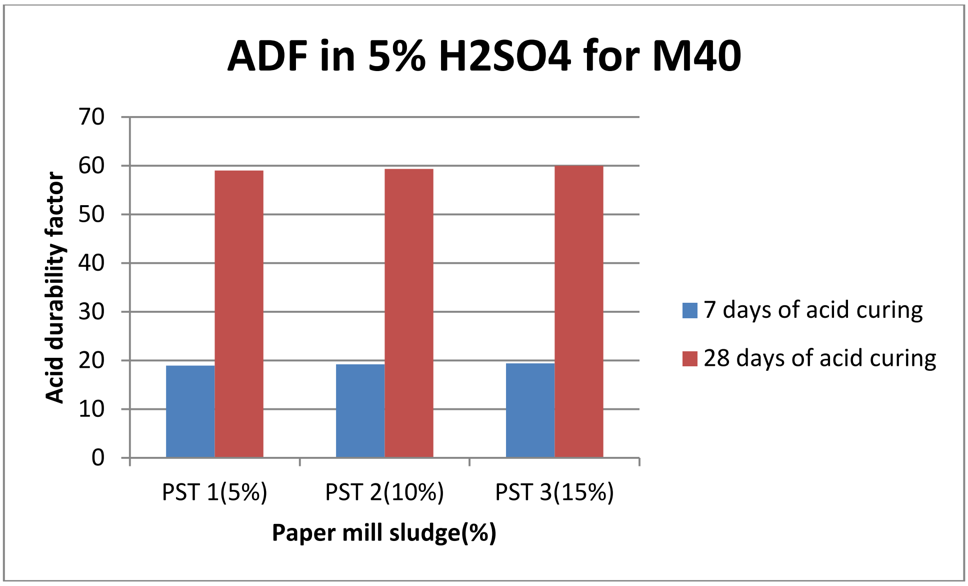


Fig 9.23 **Variation of** acid durability factorinH_2SO_4 with paper mill sludgeof M40grade for 7&28 days

CHAPTER-10
CONCLUSIONS

- Paper mill sludge and Silica fume wastes is suitable for the use in small amount of concrete mixes as a replacement for the cement, but it is not appropriate for large quantities.

- The workability is decreased because of increase in paper mill sludge and silica fume.
- The paper industry waste can be innovative supplementary cementitious construction material but judicious decisions are to be taken by engineers.
- Compressive strength and split tensile strength and flexural strengths are increased up to 5% replacement of cement with paper mill sludge for M30 and M40 mix.

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