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"Influence Of Supplementary Cementitious Materials On Concrete Strength, Durability & Also Impact On Carbon Foot Print"

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Abstract

Background:
The global warming is one of the major concern of entire world nowadays due to increased carbon foot print level. The increase in carbon foot print is mainly due to industrial pollution, continuous deforestation for urbanization & also due to poor disposal method of industrial waste like fly ash of thermal power plant. Moreover, cement industries are alone responsible for 8% anthropogenic CO_2 to the atmosphere.

***Objective**:*
To reduce carbon foot print in environment by reducing the cement consumption in construction industries by using of SCM (Supplementary Cementitious Materials) at various proportion in concrete as a partial replacement of OPC. This research work involved the comparative studies of various types SCM based concrete with only OPC based concrete for both mechanical strength and durability parameters of concrete.

Methods:
The experimental procedure involved in the research work comprising of two part like mechanical strength evaluation & durability performance analysis. For mechanical strength evaluation compressive strength & flexural strength of concrete has worked out, while for durability performance o[1]f concrete test like RCPT, ERT, Sorptivity test and Water Permeability test has been conducted. The reduction in cement consumption by using alternate supplementary cementitious materials like fly ash, silica fume etc. as a partial replacement of OPC in concrete is one of the best choice method globally accepted.

Results:
As per the experimental outcome, it has been observed that concrete with partial replacement of OPC by using SCM like fly ash and silica fume shows significantly higher strength of concrete & also better durability performance than concrete with only OPC. However, the experiment has also shows that on combination of both fly ash & silica fume shows even better strength & durability performance than using of individual SCM like either fly ash or silica fume. The experimental results also show that on adding fly ash up to 15% the workability of concrete increases due to ball bearing effect of spherical sizes fly ash, however on further increase in fly ash % the workability got decreases due to increase in surface area of fines in

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concrete. The results of fresh concrete also show that on adding of silica fume up to 5% shows improvement in workability, however on 10% it shows reduction in workability due to increased fines in concrete.

Conclusion:

The experimental results show that using of SCM in concrete as a partial replacement of OPC in concrete as a combined form like fly ash and silica fume shows significant improvement in mechanical strength of concrete and durability performance of concrete with a significant reduction in carbon foot print. In general 1 MT of cement production involved for almost 1 MT of CO_2 to the atmosphere, so 25% OPC reduction in concrete is simply reduce the carbon foot print by 25% of cement industries generated CO_2 contribution. Thus by promoting the use of SCM in concrete as a partial replacement of OPC mitigate the disposal issue of the waste & also it helps to reduce the carbon foot print contribution of cement industries. Thus by reducing the OPC consumption in concrete through using of SCM shows significant reduction of carbon foot print along with significant improvisation of concrete strength & durability performance.

Keywords: *OPC, Fly Ash, Silica Fume, Compressive Strength, Flexural Strength, ERT, RCPT, Carbon foot print, Durability.*

1.0 Introduction:

The reduction of the carbon foot print is one of the primary concern of the entire world considering the threat of global warming. The contribution of global carbon foot print has lots of sources, however in the present research work is based on the source of cement industries generated carbon foot print. As per the available data cement industries alone responsible for 8% of total CO_2 generation to the atmosphere[1]. The usage of fly ash in different segments like cement manufacturing, subgrade material of road [2], agriculture fields, bricks and tiles manufacturing, reclamamtion of low lying area, ash dyke raising, mine filling and most important concrete production in construction industry is in vogue after continuous effort taken by government to achieve the commitment made on various international forums. Thus the objective of the present research work is to find out the way to reduce the carbon foot print of cement industries by using supplementary cementitious materials as a partial replacement of OPC without compromising the mechanical strength & durability performance of concrete. The research work has been carried out with two types of supplementary cementitious materials like thermal power plant generated fly ash whose disposal is one of the major concern in thermal industries and silica fume from ferrosilicon alloy industries.The present research work shows that on partial replacement of OPC with either Fly ash or with Silica fume or with combined form of replacement by using fly ash & silica fume together shows significant improvement in mechanical strength & durability performance of concrete as compared to concrete with normal OPC along with CO_2 reduction of cement industries by 25%. The research work also shows that concrete with combined using of fly ash & silica fume as a replacement of OPC shows significantly better mechanical strength & durability performance as compared to concrete with only OPC & even concrete with either fly ash or only Silica fume. To deal with environmental concerns there is need to concentrate over the issues like waste disposal of fly ash and CO_2 emission [3], as observed, influence of mixing fly ash in concrete has been phenominal on its characteristics. Usage of fly ash has an advantage to increase the magnitute of depolymerization of SiO_4 that enhances pozzolanic reactivity [4]. As mixing of fly ash in concrete has many positive implications but 100% utilization has not been achieved due to many disadvantages [5]. The results reveals that concrete mixtures having fly ash with internal curing supports benefits in terms of decrease in transport coefficients with respect to control concrete [6].

2.0 Material and Experimental methods:

2.1. Materials

The details of the material used for the research work are hereby explained as

1. **Cement**: Cement used for the work is OPC 43 grade conforming to IS-269:2015[7]. The physical & chemical properties are recorded in Table 01.
2. **Fly ash**: Fly ash used in the research work is conforming to IS-3812[8]. The physical and chemical properties are recorded in Table 2.
3. **Silica fume**: Silica fume used in the research work is conforming to IS-15388[9]. The physical and chemical properties are recorded in Table 2.
4. **Fine aggregate**: The fine aggregates used in the research work is Kachni river(Singraulli Distt. M.P. India) sand & conforming to Zone II as per IS-383[10]. The physical properties of the fine aggregate is recorded in Table 03.
5. **Coarse Aggregate**: The coarse aggregate used in the research work is crushed stone of basalt rock(Makroher, Singraulli distt. M.P. India) conforming to IS-383[10].The physical properties of the fine aggregate is recorded in Table 04.
6. **Water**: The mixing water of concrete used in the research work is portable water having pH value 7.0 confirming IS 3025, part 17,18,24,32[11] also confirming to IS 456(2000)[12].

Table 01: Chemical & Physical properties of OPC 43 grade cement

SI. No.	Characteristics	UOM	Observed values
1	Blaine Fineness	m^2/kg	4
2.	Specific Gravity	-	3.15
3.	Standard Consistency	%	31
4.	Initial Setting Time	Minutes	150
5.	Final Setting Time	Minutes	311
6.	Compressive Strength of cement at 28 days	MPa	47.6
7	Soundness by autoclave	%	0.08
8	Soundness by Lee chatelier	mm	2.0
9	Loss of Ignition	%	2.27
10	Calcium Oxide(CaO)	%	62.04
11	Silica(SiO2)	%	21.26
12	Aluminium Oxide(Al_2O_3)	%	4.91
13	Iron Oxide(Fe_2O_3)	%	3.97
14	Magnisium Oxide(MgO)	%	2.01
15	Sulphates	%	2.0

Table 02: Physical & Chemical properties of Fly Ash & Silica Fume

SI. No.	Characteristics	Fly Ash	Silica fume
		Observed Values	Observed Values

Physical properties:			
1	Specific gravity	2.32	2.32
2.	Bulk density(kg/m^3)	410	300
3.	Color	Gray	Gray
4.	Specific surface area(m^2/kg)	289	20000
Chemical properties:			
1	Al_2O_3	22.18	0.6
2	CaO	18.51	0.90
3	Fe_2O_3	3.25	1.30
4	K_2O	1.56	0.90
5	MgO	0.98	1.20
6	Na_2O	0.95	0.80
7	S	1.85	0.50
8	SiO_2	39.77	92.6
9	Loss on Ignition	10.95	-

Table 03: Physical properties of Fine Aggregates

SI. No.	Parameters	UOM	Observed Values
1	Specific Gravity	-	2.57
2	Water Absorption	%	1.62
3	Bulk Density	Kg/l	1.61
4	Fineness Modulus	-	2.77
5	Silt content by weight	%	0.7

Table 04: Physical properties of Coarse Aggregate

SI. No.	Parameter	UOM	Observed Values
1	Specific Gravity	-	2.78
2	Water Absorption	%	0.2
3	Aggregate Impact Value	%	13.58
4	Aggregate Crushing Value	%	19.98
5	Aggregate Abrasion Value	%	19.90
6	Flakiness Index	%	13
7	Elongation Index	%	23

Table 05: Design Mix Proportions and Concrete Mix ID

Sl. no	Mix ID	Details of Cementitious materials on different Mix ID
1	M_0	(OPC-100%)
2	M_1	(OPC-80%+FA-20%)
3	M_2	(OPC-75%+ FA-25%)
4	M_3	(OPC-95%+SF-5%)

Sl. no	Mix ID	Details of Cementitious materials on different Mix ID
5	M_4	(OPC-90%+SF-10%)
6	M_5	(OPC-75%+FA-20%+SF-5%)
7	M_6	(OPC-75%+FA-15%+SF-10%)

2.2. Experimental Methods:

2.2.1. Sample preparation.

The sample was prepared in the laboratory for various test pertaining to mechanical strength like compressive strength as per IS-516[13], flexural strength as per IS-516 & durability test of concrete like RCPT as per ASTM C-1202[14] workability test as per IS 1199[15], sorptivity as per ASTMC-1585[16], Water permeability test as per BSEN-12390-8, Electrical resistivity test as per AASHTO T-288. The minimum number of test specimen used for each test are 3 nos. The tested results are the average results of 3 test specimens.

2.2.2. Workability test:

Workability test of concrete was carried out by slump test as per IS 1199[15].

2.2.3. Compressive Strength test:

Compressive strength of concrete was carried out on cube sample of having sizes 150 mm x150 mm x 150 mm as per IS 516-1959.

2.2.4. Flexural Strength test:

Flexural strength of concrete was carried out on beam shaped test specimens of dimension 150 mm x150 mm x 500 mm as per IS 516-1959.

2.2.5. Rapid Chloride Permeability test (RCPT):

Rapid chloride permeability test was carried out on circular concrete disc having diameter 100 mm & 50 mm thick as per ASTM C 1202.

2.2.6. Electrical Resistivity test (ERT):

Electrical resistivity test of concrete was carried out as per AASHTO TP-95, by wenner four probe method.

2.2.6. Sorptivity test:

The sorptivity test of concrete was carried out as per ASTM C-1585 on circular concrete disc of diameter 100 mm & thickness 50 mm.

2.2.7. Water Permeability test:

The water permeability test of concrete was carried out as per BSEN -12390-8 on concrete cube sample of sizes 150 mm x 150 mm x 150 mm.

3.0 Results and Discussions:

3.1 Workability of concrete:

Table 6: Workability of concrete by slump test of concrete.

Mix ID	Workability
M_0	145
M_1	189
M_2	171
M_3	170
M_4	160
M_5	140
M_6	130

As per the observed test results on Table-6 it has been observed that up to 15% replacement of OPC by fly ash there is an improvement in workability due to ball bearing effect of spherical shaped fly ash particle[17], while on further increase of fly ash % up to 25% the workability of concrete get reduced due to increased in fly ash content increasing the surface area of fines in concrete. The results also shows that the workability of concrete gets reduced on addition of Silica fume in concrete due to its very high fineness (> 20000 m2/kg).

Table 7: Mechanical Strength of diefferent Mix IDs

Mix ID	Compressive Strength(MPa)	Flexural strength(MPa)
M_0	45	5.2
M_1	52	5.7
M_2	54	5.9
M_3	58	6.2
M_4	61	6.5
M_5	65	6.8
M_6	72	7.2

3.2 Mechanical strength of concrete:

From the Table-07 it has been observed that concrete with increased % of fly ash shows better strength of concrete than concrete with normal OPC, while concrete with increased % of silica fume (10%) shows even better strength than concrete with increased % of fly ash (25%). However the result also shows that concrete with both fly ash & silica fume in concrete shows significantly better strength than concrete with either fly ash or silica fume. The increase in strength of concrete on using of increased fly ash or silica fume or combined using of fly ash & silica fume is mainly due to formation of secondary C-S-H gel because of the reaction between the portlandite [$Ca(OH)_2$] & amorphous silica [SiO_2] of fly ash or silica fume. The strength development of SCM based concrete is also due filling of micro pores of concrete microstructures because of small size fly ash or silica fume used in concrete.

$$2\,[3CaOSiO_2] + 6H_2O \quad = \quad 2\,[3CaOSiO_2] \quad + 3Ca(OH)_2$$

$$Ca(OH)_2 + SiO_2 \;=\; \text{Secondary C-S-H gel}$$

Fig-01: Compressive strength & Flexural strength test of concrete clicks.

Table 8: Durabality test of concrete for different Mix IDs

Mix ID	Water permeability(mm)	RCPT(Coulomb)	sorptivity(x10^{-4} g/mm^2)	ERT value (KΩ cm)
M_0	35.5	2358	18.6	42
M_1	27.4	2130	11.2	65
M_2	24.7	1670	8.25	75
M_3	21.2	1034	7.58	78
M_4	18.8	873	6.56	84
M_5	16.4	750	5.9	95
M_6	12.6	500	5.6	115

3.2 Durability performance of concrete:

From the observed durability test results of different concrete mix on Table-8, it has been observed that concrete with increased % of fly ash shows lower water permeability & sorptivity of concrete as compared to concrete with normal OPC, while the results also shows that concrete with increased % of silica fume (10%) & increased % of fly ash (25%), shows even lower value of water permeability & sorptivity as compared to concrete with reduced % of fly ash & silica fume. However the result also shows that concrete having both fly ash & silica fume in their mix with 10% silica fume shows significantly reduced water permeability & sorptivity due to formation of secondary C-S-H gel which fills the micro pores structures of concrete formerly occupied by water & dissolving cement particles [18], because of the reaction between the portlandite [$Ca(OH)_2$] & amorphous silica [SiO_2] of fly ash or silica fume as shown above. The reduction in water permeability & sorptivity is also due to filling of micro pores of concrete microstructures because of small size fly ash or silica fume used in concrete. The research work also shows that on increasing fly ash % in concrete the RCPT value gets decreased because of chloride binding phenomenon of high Al_2O_3 content of fly ash with monosulphate & forming friedel salt [3CaO Al_2O_3. $CaCl_2$. 10 H_2O] [19].

$3CaOAl_2O_3.CaSO_4.\ 12\ H_2O + 2Cl^- = 3CaO\ Al_2O_3.CaCl_2.\ 10\ H_2O + SO_4^{-2} + 2H_2O$

The results also shows that on increasing the silica fume the RCPT value is also reduced due to filling of micro pores of concrete microstructures because of very small size of silica fume (<1 micron) used in concrete and also due to chemisorption of free chloride ions by secondary C-S-H gel, [20]. The increased ERT as observed in Table-8 with increasing the % of fly ash & silica fume is due to micropore filling of concrete because secondary C-S-H gel formation & due to filling of pores by micro particles of silica fume & fly ash in concrete. Because of the filling of pore structures with secondary C-S-H gel & micro particles the resistivity of concrete get increased [21].

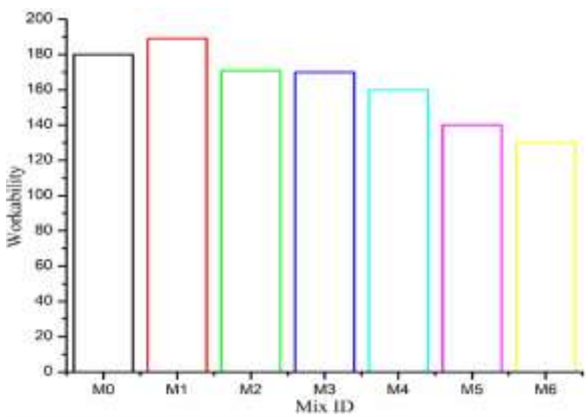

Fig. 02: Slump value of different concrete mix.

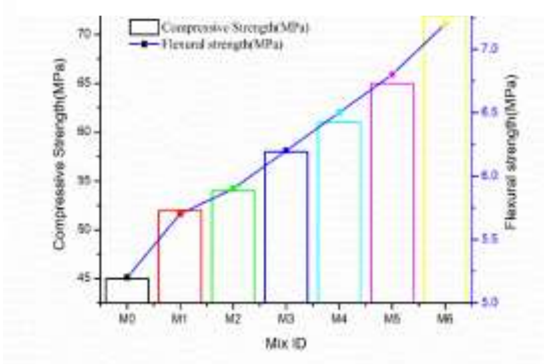

Fig. 03: Compressive strength and Flexural strength of concrete.

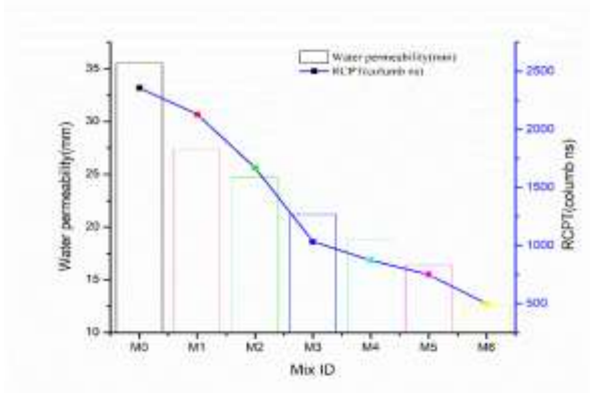

Fig. 04: Water permeability & RCPT values of different concrete mix.

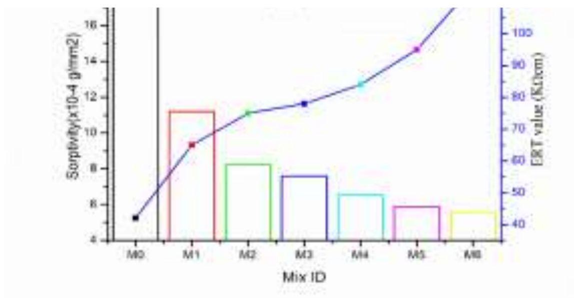

Fig. 05: Sorptivity & ERT values of different concrete mix.

4.0 Conclusion:

The outcome of the present research studies.

On addition of Fly ash as a replacement of OPC shows improved workability up to 15% while on further increasing the % up to 25% shows reduction in workability. On addition of Silica fume as a replacement of OPC shows reduction in workability due its very high fineness causing very high surface area resulting more demand of water. With increasing the % of fly ash up to 15% & silica fume up to 10% as a replacement of OPC in concrete shows improvement in mechanical strength as compared to normal OPC based concrete due to formation of secondary C-S-H gel & also due to microfilling of pores by micro size of Silica fume. Replacement of OPC with combined using of fly ash & silica fume (Mix-ID M6) shows better mechanical strength as compared to concrete with normal OPC, & partial replacement of OPC by only fly ash or silica fume due to combined effect of secondary C-S-H gel formation in empty pore spaces formerly occupied by water & dissolving cement particles & also due to filling of pores by micro size fly ash & silica fume particles.Replacement of OPC by fly ash the RCPT value of concrete get reduced due to free chloride binding action by formation of friedel salt because of rich Al_2O_3 composition of fly ash. Replacement of OPC by silica fume the RCPT value of concrete get reduced due to free chloride binding action by chemisorption process of secondary C-S-H gel, formed in pozzolonic reaction between silica fume & portlandite generated from hydration of OPC cement. The water permeability, sorptivity of concrete get reduced & ERT value get increased due to increased % of either fly ash or % of silica fume or combined using of fly ash & silica fume due to filling of micro pore structures of concrete because of secondary C-S-H gel, formed in pozzolonic reaction between fly ash or silica fume with portlandite[$Ca(OH)_2$] generated from hydration of OPC cement & also due to filling of pores by micro size particles of fly ash & silica fume. The research work shows that on replacement of maximum 25% OPC from concrete there is clear reduction in carbon foot print generated from cement industries by 25% without compromising the strength & durability performance of concrete, rather by using SCM in concrete as a partial replacement of OPC shows improved strength & durability performance of concrete.

LIST OF ABBREVIATIONS

CaO = Calcium Oxide, **SiO_2=** Silicon Oxide, **Al_2O_3=** Aluminium Oxide, **$CaSO_4$**=calcium sulphate, **$CaCl_2$=** Calcium Chloride, **$Ca(OH)_2$**= Calcium Hydroxide,

ASTM = American Society for Testing and Materials

AVAILABILITY OF DATA AND MATERIALS:

All the data and supportive information are provided within the article.

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CONFLICT OF INTEREST:

There is no conflict of interest between authors**.**

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