IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 1, May 2024

Sustainable Development of High Strength Concrete by Partial Replacement of Cement with Micro Silica and Flyash

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Abstract: *The production of Portland cement is widely recognized as both financially and environmentally burdensome due to its high energy consumption and significant carbon dioxide emissions. To address these challenges, researchers are exploring alternatives such as supplementary cementitious materials like pozzolanas, Pozzolanas which include fly ash and micro silica. These materials, though initially inert, exhibit cementitious properties when mixed with water and react chemically with calcium hydroxide during cement hydration. In this experimental investigation, to produce a high strength concrete a set of 3 different concrete mixtures were cast and tested with different cement replacement levels means fly ash (15%,17.5%,20%) and micro silica (5%,7.5%,10%) is added by the weight of cement and at each trial a PCE based superplasticizer of required amount is added to achieve the required slump and workability in M70 grade concrete. By incorporating fly ash and micro silica into the mix, Compressive strength tests are conducted at both 7,14 and 28 days to assess the performance of the concrete*

Keywords: High strength concrete, Micro silica, flyash, PCE superplasticizer

I. INTRODUCTION

Portland cement, a key ingredient in concrete, is one of the most widely used construction materials globally. However, its production is associated with significant environmental and economic challenges. The primary raw materials for Portland cement production include limestone, clay, and other minerals, which are typically mined from quarries. The extraction process not only depletes natural resources but also causes habitat destruction and landscape alteration, leading to environmental degradation. Micro silica is an extremely fine material, consisting of spherical particles with a high surface area. Its pozzolanic reactivity is significantly higher compared to other pozzolans like metakaolin or rice husk ash. Chemical formula of micro silica is SiO2, when micro silica is added to concrete, it fills the voids between cement particles, enhancing the density and reducing the permeability of the concrete matrix and its high reactivity also contributes to improved early strength development and long-term durability of concrete structures. Fly ash is a byproduct of coal combustion in power plants. It consists of fine particles that are spherical in shape. Chemical formula of fly ash is SiO2-Al2O3-Fe2O3.Fly ash reacts with calcium hydroxide (Ca(OH)2) in the presence of water to form additional calcium silicate hydrate (C-S-H) gel, which enhances the strength and durability of concrete. It also contributes to the reduction of heat of hydration, making it beneficial in mass concrete applications. When micro silica (SiO2) and fly ash are added to concrete, they react with the calcium hydroxide (Ca(OH)2) produced during the hydration of cement. The chemical reactions can be summarized as follows:

- For Micro Silica: Chemical Reaction: SiO2 + Ca(OH)2 → C-S-H gel (Calcium Silicate Hydrate) + CaO. In this reaction, micro silica (SiO2) reacts with calcium hydroxide (Ca(OH)2), a byproduct of cement hydration, to form additional C-S-H gel.C-S-H gel is the primary binder in concrete, responsible for its strength and durability. It fills the voids in the concrete matrix, enhancing its mechanical properties and reducing permeability.The reaction consumes calcium hydroxide and converts it into C-S-H gel, contributing to the densification and improvement of concrete microstructure.
- For Fly Ash: Chemical Reactions is 2(Al2O3·Fe2O3) + 3Ca(OH)2 + 6H2O → 3CaO·Al2O3·3H2O + 2(Fe2O3·3H2O) and 2(SiO2) + 3Ca(OH)2 → 3CaO·SiO2·3H2O Fly ash reacts with calcium hydroxide to form additional calcium silicate hydrate (C-S-H) gel and calcium aluminate hydrates (C-A-H), which further

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contributes to the strength and durability of concrete. Fly ash consists of various compounds, including Al2O3, Fe2O3, and SiO2, among others.

II. OBJECTIVES OF PROJECT

To reduced environmental impact and resource conservation. To determine the most effective combination of micro silica and fly ash percentages. Assess the impact of micro silica and fly ash on compressive strength properties of concrete when the specimens are tested for 7,14and 28 days.

III. MATERIAL INVESTIGATION

Concrete mix design is a process of selection of materials which will be used to make concrete to meet the minimum strength, durability and workability at as low cost as possible. The different proportions of these materials weredecided through reviewing previous articles. The tests performed at an ambient temperature of 18 degree Celsius.
Characteristics of materials used:

1. Cement:

Cement is basic binding material. in our investigation cement used is ordinary Portland cement of 53 grade. Cement for 53 grade is tested according to Indian standards 12269. Nugget free and recent cement is used.

2. Micro silica:

Silica fume works on Two levels. 1. The hydration of Portland cement produces many components, including silicate hydrates(CSH) and calcium hydroxide(CH). 2. The silica fume is added to the CH for produce the additional CSH to obtain a very good compressive strength can exceed 15000 psi. (1psi= 0.0069 mpa) The additional CSH produced by the silica fume is more resistant to attack from aggressive chemicals than the weaker CH. Chemical composition of Micro silica are

Property	SiO2	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O
Value(%)	90-96	0.6-0.3	0.3-0.8	0.4-1.5	0.1-0.6	0.3-0.7	.04-1.0

Physical characteristics of Micro silica:

Parameters	Values
Colour	Dark gray
Particle shape	Spherical
Particle size	Less than 1 micron
Average particle size	0.15 micron
Bulk density	130kg/m3 to 600kg/m3
Specific gravity	2.2 to 2.3

3. Fly Ash:

Fly ash, also known as flue-ash, is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases.

Sr. No.	Physical Properties	"Class F" fly ash
1	Color	Light brown
2	Residue retained on 45 µm, (%)	1.2
3	Specific surface area (Blaine), (m^2/kg)	392
4	Specific gravity	2.23
5	Moisture content, (%)	0.09
6	Autoclave expansion, (%)	0.04

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4. Fine Aggregate:

Fine aggregate, also known as sand, is a granular material that passes through the IS 4.75 mmsieve size. The Indian Standard specification for fine aggregate is IS 383:2016. This standard provides guidelines for theselection and quality control of fine aggregates used in construction.

5. Coarse Aggregate:

Coarse aggregate, is an essential component in the
production of concrete, particularly in high-strength concrete. In this project we have used the two coarse aggregate one is passing from 20mm sieve and the other is passing from 16mm IS sieve.

6. Water:

Water is a critical ingredient in concrete production. Water is a critical ingredient in concrete production.

7. PCE based superplasticizer:

In this experimental investigation we are using a PCE based superplasticizer as per the guidelines and recommendations provided in IS 10262-2019 concrete mix design code book. PCE-based superplasticizers work by dispersing the cement particles in a concrete mixture. The long molecular chains of polycarboxylate ethers (PCEs) wrap themselves around individual cement particles, creating a repulsive force that prevents the particles from clustering together. This dispersion effect ensures that the cement particles are evenly distributed throughout the mixture, resulting in a more homogeneous and uniform concrete matrix.

Properties of the materials:

Property	Cement	Fine Aggr.	Coarse Aggr.	FA	MS
Water absorption	-	0.9%	0.45	-	-
Specific gravity	3.16	2.67	2.75	2.2	2.2

IV. EXPERIMENTAL PROGRAME

Casting Procedure:

Casting of Concrete Cubes Concrete is mixed either by hand. The dry ingredients are mixed and water is added slowly until the concrete is workable. This mixture may need to be modified depending on the aggregate used to provide a concrete of the right workability. The mix should not be too stiff or too sloppy. It is difficult to form good test specimens if it is too stiff. If it is too sloppy, water may separate (bleed) from the mixture.


For casting, all the moulds were cleaned and oiled properly. There were securely tightened to correct dimension before casting.


Then the concrete mixture is filled into the moulds of dimensions 15*15*15cm and at each appro. 75mm the tamping 35 blows is done with tampering rod this id to void the air gaps in mixture.

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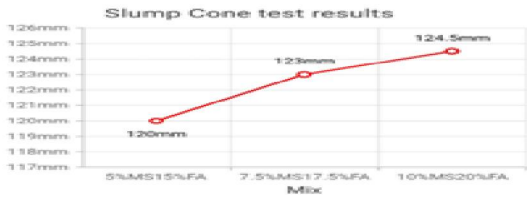
After 24hours the moulds are remoulded and they are shifted into a curing tank where cubes are kept for curing until the day of testing means it may be for 7 14 or 28days.


V. TESTS ON CONCRETE

Workability test:

When the workability test performed instability with rise and fall of values were recorded. For distinct segments of FA and MS instability in slump value were discovered. The tests performed were according to Indian standard IS 456:2000.

Mix	w/c ratio	Slump Value (mm)
Mix1	0.26+0.5%admix.by the wt. of cementitios material	120
Mix2		123
Mix3		124.5



Compressive strength:

Compressive testing is done at specified period of time after curing 7,14 and 28 days but before testing the cubes are taken out of curing tank the kept for rest for time then the test is carried out in the testing machine called “universal testing machine”.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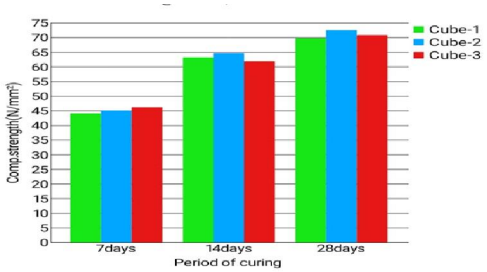
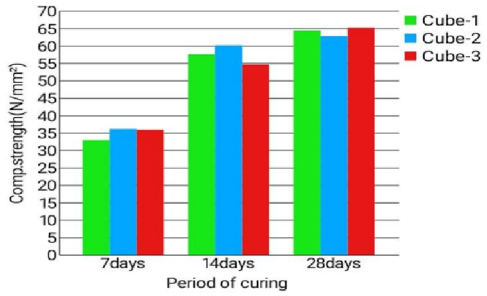
Compressive Strength for Results of mix-2:

Specimen no.	W/C ratio + Chem. admixture	7days strength (N/mm²)	14days strength (N/mm²)	28days strength (N/mm²)
1.	0.26+0.5%admix.by the wt. of cementitios material	44.102	63.27	69.98
2.		45.110	64.7	67.89
3.		46.230	61.99	68.95
		45.15	63.35	68.95



Compressive Strength for Results of mix-2:

Specimen no.	W/C ratio + Chem. admixture	7days strength (N/mm²)	14days strength (N/mm²)	28days strength (N/mm²)
1.	0.26+0.5%admix.by the wt. of cementitios material	33.02	57.66	64.53
2.		36.21	60.23	62.89
3.		36.01	54.69	65.32
		35.08	57.52	64.24



Compressive Strength for Results of mix-3:

Specimen no.	W/C ratio + Chem. admixture	7days strength (N/mm²)	14days strength (N/mm²)	28days strength (N/mm²)
1.	0.26+0.5%admix.by the wt. of cementitios material	29.96	52.94	64.16
2.		32.97	53.65	58.64
3.		29.78	56.12	60.06
		30.90	54.23	60.95

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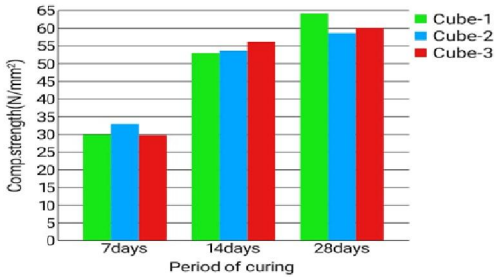
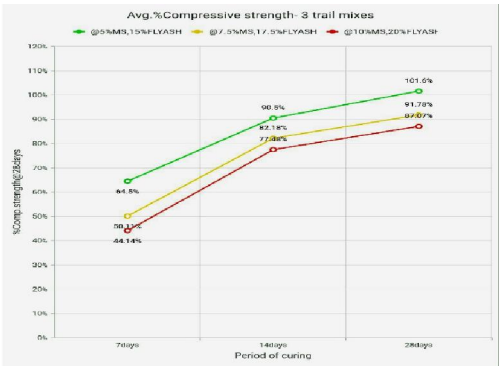


Average Compressive Strength of 3 Mixes:



Discussions about results :

It can be seen that by replacing cement with fly ash (15%,17.5%,20%), silica fume (5%,7.5%,10%) in high strength concrete(M70grade), the maximum strength (i.e., 70N/mm2) is obtained at 5%micro silica and 15% fly ash and the average maximum strength at 28 days obtained is 71.12 N/mm2 and the average maximum compressive load the specimen beared at 71.12N/mm2 is 163.11*103 kgf (1600.2*103N).The highest compressive strength was achieved in 28 days which was found about 101.6% .

And it is seen that, the increase in amount of silica flume and fly ash and decrease in amount of cement may lead to decrease compressive strength of concrete i.e., at 10%micro silica and 20%flyash at 28 days the amount of strength obtained is 60.95 N/mm2 (287.07%) that means the strength decreased is about 10.17 N/mm2 means 14.52% strength is decreased .

VI. CONCLUSION

1.Our findings, particularly the identification of the optimum combination of 5% microsilica and 15% fly ash resulting in the highest compressive strength of 71.12 N/mm²at 28 days for M70 grade concrete, underscore the efficacy of these substitutions in enhancing concrete performance. This represents a significant improvement of approximately 101.6% over conventional concrete, highlighting the potential of our approach to revolutionize construction practices.

2.Moreover, the evaluation of compressive strength at 7,14 and 28 days provides comprehensive insights into the long-term performance and durability of the concrete mixtures.

3.Finally, our project not only contributes to the development of high-strength concrete but also embodies a holistic commitment to sustainable construction. By reducing reliance on Portland cement and promoting the utilization of supplementary materials like fly ash and micro silica, WE have demonstrated a tangible pathway towards greener, more resilient infrastructure. Our meticulous experimentation, coupled with compelling results, positions our research as a cornerstone in the ongoing quest for sustainable development in the construction industry.

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