

Comparative Analysis on Partial Replacement of Cement by Mixture of Nano-Silica, Metakaolin, Ground Granulated Blast Furnace Slag

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ABSTRACT

The manufacture of cement produces lot of pollution like about produce 7% of carbon dioxide emission, which has encouraged the use of supplementary cementitious materials to develop sustainable concrete. This study investigates the effect of partial replacement of cement with nano-silica (NS), metakaolin (MK) and GGBS. Cement was partially replaced by nano-silica with different dosages are 1%, 1.5%, and 2%, metakaolin fixed dosage 8%, and GGBS at 60% by weight of cement. A conventional concrete is also prepared to comparison. Concrete specimens were cast and tested to evaluate strength of concrete. The addition of nano-silica enhanced early-age strength due to its high pozzolanic reactivity and while metakaolin contributed to improved strength. GGBS significantly improved long-term strength and sustainability by reducing cement content and heat of hydration. From the use of mixture of nano-silica, metakaolin, and GGBS improves the overall performance of concrete, with the optimum nano-silica content observed at 2% replacement. This blended cement concrete demonstrates enhanced strength characteristics and offers an eco-friendly alternative to conventional concrete.

Keywords: Cement, Nano-Silica, Metakaolin

INTRODUCTION

Experimental study is carried out on a partial replacement of cement under different parameters on the aspects of experimental and theoretical behavior with the use of nanosilica, metakaolin, granular blast furnace slag. The construction and cement industries has an adverse effect on environment, like air pollution due to it accounts for approximately 8% of carbon-di-oxide emission. Because of this researchers explores to find alternative for cement by cementitious materials partially to replace cement.

To improve or maintain the strength of concrete as similar when we use cement, from research and investigation mixture of nanosilica is good alternative for cement. Because largest specific surface area, fine particle size, strong surface adsorption, high chemical purity and good dispersion of NS, high pozzolanic reactivity and low heat of hydration of metakaolin, reduced permeability, longer strength, lower CO₂ emission, enhanced resistance to chemical attacks of blast furnace slag.

LITERATURE REVIEW

The optimum quantity of nano-silica for concrete or cement paste cannot be fixed. The research is not enough in confidence building for their use in concrete. The complete systematic experimental study is carried out to observe optimum dosage of Nano-silica. Most of the researchers worked on cement pastes and mortars only and few researchers have worked on concrete so it is open to study. Most studies focus on short term properties, so there's a need for long term assessments of Nano silica.

OBJECTIVES

- To increase mechanical properties of concrete by partially replacement of the cement by mixture of Nano silica, pozzolanic ground blast furnace slag, metakaolin.

- To improve workability of concrete using the mixture of Nano silica, pozzolanic ground blast furnace slag, metakaolin compared to referenced concrete

METHODOLOGY

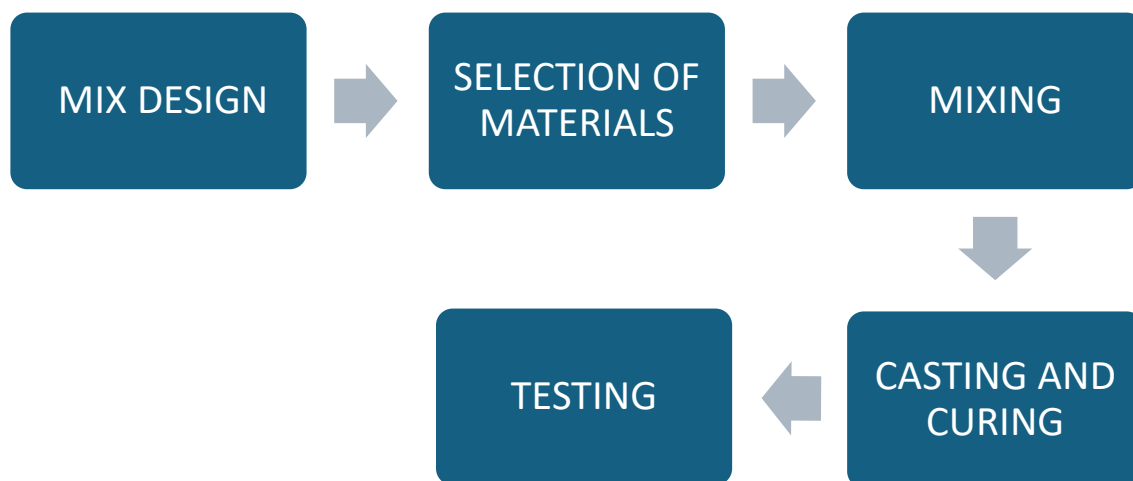


FIG. 1: Flowchart showing methodology

MIX DESIGN

The concrete mix is designed as per IS 10262-2009, IS 456-2000

DESIGN DETAILS:

1. Grade designation	:	M25
2. Type of cement	:	OPC 43 grade conforming to IS 8112
3. Maximum nominal size of aggregate:		20 mm
4. Minimum cement content (IS 456, Table-5)	:	300 Kg/m ³
5. Maximum water-cement ratio	:	0.5
6. Workability	:	75-100mm (slump)
7. Exposure condition (IS 456, Table-3)	:	Moderate
8. Method of concrete placing	:	By hand
9. Degree of supervision	:	Good
10. Type of aggregate	:	Crushed angular aggregate
11. Maximum cement content (clause 8.2.4.2 of IS 456)	:	450 Kg/m ³
12. Chemical admixture type	:	Nil

Step 1: Preliminary test datas :

- Specific gravity
 - cement : 3
 - Fine aggregate : 2.71
 - Coarse aggregate : 2.78
- Water absorption :
 - Fine aggregate : 1.01%
 - coarse aggregate : 0.705%

c) Free moisture:

- a) Fine Aggregate: Nil
- b) Coarse Aggregate: Nil

d) Sieve analysis

- a) Fine Aggregate: Confirming to grading Zone-I of table 9 of IS 383-2016
- b) Coarse Aggregate: Confirming to table 7 of IS 383-2016

Step 2: Target strength for mix proportion:

Target mean strength a) $(f'_{ck}) = f_{ck} + 1.65(S)$

$$= 25 + (1.65 \times 4)$$

$$= 31.6 \text{ N/mm}^2$$

b) $f'_{ck} = f_{ck} + X$

$$= 25 + 5.5$$

$$= 30.5 \text{ N/mm}^2$$

Where “S” is the standard deviation taken from the Table 2 of IS 10262-2019.

Where “X” is the factor based on grade of concrete taken from the Table 1 of IS 10262-2019.

Target strength for mix = 31.6 N/mm²

Step 3: water cement ratio:

From IS 10262-2019(Page 4) Fig 1

W/C ratio = 0.5

Step 4: water content:

From Table 4 of IS 10262-2019.

Max. water content for 20mm nominal size: 186 lit

(Clause 5.3 indicates that for every 25mm slump increase 3% of water)

Water content for 75mm slump = $186 + (3/100) \times 186 = 191.58\text{kg} \sim 192\text{kg}$

Step 5: Calculation of cement content:

Adopted water cement ratio: 0.5

Water content adopted: 192Kg

Cement content: Water content adopted/Water Cement ratio adopted

$$: 192/0.5$$

$$: 384 \text{ Kg/m}^3$$

Adopted cement content: 384 Kg/m³ > 300 Kg/m³, Hence OK

Step 6: Calculation Of Volume of Coarse Aggregate and Fine Aggregate:

From table 5 of IS 10262-2019, Volume of Coarse aggregate is 0.62m³

According to Clause 5.5.1, For every 0.05 increase W/C ratio increase 0.01 Volume of Coarse aggregate.

Therefore, Volume of Coarse aggregate = 0.62m³

Volume of fine aggregate: $1 - 0.62 = 0.38\text{m}^3$

Step 7: Mix calculation

- a. Volume of concrete: 1m³
- b. Volume of cement: mass of cement /Specific gravity of cement X 1/1000

- : $384/2.99 \times 1/1000 \quad 1$
- : 0.128 m^3
- c. Volume of water: mass of Water /Specific gravity of water $1/1000$
- : $192/1 \times 1/1000 \quad 1$
- : 0.192 m^3
- d. Total volume of aggregate: $1 - (0.128 + 0.192)$
- : 0.68 m^3
- e. Mass of Coarse aggregate: $0.68 \times 0.62 \times 2.78 \times 1000$
- : 1172 kg
- f. Mass of Fine aggregate: $0.68 \times 0.38 \times 2.71 \times 1000$
- : 700.264 kg

Cement	Fine aggregate	Coarse aggregate	Water
384	700.264	1172	192.00
1	1.8	3.05	0.52

QUANTITY CALCULATION

CUBE:(Conventional concrete) Quantities required for 1 Cube with 10% extra

- i. Volume of Cube: 1 m^3

$$\text{Volume of Cube} : (0.15 \times 0.15 \times 0.15) \text{ m}^3 = 3.375 \times 10^{-3} \text{ m}^3$$

$$\text{Concrete required for 1 cube} = 3.375 \times 10^{-3} \times 2500 = 8.4375$$

$$10\% \text{ for wastage} = 8.4375 + [(10/100) \times 8.4375] = 9.28 \text{ kg}$$

$$\text{Cement} : 9.28 / (1 + 1.8 + 3.05) = 1.58 \text{ kg}$$

$$\text{Fine aggregate} : 1.58 \times 1.8 = 2.84 \text{ kg}$$

$$\text{Coarse aggregate} : 1.58 \times 3.05 = 4.819 \text{ kg}$$

$$\text{Water} : 0.5 \times 1.58 \times 1000 = 790 \text{ ml}$$

Replacement Ratio	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (ml)	Cement (kg)	GGBS	Metakaolin	S
60%GGBS, 8%M,2%NS, 30% cement	2.84	4.81	790	0.47	0.948	0.126	0316
60%GGBS, 8%M,1.5%NS, 30.5% cement	2.84	4.81	790	0.48	0.948	0.126	237

60%GGBS, 8%M,1%NS, 31%cement	2.84	4.81	790	0.49	0.948	0.126	158
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Table 1. Quantities with different proportions for one cube

RESULTS

Compression strength test:

Sly No	Variations	Failure Load P (kN)	Area (A) mm ²	Compressive Strength (P/A) (N/mm ²)	Average Compressive strength (N/mm ²)
1	Conventional concrete	410	22500	18.22	18.81
		440	22500	19.55	
		420	22500	18.66	
2	Replaced (60%GGBS,8%M,2%NS,30%Cement)	502	22500	22.31	22.30
		503	22500	22.35	
		501	22500	22.26	
3	Replaced (60%GGBS,8%M,1.5%NS,30.5%Cement)	497	22500	22.08	22.08
		498	22500	22.13	
		496	22500	22.04	
4	Replaced (60%GGBS,8%M,1%NS,31%Cement)	454	22500	20.17	20.44
		458	22500	20.35	
		468	22500	20.8	

Table 2. Compressive strength of cubes (7 days)

1	Conventional concrete	566	22500	25.15	24.85
		540	22500	24	
		572	22500	25.42	
2	Replaced (60%GGBS,8%M,2%NS,30%Cement)	659	22500	29.28	29.28
		660	22500	29.33	
		658	22500	29.24	
3	Replaced (60%GGBS,8%M,1.5%NS,30.5%Cement)	623	22500	27.6	27.63
		622	22500	27.6	
		624	22500	27.7	

4	Replaced (60%GGBBS,8%M,1%NS,31%Cement)	604	22500	26.84	26.84
		603	22500	26.8	
		606	22500	26.9	

Table 3. Compressive strength results of cubes (14 days)

1	Conventional concrete	702	22500	31.2	31.4
		708	22500	31.4	
		714	22500	31.7	
2	Replaced (60%GGBBS,8%M,2%NS,30%Cement)	894	22500	39.73	39.82
		898	22500	39.91	
		896	22500	39.82	
3	Replaced (60%GGBBS,8%M,1.5%NS,30.5%Cement)	849	22500	37.7	37.6
		844	22500	37.5	
		846	22500	37.6	
4	Replaced (60%GGBBS,8%M,1%NS,31%Cement)	824	22500	36.6	36.6
		822	22500	36.5	
		828	22500	36.8	

Table 4. Compressive strength results of cubes (21 days)

CONCLUSION

- Replacement levels range between 1%, 1.5%, and 2% by weight of cement. The 2 percent of cement mass provide better performance as compared 1% and 1.5%.
- The above experiment results signifies the improvement in compressive strength of nano-silica as partial replacement of cement in concrete.
- Concrete containing Nano silica shows reduced slump and workability due to high surface area and absorption capacity.
- The particle sizes of Nano silica also effect the strength of concrete; fine particles of Nano silica give good result compared to larger particles.
- Metakaolin improves early age strength.
- Concrete containing ground granulated blast furnace slag reduces energy consumption and less emission of pollutants.

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