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A Review Paper on Partial Replacement of Cement by Fly Ashin High-Strength Concrete

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Abstracts *The demand for high-strength concrete is increasing in the construction industry. This study aims to use waste materials to make cement, concrete, and other construction materials while saving energy and protecting the environment. High-strength concrete has better properties than ordinary concrete, and achieving it requires a proper mix design process. Good quality ingredients, adequate casting and testing methods, and a low water-cement ratio are essential for high-strength concrete. This research focuses on studying the mix design of high-strength concrete with partial replacement of fly ash in different proportions. Tests were conducted to measure compressive strength, rebound hammer, and ultra-pulse velocity at 7 days and 28.*
Fly ash concrete samples showed a lower drying shrinkage than the control concrete samples when designed for the same 28-day compressive strength of the control concrete. The inclusion of fly ash reduced sorptivity and chloride ion permeation suggestively at 28 days and decreased further at 6 months. In general, the incorporation of fly ash as a partial replacement of cement improved the durability properties of concrete.
Keywords: *Fly ash replacement, 15%, 17.5%, 20%, cement, concrete, admixture*

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I. INTRODUCTION:

Concrete has to be of satisfactory quality in its fresh and hardened states. Trial mixes best accomplish this task by using certain established relationships among different parameters and analyzing already generated data, thereby developing a basis for a judicious combination of all the ingredients involved. The basic principles that underline the proportioning of mixes are Abram's law for strength development and Lyse's rule for making a mix with adequate workability for placement in a dense state to enable strength development as contemplated. From a practical point of view, compressive strength is often considered an acceptability index. This does not necessarily satisfy durability requirements unless examined under a specific context. Mix proportioning is generally carried out for a particular compressive strength or flexural strength requirement, ensuring that fresh concrete of the mix so proportioned possesses adequate workability for placement without segregation and bleeding while attaining a dense state.

II. GET PAPER REVIEWED:

Wen-Ten Kuoet al. [1] Investigated the Effect of ground-granulated blast furnace slag (GGBFS). He has tested the mechanical and electrical properties to assess the correlations among flow, compressive strength, water absorption, and electricity at 50 V and 100 V. At the curing age of 28 days, the compressive strength of the control group was 29.1- 1.7 MPa, whereas the compressive strength of PZT was 26.8 - 30.0 MPa. The control group exhibited higher results (1786–2075 X) in the electricity property test under 50 V, whereas PZT exhibited lower effects (1368–1562 X). The compressive strength and results of the electricity property tests demonstrated that the compressive strength and electrical resistance decreased as the replacement of GGBFS increased. The strength of the control group was higher than that of PZT because the piezoelectric material replaced 5% of the fine aggregate, and the piezoelectric material was water-resistant. Thus, the piezoelectric material could not be effectually combined with fine aggregate and cement.

F. Baeza et al. [2] have researched the combination of industrial waste from different sources as a partial replacement of Portland cement in pastes and mortars. He has done Binary and ternary combinations of sewage sludge ash (SSA) with marble dust (M.D.), fly ash (F.A.), and rice husk ash (RHA) as replacements in Portland cement pastes, which were assessed. He has conducted several tests at different curing ages: thermogravimetry, density, water absorption, ultrasonic pulse velocity, and mechanical strengths. Pozzolanic effects of the mineral admixtures, densities similar to the control sample, and improved absorptions when combining waste materials were identified. The compressive strength generally reaches or exceeds the cement strength class, and blending SSA, F.A., and RHA (30% cement replacement) increased strength by 9% compared to the control sample.

W.W.J. Chan et al. [3] Conducted a study on the durability of concrete made from several non-reactive waste materials, i.e., carbon black, silts and clays, and various water contents were investigated. He has studied different tests like compressive strength, workability, sorptivity, and water permeability of the concrete. He has also made a detailed investigation based on the resulting change in the microstructure and cement hydration in These concretes by means of X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy dispersive X-ray (EDX) spectroscopy. Workability can be increased by increasing the specific surface area or using a superplasticizer. So, in the present study, he has used silt and clay for research in varying proportions. He found that 25 vol.% of cement was replaced by silts and clay using a water/cement (w/c) ratio of 0.5, which gives durable concrete. The cement and water content was less than that of OPC. Also, the cost of concrete will be dropped.

O. Rodríguez et al. [4] Have analyzed several reservoir sludges' chemical, physical, morphological, mineralogical, and pozzolanic characteristics and assessed their potential for use as 20% additions in blended cement manufacture. The studied sludges exhibit good pozzolanic properties, especially sample 5, which has high SiO2, Al2O3, and Fe2O3 contents. Blended blocks of cement prepared with 20% sludge additions complied with the European standard on compressive strength of one of the standardized types of cement above 32.5 MPa at28 days of curing, except for sample 5, which showed similar compressive strength values to the reference cement and up to 2% higher values at long curing times.

Khmiri et al. [5] Investigated the pozzolanic activity of finely ground waste glass when used as a part cement replacement in mortars. The behavior of this byproduct was observed through two sets of tests: a lime–glass test to assess and clarify the pozzolanic phenomena and a compressive strength test to monitor the strength growth. Analyses by DSC, XRD, and SEM of samples containing 25% Ca (OH)2 and 75% ground glass verified that this admixture induced the formation of calcium silicate. Calcium aluminosilicate hydrates at the expense of lime and hydrated sodium carbonate. The formation of the latter stage allowed us to clarify the size stability of prepared mortars by hydrated sodium silicate formation. Compressive strength of mortars containing ground glass with particle sizes in the range 100–80 lm, 80–40 lm, <40 lm, and < 20 lm fineness indicated that the 20-lm class exhibited a good pozzolanic behavior. Correspondingly, the corresponding strength activity indexes were 82%, 95%, and 102% at 7, 28, and 90 days.

III. METHODOLOGY

1. **Material Characterization:** - Identify and characterize the properties of all materials, including cement, aggregates, water, and fly ash. Ensure they meet relevant standards and specifications.
2. **Mix Design**: - Use a systematic mix design approach to determine the optimal combination of materials. Adjust proportions to achieve the desired M65 grade strength while incorporating different percentages of fly ash.
3. **Trial Mixes:** - Conduct trial mixes with varying proportions of fly ash (e.g., 15%, 17.5%, 20%) to assess the fresh and hardened properties of the concrete. Perform tests such as slump, compressive strength, and durability to evaluate the effects of fly ash on performance.
4. **Optimization**: Analyze the trial mix results and optimize the mix proportions based on the desired M65 grade strength, workability, and durability. Consider factors like the water-cement ratio and the specific characteristics of the fly ash.
5. **Batching and Mixing:** - Batch the materials accurately, ensuring a consistent mix. Utilize proper mixing techniques to achieve uniform ingredient distribution, and consider using admixtures for improved workability or other specific requirements.
6. **Placement:** - Implement appropriate placement techniques, considering the construction requirements and structural design. Ensure proper consolidation to minimize segregation and achieve uniform compaction.
7. **Curing:** - Apply a suitable curing regime to maintain optimal hydration and strength development conditions. Follow recommended curing practices to enhance the durability of the concrete.

Mix Design Detail of M65 Grade High Strength Concrete (As Per I.S. 10262-2019)

An example illustrating the mix proportioning for M65 grade fly ash concrete is given below. The use of fly ash is generally advantageous for grades of concrete M65 and above and for high-performance concrete with special requirements, like higher workability of concrete.

Step 1: - Stipulation for Proportioning

a. Grade designation : M 65

b. Type of cement : OPC 53 grade conforming to IS 269 (Ultratech)

c. Fly - Ash : Conforming to IS 3812 Part 1

d. Maximum nominal size of aggregate : 20 mm

e. Exposure conditions as per Table 3 and Table 5 of IS 456 : Severe (for reinforced concrete)

f. Workability : 100 mm

g. Degree of supervision : Good

h. Type of aggregate : Crushed angular aggregate

i. Maximum cement (OPC) content : 450 kg/m^3

j. Chemical admixture type : Super Plasticizer Ceraplast 300 PS (Polycarboxylate ether based)

Step 2: - Test Data for Material Calculation

a. Brand of Cement used : OPC 53 Grade conforming to IS 269 (Ultratech Cement)

b. Specific gravity of

1. Cement : 3.14
2. Coarse aggregate : 2.97
3. Fine aggregate : 2.66
4. Fly ash : 2.34
5. Chemical admixture : 1.20

c. Water absorption

1. Coarse aggregate : 1.27%
2. Fine aggregate : 1.46 %

d. Moisture content

1. Coarse aggregate : 1.00 %
2. Fine aggregate : 1.20 %

e. Sieve analysis

1. Coarse aggregate : As per IS 383:2016 confirming to grading zone II

IS Sieve	Analysis of aggregate friction		Percentage of different friction			Remark
	I (20-10 mm)	II (10-4.75 mm)	I 50%	II 50%	100%	
20	100	100	50	50	100	Conforming
10	2.8	78.3	14	39.15	40.55	to Table 7 of
4.75	Nil	8.7	Nil	4.35	4.35	IS 383

1. Fine aggregate : Conforming to grading Zone I of

Table 4.3.1 (Clause: 6.3) of IS 383 – 2016					
Sr. No.	IS Sieve	Percentage Passing			
		Zone I	Zone II	Zone III	Zone IV
1.	10 mm	100	100	100	100
2.	4.75 mm	90 – 100	90 – 100	90 – 100	95 – 100
3.	2.36 mm	60 – 95	75 – 100	85 – 100	95 – 100

4.	1.18 mm	30 – 70	55 – 90	75 – 100	90 – 100
5.	600 µ	15 – 34	35 – 59	60 – 79	80 – 100
6.	300 µ	5 – 20	8 – 30	12 – 40	15 – 50
7.	150 µ	0 – 10	0 – 10	0 – 10	0 – 15
8.	Fineness Modulus	4.0 – 2.71	3.37 – 2.1	2.78 – 1.71	2.25 – 1.35

Step 3: - Target Strength for Mix Proportioning

a. fck= fck + (1.65 S)

OR

b. fck = fck + X

Whichever is higher?
Where,
fck : - target average compressive strength at 28 days,
fck : - characteristic compressive strength at 28 days,
S : - standard deviation
X: - factor based on the grade of concrete.
From Table 4.3.3, standard deviation, S = 6.0 N/mm^2
Therefore, target strength using both equations, that is,

a. fck = fck + (1.65 S)
= 65 + (1.65 × 6.0)
= 74.9 N/mm^2

OR

b. fck = fck + 8.0 (The value of X for M 65 grade as per Table 4.2 is 8.0 N/mm^2)
= 65 + 8.0
= 73.00 N/mm^2

The highest value is to be adopted. Therefore, the target strength will be 74.9 N/mm2 as 74.9 N/mm2 > 73.0 N/mm2

Sr. No.	Grade of Concrete	**Table 4.3.2** (Clause: 4.2) Pg.3 **I.S.: 10262 – 2019**	**Table 4.3.3** (Clause: 4.2.1.3) Pg.3 **I.S.: 10262 – 2019**
		Value of (X)	**Assume Standard Deviation (S)**
1.	**M 10**	5.0	3.5
	M 15		
2.	**M 20**	5.5	4.0
	M 25		
3.	**M 30**	6.5	5.0
	M 35		
	M 40		
	M 45		
	M 50		
	M 55		
	M 60		
4.	**M 65 & above**	8.0	6.0

Step 4: Approximate Air Content [**Table 4.3.4** Is: 10262 – 2019 Pg. 7 Clause: 6.2.3]

Sr. No.	**Nominal Maximum Size of Aggregate (mm)**	**Entrapped Air, as Percentage of Volume of Concrete (%)**
1.	10.0	1.0
2.	12.5	0.8
3.	20.0	0.5

From Table 4.3.4, the approximate amount of entrapped air expected in average (non-air-entrained)concrete is 0.5 percent for a 20.0 mm nominal maximum size of aggregate.

Step 5: - Selection of Water – Cementitious Material Ratio

Table 4.3.5 Recommended w/cm for High Strength Concrete made with HRWRA(I.S.: 10262 – 2019 Pg. 8 Clause 6.2.5)

Sr. No.	Target Compressive Strength at28 Days N/mm²	Water–Cementitious Materials Ratio		
		10.0 mm	12.5 mm	20.0 mm
1.	70	0.36	0.35	0.33
2.	75	0.34	0.33	0.31
3.	80	0.32	0.31	0.29
4.	85	0.30	0.29	0.27
5.	90	0.28	0.27	0.26
6.	100	0.26	0.25	0.24

From Table 4.3.5, the ratio of the water-cementitious material required for the target strength of 79.9 N/mm^2 is 0.29 for msa 20 mm. This is lower than the maximum value of 0.45.
0.29< 0.45, hence O.K.

Step 6: - Selection of Water Content

Table 4.3.6Water Content per Cubic Meter of Concrete for Nominal Maximum Sizes of Aggregate(I.S.: 10262 – 2019 Pg. 8 Clause 6.2.4)

Sr. No.	Nominal Maximum Size of Aggregate (mm)	Maximum Water Content (see Note 1)(kg/m³)
1.	10.0	200
2.	12.5	195
3.	20.0	186

From Table 4.3.6, the water content for 20 mm aggregate
= 186 kg/m3 (for 50 mm slump without super Plasticizer).
Estimated water content for 100 mm slump

$$= [\text{Max. Water Content} + (\frac{6}{100} \times \text{Max. Water Content})]$$
$$= [186 + (\frac{6}{100} \times 186)]$$
$$\mathbf{= 197.16 \approx 198\ kg/m^3}$$

As a superplasticizer (Ceraplast 300 PS) is used, the water content can be reduced by 20 percent. Hence, the reduced water content

Water Content = 198 × 0.80
= 158.4 kg/m3 ≈ 159 kg/m^3

Step 7: - Calculation of Cement Content

Water–cement ratio = 0.31
Water content = 159 kg/m^3
Cement content $= \frac{Water\ Content}{Water-Cement\ Ratio}$
$= \frac{159}{0.31}$
$= 512.50 \approx 513$ kg/m^3

It is proposed to add 15 percent fly ash into the mix, in such situations increase in cementitious material content may be warranted. The decision on increase in cementitious material content and its percentage may be based on knowledge and trial test.

NOTE: - Since the replacement of cement to add fly ash content
Fly ash @ 15 percent by weight of cementitious material

= Cementitious material content × 15%
$= 513 \times \frac{15}{100}$
= 76.95 kg/m^3

Cement content = Cementitious material content – Fly Ash
= 513– 76.95
= 436.05 kg/m^3

Revised w/cm $= \frac{Water\ Content}{Cementitious\ material\ content}$
$= \frac{159}{513}$
= 0.31

Check for minimum cementitious materials content,
320 kg/m^3 < 513 kg/m^3 (436.05 kg/m^3 OPC+76.95 kg/m^3 fly ash)
…Hence OK.
Check for maximum cement (OPC) content, 450 kg/m^3 > 436.05 kg/m^3. ... Hence OK.

Step 8: - Proportion of volume of Course & Fine Aggregate Content

Table 4.3.7 Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate for Water-Cement/Water-Cementitious Material Ratio of 0.30 (I.S.: 10262 – 2019 Pg. 10 Clause 6.2.7)

Sr. No.	Nominal Maximum Size of Aggregate (mm)	Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate		
		Zone III	Zone II	Zone I
1.	10.0	0.56	0.54	0.52
2.	12.5	0.58	0.56	0.54
3.	20.0	0.68	0.66	0.64

From Table 4.3.7, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate grading Zone II = 0.66 per unit volume of total aggregate. This is valid for water-cementitious materials ratio of 0.30. As the water-cementitious material ratio is 0.264, the ratio is taken as 0.667.

Volume of fine aggregate content
= 1 – 0.667
= 0.333 per unit volume of total aggregate

Step 9: - Mix Calculation

a. Total volume = 1 m^3

b. Volume of Entrapped air = 0.005 m^3 in wet concrete

c. The volume of cement $= \frac{Mass\ of\ cement}{Specific\ gravity\ of\ cement} \times \frac{1}{1000}$
$= \frac{436.05}{3.15} \times \frac{1}{1000}$
= 0.138 m^3

d. The volume of water $= \frac{Mass\ of\ Water}{Specific\ gravity\ of\ Water} \times \frac{1}{1000}$
$= \frac{159}{1} \times \frac{1}{1000}$
= 0.159 m^3

e. Volume of fly ash $= \frac{Mass\ of\ Fly\ As}{Specific\ gravity\ of\ Fly\ Ash} \times \frac{1}{1000}$
$= \frac{76.95}{2.20} \times \frac{1}{1000}$
= 0.035 m^3

f. Volume of chemical admixture (Ceraplast) (@ 0.5 percent by mass of cementitious material)

$$= \frac{Mass\ of\ chemical\ admixture}{Specific\ gravity\ of\ admixture} \times \frac{1}{1000}$$

$$= \frac{(516 \times 0.5\%)}{1.20} \times \frac{1}{1000}$$

$$= 0.0021\ m^3$$

g. The volume of all in aggregate

$$= [(a - b) - (c + d + e + g)]$$

$$= [(1 - 0.005) - (0.138 + 0.159 + 0.035 + 0.0021)]$$

$$= 0.660\ m^3$$

h. Mass of coarse aggregate

$$= h \times \text{Volume of coarse aggregate} \times \text{Specific gravity of coarse aggregate} \times 1000$$

$$= 0.660 \times 0.667 \times 2.96 \times 1000$$

$$= 1303.05\ kg \approx 1304\ kg$$

i. Mass of fine aggregate = h × volume of fine aggregate

$$\times \text{Specific gravity of fine aggregate} \times 1000$$

$$= 0.660 \times 0.333 \times 2.81 \times 1000$$

$$= 617.58\ kg \approx 618\ kg$$

Step 10: Mix Proportion for trial number 1 on Aggregate in Saturated Surface (SSD) Condition Calculation

- Cement = 436.05 kg/ m^3
- Fly ash = 76.95 kg/
- Water = 159 kg/m^3
- Fine aggregate = 618 kg/m^3
- Coarse aggregate = 1304 kg/m^3
- Chemical admixture = 2.58 kg/m^3
- w/cm = 0.31

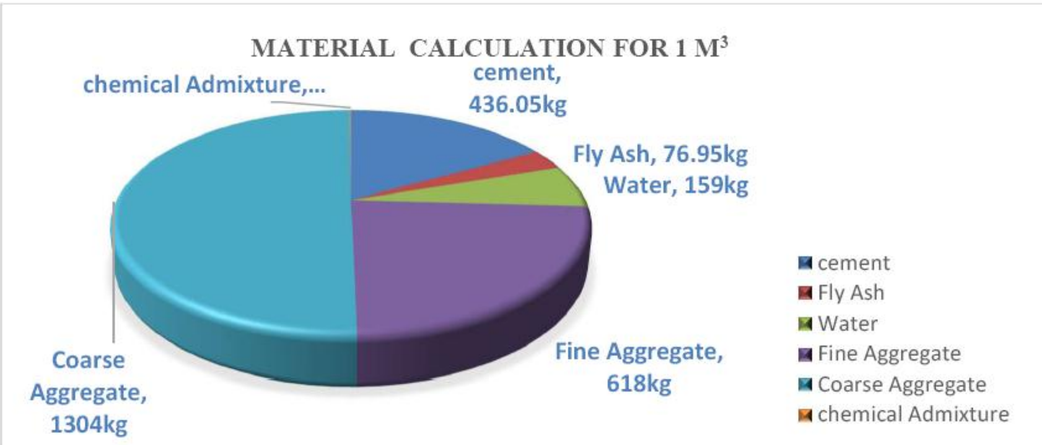

Fig 4. Material calculation for 1 m^3

IV. CONCLUSION

The studies by Wen-Ten Kuoet al., F. Baeza et al., W.W.J. Chan et al., O. Rodríguez et al., and Khmiri et al. collectively highlight the potential benefits and challenges of incorporating various industrial by-products and waste materials as partial replacements for traditional cement components in concrete. Kuo's investigation reveals that replacing fine aggregate with piezoelectric material decreases compressive strength and electrical resistance, indicating limitations in its application. Baeza demonstrates that binary and ternary combinations of waste materials can enhance mechanical properties and absorption rates, with some mixtures achieving higher strengths than control samples. Chan's research suggests that non-reactive waste materials like silts and clays can produce durable concrete with reduced costs and improved workability, especially when combined with superplasticizers. Rodríguez's analysis of reservoir sludges identifies promising pozzolanic properties, particularly in certain samples, which can meet European standards for compressive strength. Finally, Khmiri's study on ground waste glass reveals its effective pozzolanic activity and strength improvements in mortars, particularly with finer glass particles. These findings underscore the viability of using waste materials in cementitious applications, contributing to sustainability and cost-efficiency in the construction industry.

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