Design Mix of M80 Grade Concrete Using Alternative Cementitious Content - Ggbs and Silica Fume

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***Abstract*—For a very long time, concrete has played a crucial role in establishing durable and reliable infrastructure. Historically, construction projects have apparently used concrete with a compressive strength ranging from 20 to 40 N/mm². Over time, the inadequate performance of such concrete due to deterioration, along with the need for cost-effectiveness a standard by which a valuable material is often judged has driven the evolution of newer alternatives. This has led to the development of materials that not only support innovative, lightweight designs but also promote environmentally friendly and economically viable structures, with enhanced long-term durability and reduced maintenance needs.**

One of the major developments in concrete technology has been the advancement of High Strength Concrete (HSC). Though higher strengths have been achieved and applied, HSC is typically characterized by a specified cube strength between 40 and 100 N/mm². Strength levels between 80 and 100 N/mm² and even beyond are now being used in both precast and cast-in-place construction. High Strength Concrete becomes essential in scenarios where reducing structural weight is important or where architectural design requires fewer load-bearing components.

This experimental project designed for the compressive strength of concrete with M80 grade of high strength concrete. The project consists of designing a proportioned concrete mix with alternate cement contents with three different proportions, casting and testing of total 18cube specimens. The specimen of the standard cube (150mm x 150mm x 150mm) used to cast the concrete cubes. Compressive testing machine (CTM) used to test all the specimens. Cement used in the experimental work is Ordinary Portland Cement (OPC) of 53grade (Nagarjuna brand) conforming to IS: 12269-1987. GGBS is produced by grinding Granulated Blast furnace Slag to a controlled fineness, confirming to IS 12089:1987. The maximum size of the aggregates used will be 20mm. Mineral admixtures ground granular blast furnace slag (GGBS) and Silica fume will be used. Poly carboxylate admixture of brand DON-Supaflo PC555 is used as a super plasticizer for obtaining better strength and workability.

***Index Terms*—High strength concrete (HSC), compressive strength, cost-effective, workability, durability, affordability, Compressive testing machine (CTM), Superplasticizer.**

I. LITERATURE REVIEW

Hemant Chore (2014): Industrial by products such as Blast furnace slag, fly ash, silica fume & engineering materials metakaolin have conventionally been used for concrete as supplementary cementitious materials primarily from the aspect of the effective utilization of industrial waste. Considering natural resources conservation and prevention of global warming, new tailor-made material which does not generate extra CO2 emission should be urgently established in concrete-related industries. Concrete is an environmentally friendly material and the overall impact on the environment per ton of concrete is limited. Concrete accounts for large percentages of both resources input and CO2 emission. This paper profiles various high grade of concrete M80, M90 and M100& analysis of CO2 emulsion and implement reduction of CO2 load on environment by employing the best cementitious substitutions. Relation between cubical and cylindrical concrete mould for 28days compressive strength were also developed.

Malavika Chakravarthy (2016): It is aimed to study about the performance of M 80 grade multi blended cement mixes with supplementary cementitious materials like Fly ash (FA), Silica fume (SF) and Metakaolin (MK) to produce High performance concrete mixes. In this present investigation, an attempt of understanding the result acquired for High performance multi blended concrete mixes compared with results of ordinary Portland cement concrete mixes (OPC) were made. The multi blended high performance concrete mixes investigated are the combinations of 5%,10% and 15% of partial replacement of FA, SF, MK individually and the combinations as 15%FA + 10%SF, 15%FA + 10%MK and also 10%FA+7.5%SF+7.5%MK by the weight of the cement with a constant 0.3 water binder ratio. The M80 grade concrete strength is evaluated by Compressive and Tensile Strength tests determining at 3,7,28 days. The steel fibers and super plasticizer were also added to achieve greater strength and the required degree of workability for all the mixes prepared. It is observed that the multi blended M80 grade concrete exhibited greater compressive strength than that of OPC mixes and also a good performance of strength development in a short period of time, which were discussed in this paper.

S. Lakshmikanth (2022): India currently being the second-largest producer of steel in the world and is blooming, meeting the market demand of the robustly growing infrastructure industry, and subsequently producing a massive amount of slag influx as a by-product. This slag is used to produce ground granulated blast furnace slag (GGBFS). GGBFS has already established itself as a good cementitious material in the concrete world. High-strength concrete (HSC) is extensively used in various civil engineering constructions. The necessary ingredients recommended in IS 10262–2019 code are mineral admixtures such as micro-silica and (GGBFS) as replacements to cement to produce cost-effective and environmentally friendly concretes. In addition, the high range water reducer (HRWR) plays a vital role in producing high workable HSC with low to very low water-cement (w/c) ratios. In this work, an attempt has been made to study the mix design for standard concretes ranging from M30 to M60 and HSCs from M65 to M100 based on the provisions of new code IS 10262-2019. Excel platform is used for the mix design covering a range of parameters. Three typical grades namely M30, M80, and M100 concrete are considered for the laboratory studies, keeping in mind the importance of trial mixes. The various tests conducted on these concretes are compressive strength, split tensile strength, flexural strength, water absorption, rapid chloride permeability test (RCPT), and microanalysis by conducting scanning electron microscope (SEM), energy-dispersive spectroscopy (EDS), and X-ray diffraction (XRD) tests. The new mix design code is a boon to civil engineers for producing HSC. Few important conclusions are drawn based on the experimental results.

Dr Hemanth Kumar V (2023): Concrete makes up a significant part of any modern building's infrastructure. High strength concrete is used widely all over the world for increased durability, reducing self-weight, construction cost and time, creep and deflection of the structure. Studies have been carried out to produce high strength concrete with economical mix design by utilizing a broad range of materials as higher replacement materials for cement such as mineral admixture and superplasticizer in the production of concrete. This study investigated the strength properties of ground granulated blast furnace slag (GGBS), fly ash, micro-silica, Alco fine and metakaolin concrete in different proportions. High strength concrete of 10 different concrete mixture were casted and tested with different proportions of mineral admixtures (5%, 6.25%, 8%, 15%, 23% and 25%). The mix with aggregates size of 12.5mm gave the optimum results. The combination with 23% fly ash and 6% micro-silica gave the desired high strength with economic mix design.

P.M. Walunjkar (2024): The main drawback of producing concrete by traditional methods is the rise in carbon emission. Graphene has many remarkable features such as an eco-friendly concrete material, high elasticity; Elastic modulus © around 425Gpa, tensile strength is around 1.3Tpa so designated as 21st century material. This study investigates the effect of Graphene Oxide (GO) reinforcement to improve compressive and split tensile strength of concrete. The structure, TEM and AFM images of GO are studied. The GO was mixed at 0.01%, 0.02%, 0.03%, 0.04%, 0.06%, 0.08% and 0.1% by weight of cement in concrete for various studies. The effect of GO to improve the compressive strength and split tensile strength for M20, M25, M40, M60, M80 concrete grades is worked out. The average maximum rise ©n compressive strength and split tensile strength was found to be 24.3 % and 51.9% respectively. The highest rise in compressive strength of 34.08%, 46.3% was found to be for M25 grade similar proportion concrete and M25 fly ash concrete at 0.08%, 0.03%

GO. The highest rise in split tensile strength of 45.6%, 189.2% was found to be for M40 fly ash, M80 fly ash GGBS concrete at 0.03% and 0.1% GO. From the study it can be concluded that use of GO in various grades of concrete is effective to enhance both compressive and split tensile strength of concrete. GO dosages like 0.03%, 0.08% and 0.1% proved to be optimum dosages in higher strength achievement.

Design mix

In a broad sense “designing” a concrete mix means selecting the proportions of fine and coarse aggregate, cementitious materials, admixtures, and water, that when combined will produce concrete having certain desired qualities and properties. Requirements to be met by the mix design are generally selected based on the intended use of the concrete, exposure conditions, dimensions of structural elements, and physical properties of the concrete required. Concrete quality is directly related to the amount and properties of the materials used, and methods and environment in which it is placed, finished, and cured. Concrete mixtures should be kept as simple as possible, as an excessive number of ingredients often make a concrete mixture difficult to control.

High Strength Concrete M80

According to IS code 10262-2019, High strength concrete has a characteristic compressive strength of 65 N/mm2 or more. High strength concrete is used globally where nuclear power plants, oil, gas and high-rise buildings are among. High strength concrete is considered as superior structural performer, eco-friendly and energy conserving indicator. The demand for High Strength concrete is increasing rapidly due to this tremendous property. Usually, for high strength mixes of concrete, mineral admixtures and super plasticizers are used along with that, low water–cement ratio is necessary. The procedure for proportioning of high strength concrete is similar to that of normal concrete. This procedure consists of steps that when followed, provides a good workability, durability and strength. To achieve high strength concrete optimum proportions shall be selected, such as cement and other cementitious materials, aggregate gradation, aggregate quality, admixture dosage, type and mixing. Fly ash, ground granulated blast furnace slag (GGBS), micro-silica, ultrafine and metakaolin are widely used as cementitious materials or mineral admixtures in high strength concrete. High strength concrete mixes usually have a low water-cement ratio (w/c). These low w/c ratios are generally attainable with high-range water-reducing admixtures. PCE type (Poly carboxylate ether based) super plasticizers are used which reduce water content by 30 percent or above at appropriate dosages.

Necessity of M80 Grade Concrete

M80 grade concrete is essential for projects where high strength, durability and long-term performance are critical. Its uses in taller, heavier, and more complex structures that can resist harsh environmental conditions and heavy loads while maintaining structural integrity and safety over time. These factors make M80 concrete indispensable in modern construction and infrastructure development.

Objectives of Designing HSC(M80)-

The project work aims the following objectives:

- To Achieve high compressive strength and durability which ensures the structural integrity of large-scale projects such as Dams, Nuclear power plants, Bridges and high-rise buildings.
- To promote sustainability and long-term cost efficiency by optimizing material used and minimizing maintenance needs of a structures.
- To ensure the safety and resilience of critical infrastructures such seismic resistant structures where high strength and durability plays a crucial role for withstanding extreme forces and environmental conditions.

Materials Used-

Cement: Ordinary Portland cement (OPC) confirming to IS 269-2015 (53 Grade) used for the experimental work. Laboratory tests were conducted on cement to determine specific gravity, fineness, standard consistency, initial setting time, final setting time and compressive strength.

GGBS: Ground Granulated Blast Furnace Slag (GGBS) confirming to IS 16714-2018, Non-metallic silicates and aluminates of calcium and other bases. The molten slag is rapidly chilled by quenching in water to form a glassy sand like granulated material. The granulated materials when further ground to less than 45 microns will have specific surface of about 400 to 600 kg/m2 (Blaine). Ground granulated blast-furnace slag – GGBS is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. Ground granulated blast furnace slag is a latent hydraulic binder forming calcium silicate hydrates (C-S-H) after contact with water. It is a strength-enhancing compound improving the durability of concrete. It is a component of metallurgic cement. Its main advantage is its slow release of hydration heat, allowing limitation of the temperature increase in massive concrete components and structures during cement setting and concrete curing, or to cast concrete during hot summer.

Silica fume: Silica Fume is also known as micro silica, is an amorphous polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a byproduct of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150nm. The main field of application is as pozzolanic material for high performance concrete. It sometimes confused with fumed silica known as pyrogenic silica, However, the production process, particle characteristics and fields of application of fumed silica are all different from those of silica fume. Silica fume is an ultrafine material with spherical particles less than 1micrometer in diameter, the average being about 0.15micrometer. This makes it approximately 100 times smaller than the average cement particle. The bulk density of cement particle depends on the degree of densification in the silo and varies from 130 to 600kg/c. The specific gravity of silica fume is generally in the range of 2.2 to 2.3. The specific surface area of silica fume can be measured with the BET Method or nitrogen adsorption method. It typically ranges from 15000 to 300000sq.m/kg.

Aggregates:

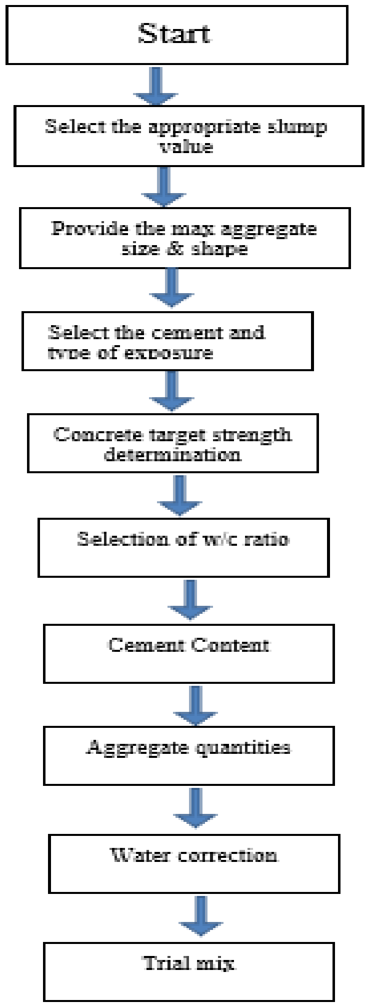
Fine aggregate – The size of fine aggregate is below 4.75mm, It should properly washed and tested to a certain total percentage of clay, silt and other organic matter does not exceed this specified limit. The composition, shape and size of the aggregate of all have signified impact on the workability, durability, strength weight and shrinkage of the concrete.Manufactured sand was used as fine aggregate. Laboratory tests were conducted on fine aggregate to determine the different physical properties as per IS 2386 (Part III)-1963. Fineness modulus is the index of coarseness or fineness of material. It is an empirical factor obtained by adding cumulative percentage of aggregate retained on each of the standard sieves and dividing this by100.

Coarse aggregate – Coarse aggregate sizes are larger than 4.75mm, Size of coarse aggregate depends upon the nature of the work. The aggregates are free from dust before used in the dust. The coarse aggregate used in the experimental investigation is 20mm sized crushed angular in shape. It includes gravel, crushed stone, sand, slag, recycled concrete and geosynthetic aggregates.

Chemical Admixture: Chemical admixtures are substances added to concrete during mixing to improve its properties. They can improve the concrete's workability, strength, durability.

Fig 1. Raw Materials Sample

Flow Chart to prepare Design mix-



Mix design for M80 grade concrete-
M80 grade of concrete was used in this work as per guidelines of IS 10262:2019.

TARGET STRENGTH:
Fck = fck +1.65s
=80+1.65 x 6.0
=89.9 N/sq.mm

WATER CEMENT RATIO (W/C):
W/C =0.3 [IS10262: 2019]

WATER CONTENT:
WATER CONTENT =186kg [for 20mm size of CA] for 150 slump
water content =186+(12/100x186)
=208.32 Kg/m^3
As super plasticizer is used 25% reducing water content
=208.32x0.75
=156.24kg/m^3

CEMENT CONTENT:
W/C =0.24
Cement content ©=W/0.24
=156.24/0.24
=651kg/m^3
As per IS 10262 code 10% cementitious increase for high grades
Total cementitious = 651x1.10
=716.1kg/m^3
So as per IS code we can use only 450kg/m^3 maximum cement content.
So, we are taking mineral admixture as partial replacement of cement

I) Taking GGBS 28.4% by total weight of cementitious
=28.4%x716.1
=203.37kg/m^3

II) Taking Silica fume 8.7% by total weight of cement
=8.7%x716.1
=62.30kg/m^3

Volume of Coarse Aggregate and Fine Aggregate
volume of coarse aggregate =0.6048
volume of fine aggregate =0.3952
3.8.1 Mix Calculations
a) Volume of concrete = 1m3
b) volume of entrapped air = 0.005m3
c)Volume of cement = (mass of cement/sp.gravity of cement) x1/1000
= (450/3.15) x1/1000
=0.1428m3
d)Volume of GGBS = (mass of GGBS/sp.gravity of GGBS) x1/1000
= (203.37/2.85) x1/1000
=0.071m3

e) Volume of silica fume = (mass of silica fume /sp. Gravity of silica fume) x1/1000
= (62.30/2.20) x1/1000
=0.0283m3

f) Volume of water = 0.156m3
g) Volume of admixture = (mass of admixture /sp.

Gravity of admixture) x1/1000
= (716x0.75%/1.120) x1/1000
=0.00479m3
h) Volume of all in aggregate = (a – b) – (c + d + e + f + g)
= 0.59187
Mass of coarse aggregate = h x volume of coarse aggregate x specific gravity x 1000
= 0.59187x2.65x0.6048x1000
=945.02kg/m3

Mass of fine aggregate = h x volume of fine aggregate x specific gravity x 1000
= 0.59187x2.65x0.3952x1000
=608.2kg/m3

3.8.2 Mix Proportion-

CEMENT: FA : CA
716kgs: 945kgs : 608kgs
1: 0.85 : 1.32
W/C =0.24

M80 Design mix Trial Sheets			
Trail-1			
Sl.no	Contents	Weight	Remark
1	Total Cement Content	680Kgs	
2	Cement	450Kgs	
3	GGBS	170Kgs	25% of total cement
4	Silica Fume	60Kgs	8.8% of total cement
5	Fine Aggregate	610Kgs	
6	Coarse Aggregate	940Kgs	
7	Water Content	157Kgs	
8	Admixture - HPCE	5.3kgs	0.78% of cement
	W/C Ratio	0.23	

Table-1.1 *Mix Proportions for Trail mix-1*

Trail-2			
Sl.no	Contents	Weight	Remark
1	Total Cement Content	617.5Kgs	
2	Cement	445Kgs	
3	GGBS	135Kgs	21.86% of total cement
4	Silica Fume	37.5Kgs	6.07% of total cement
5	Fine Aggregate	775Kgs	
6	Coarse Aggregate	950Kgs	
7	Water Content	135Kgs	
8	Admixture - HPCE	6.67Kgs	1.08% of cement
	W/C Ratio	0.22	

Table-1.2 *Mix Proportions for Trail mix-2*

Trail-3			
Sl.no	Contents	Weight	Remark
1	Total Cement Content	710Kgs	
2	Cement	450Kgs	
3	GGBS	200Kgs	28.16% of total cement
4	Silica Fume	60Kgs	8.45% of total cement
5	Fine Aggregate	610Kgs	

6	Corse Aggregate	940Kgs	
7	Water Content	156Kgs	
8	Admixture - HPCE	5.325Kgs	0.75% of cement
	W/C Ratio	0.24	

Table-1.3 *Mix Proportions for Trail mix-3*

Experimental procedure:

Sampling of Materials-Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material.

Proportioning- The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work.

Weighing- The quantities of cement, each size of aggregate, and water for each batch. shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.

Mixing Concrete-The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.

Mould-Test specimens cubical in shape shall be 15 x 15 x 15 cm. If the largest nominal size of the aggregate does not exceed 2 cm, 10 cm cubes may be used as an alternative. Cylindrical test specimens shall have a length equal to twice the diameter.

Compacting-The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance.

Curing- The test specimens shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27° ± 2°C for 24 hours + ½ hour from the time of addition of water to the dry ingredients.

Placing the Specimen in the Testing Machine-The bearing surfaces of the testing machine shall be wiped clean and any loose sand or other material removed from the surfaces of the specimen which are to be in contact with the compression platens.

Fig 2. Concrete Mix Preparation

Fig 3. Checking Slump & Casting Cubes

Fig 4. Curing of Casted Cubes

Fig 5. 7Days Cubes Strength Testing

Fig 6. 28Days Cubes Strength Testing

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NAGARJUNA READY MIX CONCRETE
HYDERABAD DIVISION
CONCRETE CUBE COMPRESSIVE TEST REPORT

PLANT LOCATION : KOTHWALGUDA

Source of Sample : Sample submitted by Mohammed Khaja-PG Scholar
No. of Cubes tested : 06 Cubes
Name of Project : Design mix of M80 Grade concrete using alternative Cementitious Content-GGBS & Silica fume

Cube Ref No	Grade of Concret	Date of Casting	Date of Testing	Age in days	Dimensions (mm) L	W	H	Weight (Kgs)	Density (Kg/CM³)	Load in (KN)	Strength (Mpa) (N /MM²)	Average Strength (N/MM²)	Variation of cubes	Acceptance Criteria
Cube Ref No: TM-01	M80	20.02.25	27.02.25	7 Days	150.0	150.0	150.0	8.36	2.477	1386	61.60	62.10	-0.81	60% of fck
					150.0	150.0	150.0	8.45	2.504	1450	64.44		3.77	
					150.0	150.0	150.0	8.24	2.441	1356	60.27		-2.96	
Cube Ref No: TM-01	M80	20.02.25	20.03.25	28 Days	150.0	150.0	150.0	8.45	2.504	1950	86.67	88.64	-2.22	fck
					150.0	150.0	150.0	8.43	2.498	1983	88.13		-0.57	
					150.0	150.0	150.0	8.40	2.489	2050	91.11		2.79	
Cube Ref No: TM-02	M80	08.09.23	15.09.23	7 Days	150.0	150.0	150.0	8.36	2.477	1180	52.44	54.34	-3.49	60% of fck
					150.0	150.0	150.0	8.46	2.507	1360	60.44		11.23	
					150.0	150.0	150.0	8.51	2.521	1128	50.13		-7.74	
Cube Ref No: TM-02	M80	08.09.23	15.09.23	28 Days	150.0	150.0	150.0	8.43	2.498	1860	82.67	82.81	-0.18	fck
					150.0	150.0	150.0	8.40	2.489	1800	80.00		-3.40	
					150.0	150.0	150.0	8.38	2.483	1930	85.78		3.58	
Cube Ref No: TM-03	M80	08.09.23	15.09.23	7 Days	150.0	150.0	150.0	8.40	2.489	1680	74.67	74.37	0.40	60% of fck
					150.0	150.0	150.0	8.42	2.495	1580	70.22		-5.58	
					150.0	150.0	150.0	8.31	2.462	1760	78.22		5.18	
Cube Ref No: TM-03	M80	08.09.23	15.09.23	28 Days	150.0	150.0	150.0	8.46	2.507	2280	101.33	99.56	1.79	fck
					150.0	150.0	150.0	8.30	2.459	2180	96.89		-2.68	
					150.0	150.0	150.0	8.47	2.510	2260	100.44		0.89	

IS Code Ref : IS 516 - (2017) Method of test for strength of concrete.
IS 456 - (2000) Code of practies for plain and reinforced concrete.(Amendment 1 to 5)
fck - Characteristic compressive strength of concrete.

Test Conducted by : MOHAMMED OSAMA, QA/QC ENGINEER

Approved by : Santosh, QA/QC MANAGER

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Table-2 *Result of Compressive Strength Test 7&28 days*

Compressive Strength VS Curing Period of 3 Trials

II. CONCLUSION

The experimental investigation on M80 grade concrete using GGBS and Silica Fume as partial replacements for cement demonstrates that these supplementary cementitious materials significantly enhance both strength and durability. The trial mixes achieved compressive strengths close to and above the target values, proving the suitability of incorporating around 30–38% combined GGBS and Silica Fume. Along with improving mechanical performance, this approach reduces the dependency on ordinary Portland cement, thereby lowering costs and minimizing the environmental impact of CO_2 emissions. The development of M80 high-strength concrete (80 MPa characteristic strength) necessitates a careful balance of materials and mix proportions to ensure superior strength, workability, and durability. Mixes typically use OPC 53-grade cement, low water-to-binder ratios (0.23–0.30), and superplasticizers (often polycarboxylate ether-based) to reduce water demand by ~30–40%. Supplementary cementitious materials such as fly ash, silica fume, GGBS, metakaolin, or ultrafine are incorporated to enhance performance and reduce cost. Typical combinations include 28.4% GGBS + 8.7% Ultrafine, which achieved compressive strengths between 84-90 MPa at 28 days. Aggregate selection is crucial a fine/coarse aggregate ratio near 1:1, maximum aggregate sizes of 20 mm, and specific gravity around 2.5-2.7 are recommended. The preparation of M80 high-strength concrete—targeted at ~80 MPa characteristic strength—can be made far more sustainable by incorporating high levels (30–80%) of supplementary cementitious materials such as fly ash, silica fume, GGBS, calcined clay (e.g., LC_3), or recycled materials, achieving CO_2 emissions reductions of up to ~70–80% per m^3 while often enhancing long-term strength and durability. Looking ahead, innovations such as geopolymer binders using industrial by-products, carbon capture/injection technologies (e.g. Carbon Cure, mineral-embedded carbon), and AI-driven mix optimization via Bayesian methods enable the design of greener, high-performance M80 mixes with fewer trials and better environmental metrics. Emerging techniques like nano-silica enhancement, hybrid fiber reinforcement, and recycling of demolished concrete as geopolymer aggregates also show promise for creating self-healing, ultra-durable, and eco-efficient forms of M80 in future applications.

1. Compressive strength improved when cement was partially replaced with GGBS (≈28–33%) and Silica Fume (≈6–9%), achieving values close to or exceeding the target strength of M80 grade.
2.Workability was maintained with the use of polycarboxylate-based superplasticizer, showing that even at low water–cement ratios, the mixes remained consistent and workable.
3.Sustainability and cost-effectiveness were enhanced by reducing the overall cement content and incorporating industrial by-products, lowering environmental impact without compromising performance.

III. FUTURE SCOPE

- Conduct durability studies on chloride, sulfate, carbonation, and freeze–thaw resistance.
- Perform microstructural analysis using SEM, XRD, and EDS.
- Apply AI and machine learning for mix design optimization.
- Explore nanomaterials like nano-silica and graphene oxide.
- Investigate low-carbon alternatives such as fly ash and LC^3.
- Test field-scale applications in beams, slabs, and columns.
- Carry out life cycle assessment (LCA) for sustainability evaluation.
- Support development of updated design codes and guidelines.

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