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Experimental investigation of M30 grade lightweight concrete using sintered aggregate

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Abstract

Lightweight concrete (LWC) is gaining traction in contemporary construction due to its reduced density and enhanced thermal characteristics. Among various LWC types, sintered aggregate-based concrete is notable for its capability to lessen weight while satisfying strength standards. Although earlier studies, such as the one by Saha, Guntakal, and Selvan (2018) that investigated the properties of lightweight concrete by varying different parameters, have analyzed various lightweight aggregates, research on the combination of sintered and conventional aggregates in M30 grade concrete remains scarce. This study seeks to examine how varying proportions of these aggregates influence the mechanical properties of M30 lightweight concrete, aiming to find an ideal mix that offers a balance between strength, durability, and weight reduction.

For this investigation, three distinct mix proportions were formulated using both sintered and traditional aggregates. Following standardized methods, the concrete samples were tested for compressive strength to ensure accurate and reliable outcomes. By studying the effects of sintered aggregates on concrete performance, this research aims to identify the most efficient mixture.

The results from this study could significantly contribute to the development of lightweight structural concrete, especially for uses such as deck slabs and precast components. By decreasing the overall dead load of structures without sacrificing strength, this method provides a sustainable and effective solution to meet the needs of modern construction.

Keywords: Lightweight Concrete; Sintered Aggregate; M30 Grade; Compressive Strength of Lightweight Concrete; Concrete for Deck Slab

1. Introduction

Concrete is the most extensively used construction material worldwide due to its versatility, strength, and cost-effectiveness. However, its production has substantial environmental implications, including high energy consumption, significant CO_2 emissions, and extensive use of natural resources. One of the primary contributors to these concerns is the use of conventional coarse aggregates derived from natural stone, which increases the overall weight of concrete structures and places additional stress on both the environment and structural systems.

In response to these challenges, sintered fly ash aggregate (SFA) has emerged as a promising alternative in the development of lightweight concrete (LWC). SFA is a manufactured aggregate produced by sintering fly ash, an industrial byproduct of coal combustion. This process transforms a potential environmental liability into a valuable

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construction material. By incorporating SFA into concrete mixtures, it is possible to create concrete that is 20–50% lighter than conventional types, while maintaining adequate structural strength for a variety of applications.

The use of SFA in concrete not only reduces dead loads and construction costs but also aligns with the principles of sustainable development. It promotes resource conservation by minimizing the extraction of natural aggregates, diverts fly ash from landfills, and reduces the carbon footprint associated with concrete production. Furthermore, SFA-based concrete enhances thermal insulation, thereby contributing to the energy efficiency of buildings.

Despite its numerous advantages, widespread adoption of SFA in the construction industry is limited by several factors, including inconsistent aggregate quality, lack of inclusion in standard codes, and low awareness among stakeholders. These barriers necessitate further research to validate its performance and establish standardized mix designs.

This study aims to design and evaluate an M30-grade lightweight concrete mix incorporating sintered fly ash aggregates, with the goal of achieving structural strength comparable to conventional concrete while reducing material density and environmental impact. The research specifically focuses on:

- Developing an optimal mix design using SFA.
- Achieving the required compressive strength for M30 grade concrete through admixture optimization.
- Comparing the cost efficiency of SFA-based concrete with traditional concrete mixtures.

By addressing both the performance characteristics and sustainability aspects of this innovative material, the study contributes to the ongoing efforts to modernize construction practices in line with global environmental objectives. This research was conducted through detailed material characterization and experimental validation using locally available materials, ensuring its practical relevance and applicability in real-world construction scenarios.

2. Literature review

2.1. Review of Previous Studies

The use of lightweight concrete (LWC), especially incorporating sintered fly ash aggregates (SFA), has garnered increasing attention due to its potential to reduce structural dead loads and promote sustainable construction. Various studies have explored the material, mechanical, and environmental aspects of LWC and its comparative advantages over traditional reinforced concrete (RC).

Jagtap et al. (2020) conducted a comparative study between LWC and RC, emphasizing the benefits of reduced dead load, faster construction, and improved sustainability in LWC applications. The paper highlighted the need to balance reduced density with adequate strength, particularly when selecting LWC for structural applications.

Kumar and Dilip (2014), in their work published in the SSRG International Journal of Civil Engineering, examined the substitution of conventional coarse aggregates with sintered fly ash aggregates. They reported enhanced compressive and flexural strength and emphasized the economic and environmental advantages of using SFA. The authors stressed the importance of utilizing industrial waste products to reduce environmental degradation.

In a separate study, Kumar et al. (2014) addressed the cost-effectiveness of using SFA for low-cost concrete. Their research demonstrated that replacing natural coarse aggregates with SFA significantly reduces the overall cost of concrete while addressing fly ash disposal challenges, thus contributing to sustainable construction.

Further expanding on this, Kumar and Dilip (2014) in the International Journal for Innovative Research in Science & Technology analyzed how SFA reduces concrete density, contributing to lightweight structural design. They concluded that integrating SFA could produce concrete mixes with a favorable strength-to-weight ratio and enhanced performance.

Fikry et al. (2021) investigated the role of various admixtures in enhancing the properties of LWC. Their findings highlighted the importance of admixtures in optimizing compressive strength and improving density, which are critical to ensuring the reliability of lightweight structural elements.

Nadesan and Dinakar (2017) provided an in-depth review of sintered fly ash lightweight aggregates in structural concrete. Their study, published in Construction and Building Materials, evaluated the chemical and physical properties of SFA, concluding that these aggregates exhibit superior durability and sustainability compared to conventional aggregates. The paper called for standardization of SFA usage in mainstream concrete production.

Gopalachari and Suresh (2020) evaluated the impact of mineral admixtures and steel fibers on LWC performance. Their research underscored that such modifications improve compressive, tensile, and flexural strengths while enhancing crack resistance and permeability. The study suggests that incorporating fibers could make LWC more suitable for load-bearing applications.

Vijaykumar and Ramesh explored the performance of LWC under extreme conditions, such as freeze-thaw cycles. Their findings support the use of chemical admixtures like superplasticizers and air-entraining agents for improving workability, strength, and durability without increasing the water-to-cement ratio.

Lu et al. (2022) conducted a comprehensive study on lightweight ultra-high-performance concrete (L-UHPC). Using the Central Composite Design (CCD) method, they optimized the mix design for improved strength and durability. The study demonstrated that L-UHPC could achieve structural efficiencies previously associated only with standard UHPC, but at significantly lower densities.

Thoker and Jaggi (2020) examined the effects of fiber reinforcement in lightweight, high-strength concrete. Their study revealed that the addition of steel fibers substantially improved mechanical properties and durability, validating the use of such composites in high-stress environments.

Bhavana et al. (2017) compared LWC and conventional concrete in terms of density, absorption, and strength. Their work highlighted the benefits of using expanded aggregates for achieving lower weight and better adhesion, reinforcing the viability of LWC in modern construction where weight savings are critical.

2.2. Findings from Literature Review

An analysis of the literature reveals several key insights into the use of sintered fly ash aggregates and the development of lightweight concrete

- Compressive Strength Optimization: At 12% replacement of conventional coarse aggregate with SFA, compressive strength values of up to 36.25 N/mm^2 have been achieved. However, at 20% replacement, the minimum strength recorded was 26.68 N/mm^2, indicating the need for optimized replacement levels depending on application requirements.
- Density Reduction: LWC has significantly lower density, typically ranging from 300 to 1850 kg/m^3, compared to conventional concrete (2200–2500 kg/m^3). This results in substantial reduction in dead loads, making it ideal for deck slabs and high-rise construction (Kumar et al., 2014).
- Properties of Sintered Fly Ash Aggregates:
    - Fineness Modulus: 6.24
    - Bulk Density: 645–755 kg/m^3
    - Aggregate Size: 4.70–10.0 mm
    - Water Absorption: 0.14%
- Performance in High-Strength Mixes: Some studies reported surface-dry densities of 1929 kg/m^3, qualifying as L-UHPC. The combination of lightweight geopolymer materials (HGM) and SFA was effective in producing mixes that were both lightweight and high-strength.
- Role of Admixtures: The use of water reducers, superplasticizers, and air-entraining agents is critical in maintaining workability, enhancing strength, and improving durability. These admixtures allow for lower water-to-cement ratios without compromising mix performance.
- Density Comparison Across Mixes:
    - Maximum cube density (0% SFA): 2814.4 kg/m^3
    - Minimum cube density (25% SFA): 2414.8 kg/m^3
    - Average densities ranged from 2687.3 kg/m^3 (max) to 2461.2 kg/m^3 (min)

2.3. Research Gap

While numerous studies confirm the advantages of using SFA in concrete, there remains a lack of standardized mix designs specifically tailored for M30-grade lightweight concrete. Further, a detailed evaluation of cost-efficiency, long-term durability, and performance under varied environmental conditions is still needed. This research aims to bridge these gaps by developing and evaluating an optimized M30 LWC mix using sintered fly ash aggregates, ensuring it meets both structural and sustainability requirements.

3. Methodology

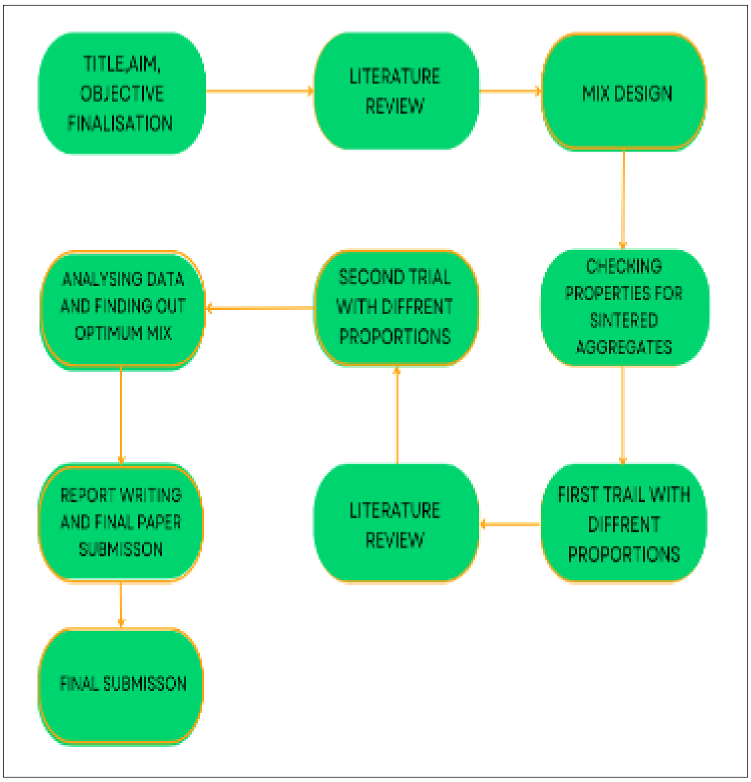

Figure 1 Detailed procedure of methodology

This chapter outlines the systematic process followed during the experimental investigation. The overall approach was divided into a series of structured steps to ensure clarity and reproducibility. The methodology began with the preparation of concrete samples incorporating sintered lightweight aggregates derived from fly ash. These aggregates were sourced from the by-products of thermal power plants, providing a sustainable alternative to traditional materials.

The experimental setup consisted of standard laboratory equipment, including a compression testing machine and weighing balance. Concrete cubes of size 150 mm × 150 mm × 150 mm were cast and cured under water at a constant temperature of 27°C. The primary tests conducted were for compressive strength at 28 days, along with measurements of bulk density, apparent density, and water absorption. Data collected from these tests were systematically recorded and analyzed to derive meaningful insights into the behavior of the lightweight concrete in comparison to conventional mixes.

The Indian Standard IS 10262:2019 was followed for the design of the concrete mix. This standard emphasizes a performance-based approach and allows for the inclusion of supplementary cementitious materials (SCMs) such as fly ash. The target mean strength of the concrete was calculated using the formula fck(target)=fck+t·Sf_{ck(target)} = f_{ck} + t \cdot Sfck(target)=fck+t·S, where fckf_{ck}fck is the characteristic strength, ttt is the statistical constant (1.65 for 95% confidence), and SSS is the standard deviation. For M30 grade concrete, a target strength of 38.25 MPa was derived.

Based on the moderate exposure condition as per IS 456:2000, the water-cement ratio was limited to 0.45. The water content for a slump of 75 mm was adjusted to 149 kg/m^3 due to the use of a superplasticizer, which allowed for a 20% reduction. Cement content was calculated using the water-cement ratio, yielding 331.1 kg/m^3, which satisfies the minimum requirement of 300 kg/m^3 for moderate exposure.

Aggregate proportions were determined based on IS guidelines, with coarse aggregate volume fraction taken as 0.62, and fine aggregate fraction as 0.38. Masses of aggregates were calculated using typical specific gravity values—2.7 for coarse and 2.6 for fine aggregates. Adjustments for moisture content in the aggregates were also considered to ensure the accuracy of mix proportions. A trial mix was prepared and tested for workability and strength. If the properties did not align with target requirements, modifications were planned in terms of water content or aggregate distribution.

The role of the water-cement ratio was critical in determining the mechanical and durability characteristics of the concrete. A lower water-cement ratio improved strength and reduced permeability, whereas higher values increased workability but compromised durability. To overcome the challenges posed by low water content in concrete mixes, chemical admixtures were employed. These included superplasticizers to enhance workability, accelerators for faster setting, retarders to delay setting in hot weather, air-entraining agents for freeze-thaw resistance, and waterproofing compounds.

Fly ash, a pozzolanic by-product, played a significant role in the concrete mix design. It improves workability due to its spherical particles, reduces water demand, and enhances long-term strength through the formation of additional calcium silicate hydrate (C-S-H) gel. Although fly ash slows early strength gain, it improves overall durability by lowering permeability and increasing resistance to sulfate attack, chloride penetration, and alkali-silica reactions. In this study, fly ash was used to partially replace cement by 15–30%, thus reducing both environmental impact and cost.

The influence of fly ash on mix design required careful consideration. Lower water requirements allowed for a reduced water-cement ratio, and prolonged curing ensured sufficient strength development. Extended curing times were necessary to support the slow pozzolanic reaction of fly ash. Final adjustments to mix design were made after considering fly ash content, moisture in aggregates, and test results from initial mixes.

Through this systematic methodology, the research effectively examined the potential of fly ash-based lightweight aggregate concrete to serve as a durable and sustainable material in construction applications.

4. Properties of Sintered Fly Ash Aggregates

Sintered fly ash aggregates (SFA) are manufactured by heating fly ash to high temperatures, typically around 1100°C to 1200°C, to form lightweight and porous aggregates. These aggregates present several physical and mechanical properties that make them suitable for construction. One of the most prominent features of SFA is its lightweight nature, with a density ranging from 1000 to 1600 kg/m^3, significantly lower than natural aggregates. This results in reduced dead load in structural applications. Their high porosity contributes to excellent thermal and acoustic insulation, although it also increases water absorption. Compressive strength of SFA varies based on the sintering process and the additives used, and is generally adequate for both structural and non-structural uses.

Water absorption in these aggregates is relatively high, often up to 20% or more, and typically requires pre-soaking before mixing in concrete. However, the aggregates exhibit good durability and resistance to adverse environmental conditions, contributing to the longevity of concrete structures. The rounded shape and rough texture of sintered aggregates enhance their bond with cement paste, improving the mechanical performance of the composite. Their production using fly ash, an industrial by-product, aids in environmental conservation by recycling waste material and reducing dependency on natural resources.

Despite these advantages, the practical implementation of SFA faces several challenges. Commercial production remains limited due to the need for specialized sintering technology and equipment, resulting in restricted availability and higher initial costs. Transport over long distances further adds to cost and environmental impact. The quality of raw fly ash can vary greatly depending on the combustion process at the source, which in turn affects the uniformity and reliability of the sintered product. High porosity, if not controlled, can negatively influence durability and increase the water demand of concrete mixes.

Mix design using SFA requires special attention due to increased water absorption. Conventional admixtures may not perform predictably with these aggregates, often requiring re-calibration of the mix design. The lower density of SFA can lead to segregation during mixing if the gradation is not optimized and compaction is not adequately managed. Concrete with SFA may also show lower early-age strength, which can be critical in time-sensitive projects. Durability under aggressive exposure conditions, such as marine environments or freeze-thaw cycles, can be compromised if the mix is not properly designed. Although fly ash is generally non-reactive, poor-quality sources may introduce alkali-silica reaction risks, further impacting long-term performance.

Environmental concerns also arise from emissions during the sintering process, including CO_2 and particulates, which can partially offset the sustainability benefits. Fine particles generated during handling pose health risks and necessitate proper dust control and safety measures. The lack of standardized testing methods and design codes for SFA restricts its widespread adoption. Many regions lack specific guidelines, and limited field experience adds to the hesitancy of engineers and contractors to adopt this material on a broader scale.

To overcome these challenges, it is essential to promote research and development aimed at optimizing sintering processes and improving the physical and mechanical properties of SFA. There is a need for developing standard codes and quality control guidelines for testing and structural design. Pilot projects and field trials should be initiated to gather long-term performance data and practical insights. Government incentives or subsidies could also support the economic viability of SFA production and use, thereby encouraging sustainable construction practices.

Experimental testing was conducted to understand key properties of sintered fly ash aggregates. The water absorption test involved soaking a 2 kg sample of coarse aggregate in water for 24 hours, surface drying it to a saturated surface dry (SSD) condition, and then weighing it. The SSD weight was recorded as 1942 grams, while the oven-dried weight after 24 hours of heating at 100°C–110°C was found to be 1681 grams. Using the formula: Water Absorption (%) = (SSD Weight – Oven Dry Weight) / Oven Dry Weight × 100, the water absorption was calculated as 15.53%, which falls within the standard range of 12% to 16%, indicating satisfactory performance.

Another test performed was for specific gravity. A fully saturated SSD sample weighed in air was 1942 grams, submerged weight in water was 927 grams, and the oven-dried weight was 1681 grams. Using the formula: Specific Gravity = Oven Dry Weight / (SSD Weight − Submerged Weight), the specific gravity was calculated to be 1.65, which is within the expected range of 1.45–1.65 for sintered fly ash aggregates. The tests concluded that the physical properties of the aggregates, including water absorption and specific gravity, met the necessary standards for construction applications.

Table 1 Comparison of properties

Properties	Sintered Aggregate	Natural Aggregates
Bulk Density	750-900 kg/cum	1450-1750 kg/cum
Bulk Porosity	35%-40%	40%-50%
Water Absorption	12%-16%	0.5%-1.5%
Specific Gravity	1.45-1.65	2.75-2.95
LOI of Product	<4%	<4%
Weight of Concrete	1800-1900 kg/cum	2400-2750 kg/cum
Shape	Round	Angular

A comparison was made between the properties of sintered fly ash aggregates and conventional natural aggregates. SFA had a bulk density of 750–900 kg/m^3, much lower than the 1450–1750 kg/m^3 observed for natural aggregates. Bulk porosity was comparable (35%–40% vs. 40%–50%), but water absorption for SFA was significantly higher (12%–16%) than for natural aggregates (0.5%–1.5%). Specific gravity for SFA ranged from 1.45 to 1.65, in contrast to 2.75–2.95 for natural aggregates. Despite the differences in weight and absorption, the shape of SFA was typically round, while natural aggregates are more angular. The lighter weight of concrete made using SFA, typically in the range of 1800–1900 kg/m^3, compared to 2400–2750 kg/m^3 for conventional concrete, presents a major advantage in terms of structural efficiency.

In conclusion, sintered fly ash aggregates offer a sustainable and efficient alternative to natural aggregates in concrete construction. Although several practical and technical challenges remain, ongoing research, appropriate standardization, and supportive policies can enable their broader adoption and help drive environmentally responsible construction practices.

5. Experimentation

The trials were carried out to test the compressive strength on concrete made with SFA. The cubes were casted and tested for compressive strength at 7 days and 28 days. The aim of the trials was to reduce the weight of concrete by using SFA instead of natural aggregates and to achieve desired strength. Various factors were taken into account such as water absorption and specific gravity while doing the mix design for the concrete. The changes were incorporated into successive trials to meet the objectives.

5.1. Preparation of Trial 01 Lightweight concrete

5.1.1. Materials Used

- Cement Type and Grade: Ordinary Portland Cement (OPC), Grade 53
- Coarse Aggregate: Sintered fly ash aggregates with a maximum nominal size of 10mm
- Sintered aggregate of size 10mm
- Fine Aggregate: conforming to Zone II grading
- Fly ash
- Admixture
- Water: Potable water used for mixing and curing

5.1.2. Mix Design Parameters

- Minimum Cement Content: 300 kg/m^3 (IS 456:2000, Table 3 – Moderate exposure)
- Workability (Slump Value): Achieved slump of 100 mm to ensure suitable workability (IS 456:2000, Cl. 7.1)
- Standard Deviation for Mix Design: 5 N/mm^2 (as per IS 10262:2019, Table 2)
- Exposure Condition: Moderate

5.2. Summary of mix design (For single cube of 150X150X150 mm)

- Cement-0.992 kg.
- Water-600 ML.
- Fine Aggregate-3.20 Kg.
- Coarse Aggregate-1.21 Kg.
- Sintered Aggregate-1.82 Kg.
- W/C ratio-0.45
- Fly Ash-0.33 kg.
- Admixture-15 ml.

5.3. Description of the Mix

This mix utilizes sintered fly ash aggregate to natural coarse aggregates in the ratio of 60:40. Sintered aggregates, known for their lower density and environmental benefits, contribute to the lightweight nature of the concrete while maintaining desirable mechanical and durability properties. The selected water-cement ratio of 0.45 balances workability and strength, while the use of Zone II sand ensures good particle packing and reduced voids. With a slump of 100 mm, the mix demonstrates satisfactory workability for casting and compaction

5.3.1. Results of Trial 01

Table 2 Trial no 1 7- and 28-days strength

Days	Strength Achieved (MPa)			Avg.
	Sample 01	Sample 02	Sample 03	
7 days	18.42	14.5	17.21	16.5Mpa
28 days	24.2	23.56	26.7	25.5Mpa

5.3.2. Observation

The 28-day compressive strength of the M30 grade lightweight concrete averages 25.5 MPa, which is below the specified characteristic strength of 30 MPa as per IS 456:2000. This indicates that the concrete mix does not meet the required strength criteria for M30 grade.

Table 3 Trial no 1 7- and 28-days weight and density

Days	Weight of Block (kg)			Average weight (kg)	Avg. Density (kg/m3)
	Sample 01	Sample 02	Sample 03		
7 days	6.58	6.28	6.15	6.33	1877.53
28 days	6.81	6.79	6.75	6.78	2008.8

5.3.3. Observation

Average density of M30 grade light weight concrete on 28th day averages 2008.8 kg/m^3, which is nearly satisfied for standard density of 1800 kg/m^3, but further decrease in density required to meet expectations.

5.4. Preparation of Trial 02

5.4.1. Materials Used

- Cement Type and Grade: Ordinary Portland Cement (OPC), Grade 53
- Coarse Aggregate: Sintered fly ash aggregates with a maximum size of 10 mm
- Fine Aggregate: conforming to Zone II
- Sintered aggregate (10mm)
- Fly ash
- Admixture
- Water: Potable water suitable for mixing and curing

5.4.2. Mix Design Parameters

- Minimum Cement Content: 300 kg/m^3 (IS 456:2000, Table 3 – Moderate exposure)
- Workability (Slump): Achieved 100 mm slump (IS 456:2000, Clause 7.1)
- Standard Deviation: 5 N/mm^2 (IS 10262:2019, Table 2)
- Exposure Condition: Moderate

5.4.3. Summary of mix design:(For single cube of size 150X150X150 mm)

- Cement-0.91 kg.
- Water-0.595 ML.
- Fine Aggregate-2.36 Kg.
- Coarse Aggregate-1.26 Kg.
- Sintered Aggregate-1.89 Kg.
- Fly Ash-0.13 kg.
- Admixture-11 ml.

5.5. Description of the Mix

This mix utilizes sintered fly ash aggregate to natural coarse aggregates in the ratio of 60:40. This sample incorporates 10 mm sintered fly ash aggregates to assess the effect of smaller aggregate size on the strength and density of lightweight concrete. The increased water-cement ratio of 0.56 is expected to improve workability, but may influence strength development. The consistent use of Zone II fine aggregates helps in achieving proper gradation and minimizing voids in the mix.

5.5.1. Results of Trial 02

Table 4 Trial no 2 7- and 28-days strength

Days	Strength Achieved (MPa)			Avg
	Sample 01	Sample 02	Sample 03	
7 days	20.2	26	21.2	22.01Mpa
28 days	29.4	34.5	38.5	34.23Mpa

5.5.2. Observation

The M30 grade concrete exhibits an average 28-day compressive strength of 34.23 MPa, surpassing the specified characteristic strength of 30 MPa as per IS 456:2000. This indicates that the concrete mix meets and exceeds the required strength criteria for M30 grade.

Table 5 Trial no 2 7- and 28-days weight and density

Days	**Weight of Block (kg)**			Avg.	Avg. Density (kg/m3)
	Sample 01	**Sample 02**	**Sample 03**		
7 days	7.59	7.41	7.48	7.49	2220.24
28 days	7.75	7.85	7.89	7.82	2319.6

Average density of M30 grade light weight concrete on 28th day averages 2319 kg/m^3, which is far more than standard density of 1800 kg/m^3, so further improvisation in reducing density required.

5.6. Preparation of Trial 03

5.6.1. Materials Used

- Cement Type and Grade: Ordinary Portland Cement (OPC), Grade 53
- Coarse Aggregate: A blend of 75% sintered fly ash aggregates and 25% conventional coarse aggregates (max size: 10 mm)
- Fine Aggregate: conforming to Zone II
- Water: Potable water
- Water-Cement Ratio: 0.56

5.6.2. Mix Design Parameters

- Minimum Cement Content: 300 kg/m^3 (IS 456:2000, Table 3 – for very severe exposure)
- Slump (Workability): 100 mm (IS 456:2000, Clause 7.1)
- Standard Deviation: 5 N/mm^2 (IS 10262:2019, Table 2)
- Exposure Condition: Very Severe — requires enhanced durability and denser concrete

5.7. Description of the Mix

This concrete mix is designed to combine the benefits of both sintered fly ash aggregates (for reduced density and sustainability) and conventional aggregates (for strength retention). The blended proportion (75:25) aims to strike a balance between lightweight properties and structural integrity.

The relatively high water-cement ratio of 0.56 assists in achieving workability, especially with smaller 10 mm aggregates and higher fines content.

5.7.1. Summary of mix design

- Cement-0.813 kg.
- Water-0.487 ML.
- Fine Aggregate-2.36 Kg.
- Coarse Aggregate-0.78 Kg.
- Sintered Aggregate-2.36 Kg.
- Fly Ash-0.178 kg.
- Admixture-10.1 ml.

5.7.2. Results of Trial 03

Table 6 Trial no 3 7- and 28-days strength

Days	Strength Achieved (Mpa)			Avg.
	Sample 01	Sample 02	Sample 03	
7 days	16.1	20.32	20.15	19.47Mpa
28 days	28.21	30.11	30.05	29.44Mpa

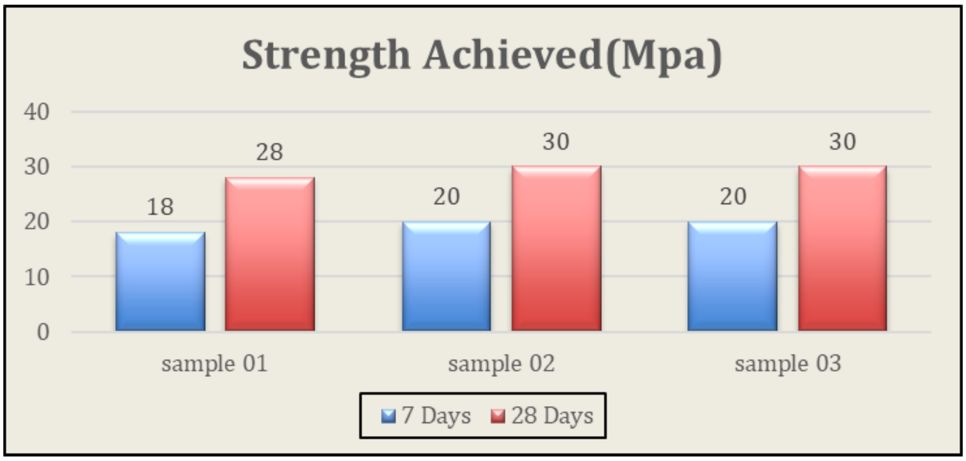

Figure 2 Strength achieved on 7th and 28th days of Trial 03

5.7.3. Observation

Table 7 Trial no 3 7- and 28-days weight and density

Days	Weight of Block(kg)			Avg.	Avg. Density (kg/m3)
	Sample 01	Sample 02	Sample 03		
7 days	7.02	7.08	7.45	7.15	2118.5
28 days	7.01	7.12	7.09	7.08	2197.7

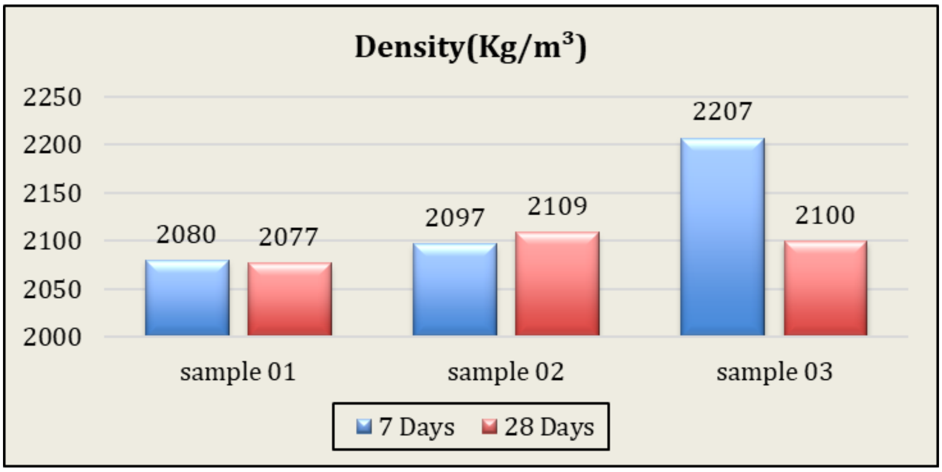

Figure 3 Density achieved on 7th and 28th days of Trial 03

The M30 grade concrete achieved an average 28-day compressive strength of 29.44 MPa, which is marginally below the specified characteristic strength of 30 MPa as per IS 456:2000. This indicates that the concrete mix is close to meeting the required strength criteria for M30 grade.

5.7.4. Observation

The measured densities of the lightweight concrete samples are 2118.5 kg/m^3 at 7 days and 2097 kg/m^3 at 28 days, both exceeding the typical maximum density of 1800 kg/m^3 for structural lightweight concrete. This indicates that the concrete mix does not meet the standard density criteria for lightweight concrete, suggesting the need to adjust the mix design to reduce density.

5.8. Comparative study with conventional M30 concrete

This project investigates the use of sintered fly ash aggregates (SFA) in producing lightweight M30-grade concrete and compares its performance against conventional M30 concrete. The comparison focuses on compressive strength, density, cost, and environmental impact, as per Indian Standard Codes. The results show that the SFA-based mix achieves a compressive strength of 34.23 MPa with a density of 2319 kg/m^3, outperforming conventional M30 concrete in strength but at a 55% higher cost. While not significantly lighter, the mix contributes to sustainable construction by utilizing industrial by-products, thus reducing environmental degradation.

6. Results and discussion

6.1. Compressive Strength

Table 8 Comparison of Strength of conventional and LWC

Concrete Type	Compressive Strength (MPa)
Conventional M30	30–32 (Avg)
Lightweight M30 (SFA)	34.23 MPa

The SFA mix surpasses the conventional strength requirement of M30 grade, demonstrating suitability for structural applications.

6.2. Density

Table 9 Comparison of Density of conventional and LWC

Concrete Type	Density (kg/m^3)
Conventional M30	2400–2500
Lightweight M30 (SFA)	2319

Although not drastically lower, the density reduction indicates that sintered fly ash aggregates offer moderate weight savings.

6.2.1. Comparing Of final Tests Results:

Table 10 Comparison of strength

Days	Strength Achieved (MPa)		
	Test 01	Test 02	Test 03
7 Days	16.5	22.01	19.47
28 Days	24.5	34.23	29.44

6.2.2. Observation

The compressive strength results of the three M30-grade concrete samples indicate a consistent strength gain from 7 to 28 days, demonstrating proper hydration and curing. At 28 days, all samples exceeded the required 30 MPa target (or came very close), with Sample 2 showing the highest strength (34.23 MPa), confirming an optimal mix. Samples 1 and 3 reached 24.5 MPa and 29.44 MPa, respectively—Sample 1 slightly underperformed, likely due to mix or curing variations, while Sample 3 was nearly at the target. Overall, the mixes are effective, with scope for refinement in the lower-performing trials.

Table 11 Comparison of Density

Days	Density (kg/m^3)		
	Test 01	Test 02	Test 03
7 Days	1877.53	2220	2119
28 Days	2008.80	2320	2198

6.2.3. Over all Observations:

The density results at both 7 and 28 days for all three M30-grade concrete samples exceed the desired target of 1800 kg/m^3, with values ranging from 1877.53 to 2320 kg/m^3. While Sample 1 (2008.80 kg/m^3) comes closest to the target, none of the mixes meet the lightweight criteria. This indicates that the sintered aggregate content may need to be increased to achieve the intended density reduction, and further optimization—such as increasing the percentage of sintered aggregates or incorporating lighter fine materials—is needed to bring the mix within the desired lightweight concrete range.

6.3. Cost Analysis

The cost of lightweight concrete using SFA is observed to be approximately 55% higher than conventional concrete due to the energy-intensive sintering process and procurement of fly ash aggregates. However, this cost could be offset in long-term projects due to reduced dead load and potential savings in structural design.

Table 12 Analysis based on cost effectiveness

Materials	Unit Price (Rs/kg)	Std. Mix (kg/m3)	Std. Cost (Rs)	Dev. Mix	Dev. Cost (Rs/kg)
Cement	8.00	400	3200	400	3200
Flyash	1.50	50	75	50	75
Sintered Aggregates	7	-	-	423.0	2961
Coarse Aggregates	0.72	739	532.80	316.54	227.90
Fine Aggregates	0.72	683.20	491.90	683.20	491.90
Admixture	120	4(lit)	480	4(lit)	480
Total			4779.70		7435.80

Cost Difference: ₹7,435.80 – ₹4,779.70 = ₹2,656.10

Percentage Increase: ₹2,656.10/₹4,779.70×100= 55.6%

6.4. Environmental Impact

6.4.1. Conventional Concrete

- Uses natural aggregates, leading to resource depletion and land degradation.
- High cement usage increases CO_2 emissions.

6.4.2. Lightweight Concrete (SFA):

- Utilizes industrial waste (fly ash), reducing environmental burden.
- Reduces demand for natural aggregates.
- Energy-intensive sintering process slightly offsets sustainability but still offers a net positive impact when fly ash is sourced nearby.

Lightweight concrete using sintered fly ash aggregates demonstrates comparable or superior strength to conventional M30 concrete, with modest reductions in density. Though the material cost is significantly higher (by 55%), the environmental benefits and sustainability factor make it a promising option for green building applications.

Given its performance, this mix is recommended for

- Precast elements
- Load-bearing and non-load-bearing walls
- Structures where reduced self-weight is advantageous

Further research is recommended on optimizing the sintering process and increasing economic feasibility.

7. Conclusion

The study successfully developed an M30 grade lightweight concrete mix using sintered aggregates, achieving target strength levels while highlighting areas for improvement in density and mix optimization. Although the cost was higher than conventional concrete, the mix demonstrates long-term value through reduced structural load, enhanced sustainability, and effective use of industrial waste.

- Mix Development & Strength: An optimal mix of M30 lightweight concrete using sintered aggregates was developed, achieving compressive strengths of 29.44 MPa and 34.23 MPa, fulfilling the target strength criteria.
- Workability & Density: While strength was achieved, some mixes exceeded the desired density range, indicating the need for further optimization in mix proportions, w/c ratio, and admixture dosage to balance strength and weight.
- Cost Analysis: The developed mix showed a ~55% increase in cost compared to conventional concrete but offers benefits like reduced structural load, improved sustainability, and the use of green waste— Potentially making it more cost-effective over time.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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