Mechanical Behavior of Angular Fly Ash Aggregates in Lightweight Concrete: Strength Development Properties

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Abstract — This research investigates the viability of using angular fly ash aggregates (AFAA) as a partial or complete replacement for natural coarse aggregates in lightweight concrete production. Experimental analysis evaluated five different replacement proportions (0%, 25%, 50%, 75%, and 100%) with compressive strength measurements conducted at 7, 14, 21, and 28 days of curing. Physical characterization of aggregates revealed that AFAA exhibited higher impact value, crushing value, abrasion value, and water absorption compared to natural aggregates, while having lower specific gravity (1.33 vs 2.55). Fresh concrete properties showed decreasing workability (measured by slump values) with increasing AFAA content. Compressive strength results demonstrated a consistent strength development pattern across all mixtures, with strength inversely proportional to AFAA content. The optimal replacement level was identified at 50% AFAA, achieving a 28-day compressive strength of 25.93 MPa while maintaining satisfactory workability. A regression-based mathematical model was developed to predict strength evolution over time, showing high correlation (R^2 values between 0.914-0.992) across all mixture proportions. Beyond mechanical performance, AFAA incorporation offers significant environmental benefits through waste utilization, natural resource conservation, and reduced carbon footprint compared to traditional aggregates. The findings suggest that appropriately proportioned AFAA can serve as a viable alternative in lightweight concrete applications, supporting sustainable construction practices while maintaining adequate structural performance.

Keywords: Angular Fly Ash Aggregates, Lightweight Concrete, Compressive Strength, Regression-Based Model, Sustainable Construction, Strength Development, Waste Utilization, Environmental Impact, Workability, Aggregate Properties, Specific Gravity, Water Absorption, Coarse Aggregate Replacement

I. INTRODUCTION

1) General: - Concrete is one of the most frequently used building materials and has a great capacity to dispose of industrial wastes. The use of waste and byproduct components as cement and aggregate substitutes in concrete is a tempting way to lessen the terrible ecological impact of concrete as interest in it grows. Flyash is one type of waste that is produced in large quantities as a byproduct from thermal power plants. There are ecological and storage problems caused by leaving a sizable amount of flyash fallow. A convincing method for getting rid of a lot of flyash is to use it to make sintered lightweight aggregates. Many different types of buildings and construction projects use aggregates.
2) Lightweight aggregate concrete: - Concrete that has been made lighter than standard concrete by changing the composition of the materials or the manufacturing process is known as lightweight concrete. Lightweight aggregate concrete is created by using lightweight aggregates in place of traditional ones. Density in typical concrete ranges from 24 to 25 kN/m3. The uneconomical structural material deviates from fly ash aggregate concrete's low self-weight due to its significant self-weight. The self-weight of structural and non-structural elements must be reduced in order to produce concrete with the anticipated density to cover the critical application. As a result, the economy can provide the structural support needed for the expansion of lightweight concrete.
3) Fly ash:- It is a byproduct of the burning of pulverized coal in thermal power plants, and it is a fine, powdery substance. As one of the most abundant industrial byproducts, it consists of inorganic mineral matter that becomes airborne and solidifies as it cools down during the combustion process. The type of coal used, the combustion circumstances, and the effectiveness of the emission control systems utilized in the power plant can all affect the composition of fly ash. Aluminum, iron, calcium oxide, silicon dioxide, and minor amounts of other elements are the main constituents.
4) Utilizing fly ash as a sustainable alternative to natural aggregate offers numerous significant benefits:
   - Conservation of Natural Resources: By using fly ash as a substitute for natural aggregate in construction materials, we can reduce the demand for extracting and depleting natural resources such as sand, gravel, and stone. This conservation helps preserve the environment and maintain the ecological balance of ecosystems.
   - Waste Reduction: By diverting fly ash from landfills and incorporating it into construction materials, we can minimize the environmental impact associated with its disposal and contribute to waste reduction efforts.
   - Energy and Carbon Footprint Reduction: The production of natural aggregate requires extensive energy inputs, including extraction, processing, and transportation. By replacing natural aggregate with fly ash, we can significantly reduce the energy consumption associated with aggregate production. Moreover, the carbon emissions generated during the extraction and processing of natural aggregate can be mitigated by utilizing fly ash, as it is a recycled material.

II. LITERATURE SURVEY

1) General: - In the construction sector, research on lightweight concrete and the use of substitute aggregates has been a prominent topic of study. The results of earlier studies on various elements of lightweight concrete are summarized as follows:
2) Mechanical Characteristics Studies employing a variety of substitute aggregates have looked at the compressive strength, tensile strength, and flexural strength of lightweight concrete. The outcomes have demonstrated that lightweight concrete can attain structurally sound strength while having a lower density than traditional concrete.
3) Mix Design and Proportioning: For lightweight concrete to have the appropriate qualities, mix design and proportioning are extremely important. Prior studies have concentrated on the use of chemical admixtures and the optimization of mix proportions, water-to-cement ratios, aggregate-to-cement ratios, and mix proportions to increase workability, strength, and durability. The development of mix design recommendations for lightweight concrete has made use of mathematical models and statistical techniques.
4) Study: Ling, T. C., Poon, C. S., & Lam, L. (2017) This study concentrated on the utilisation of recycled aggregate and fly ash in the creation of geopolymer concrete, an alternative to traditional cement-based concrete. The effects of using different amounts of fly ash as a substitute for natural aggregate in geopolymer concrete were examined by the researchers. The findings demonstrated that the mechanical qualities of the geopolymer concrete containing fly ash were on par with or even superior to those of the control concrete. By lowering carbon dioxide emissions and using waste, the addition of fly ash improved the sustainability features of geopolymer concrete.
5) Nadesan, M. S., & Dinakar, P. (2017) The mix design and characteristics of structural lightweight concrete using fly ash waste as lightweight aggregates were the main topics of this investigation. The mix proportions that were tested by the researchers were compared, and the mechanical and durability characteristics of the resulting concrete were assessed. The results showed that using fly ash waste lightweight aggregates in structural lightweight concrete is feasible and gave advice on how to improve the mix design for better performance.
6) Nadesan, M. S., & Dinakar, P. (2017) The usage of lightweight aggregates made from sintered fly ash in structural concrete was covered in this review paper. It gave a general review of the production method, characteristics, and uses of lightweight sintered fly ash aggregates. The mechanical, thermal, and durability properties of concrete made with these aggregates were also covered in the review. Understanding the potential and difficulties of using sintered fly ash lightweight aggregates in structural concrete is made easier thanks to the information provided in this article.
7) Rama Prasad, C.V.Siva. (2017) The construction of lightweight concrete utilising fly ash aggregates was studied and described in this research paper. Compressive strength, density, and workability of lightweight concrete were all factors that were investigated in the study. The results showed that employing fly ash aggregates instead of conventional coarse aggregates in the creation of lightweight concrete is feasible. The study advances our knowledge of the functionality of fly ash aggregates in lightweight concrete.

III. RESULT OF LAB TEST ON FRESH AGGREGATE AND ANGULAR FLYASH AGGREGATE

S.N.	Experiment	Fresh Aggregate	Angular fly ash aggregate
1	Impact Test I.V.	18.92%	32.14%
2	Crushing Test C.V.	19.05%	21.18%
3	Sieve Test (F.M.)	2.7	2.25
4	Abrasion Test	12.66%	35.44%
5	Specific Gravity Test Specific Value	2.55	1.33
6	Water Absorption	1.58%	19.48%

Table 6.1: Properties of Fresh and Waste Concrete Aggregate

A. Slump Value of Angular FLYASH Aggregate in Concrete M-25

Fresh Aggregate	Concrete Aggregate	Slump Value
Control Mix	00	90
75	30	83
50	50	80
25	80	76
00	100	68

Table 6.2: Slump Test Results angular flyash aggregate in Concrete M-25

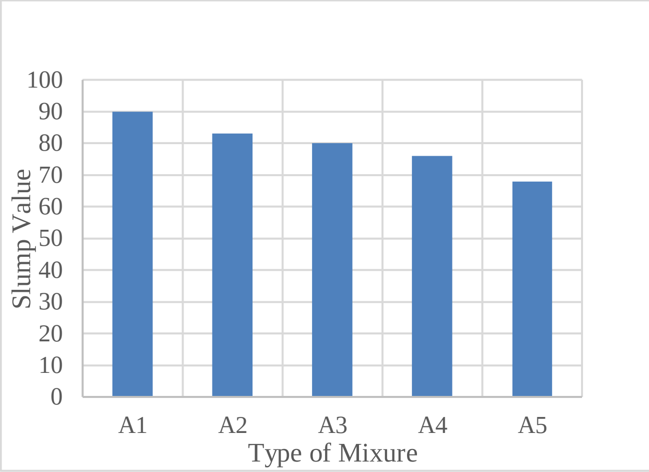

Fig. 6.1: Slump Test Results angular fly ash aggregate in Concrete M-25

B. All mix combinations' compressive strength at 7, 14, 21, and 28 days

Figures 8(a) and (b), respectively, show the findings of the compressive strength of recycled concrete aggregate with samples A1, A2, A3, A4, and A5. Nearly all the mixes attain the desired value of compressive strength and demonstrate strength development with age.

Serial no.	Natural Aggregate & angular fly ash aggregate	Compressive Strength (N/mm2)			
		7 days	14 days	21 days	28 days
A1	0	16.89	20.15	29.63	31.70
A2	25	15.26	19.26	25.19	26.81
A3	50	14.07	18.07	23.26	25.93
A4	75	13.63	16.44	20.59	22.22
A5	100	12.44	14.96	18.07	19.70

Table 6.3: Compressive strength of all mix combinations at 7, 14, 21, and 28 days

IV. CONCLUSIONS

In this study, the feasibility of using angular flyash aggregate as a substitute for natural coarse aggregate in concrete was investigated. The influence of various particle sizes of angular flyash aggregate was also examined. Based on the analysis of the experimental findings, the following conclusions can be drawn:

– Fresh aggregate properties exhibited better physical characteristics compared to angular flyash aggregate.
– As the content of angular flyash aggregate increased, the slump value decreased.
– An increase in angular flyash aggregate content resulted in a decrease in compressive strength.
– Optimum strength for the m-25 mix design was achieved with a 50% replacement of angular flyash aggregate.

A. Future Scope of the Study:

The following recommendations are proposed for further research:

– If further investigations support the use of concrete buildings, it is suggested to revise existing specifications to permit and encourage the utilization of other waste materials.
– Conduct additional trials with varying percentages of steel fiber, jute fiber, and coir fiber replacements.
– Further explore the durability, creep, and shrinkage characteristics of steel fiber, jute fiber, and coir fiber materials in new concrete through comprehensive laboratory tests.

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