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Experimental Investigation on Partial Replacement of Cement by Fly Ash and Coarse Aggregate by Recycled Concrete Waste in M25 Grade Concrete

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Abstract- *This paper presents experimental research on the mechanical behaviour of M25 grade concrete with fly ash as a partial replacement for cement and recycled concrete aggregate (RCA) as a partial replacement for natural coarse aggregates. Fly ash was injected at replacement levels of 0, 15, 20, 25, and 30 M and RCA at 30, 40, 50, 60 and 70 M replacement with the optimum fly ash dosage. An extensive experimental program was performed, which comprised compressive strength tests at 7, 28, 56 and 90 days, and flexural strength tests at the same ages. Findings show that replacement of up to 25 per cent fly ash increases compressive strength due to better particle packing and pozzolanic reactivity, with the maximum 28-day compressive strength of 38.4 MPa corresponding to 25 per cent fly ash, which is greater than that of the control mix (33 MPa). The combination of RCA at 40 per cent with 25 per cent fly ash exhibited the most promising performance, with the compressive strength of 40.6 MPa after 28 days being far greater than that of the control mix. The flexural strength was 3.47 MPa (control), 3.6 MPa (25% fly ash) and 3.8 MPa with the mixed mix. These findings prove that it is possible to obtain better strength characteristics in sustainable concrete with the use of up to 25 per cent fly ash and 40 per cent RCA instead of conventional concrete. This research contributes to the creation of environmentally friendly concrete, which is resource-efficient to be use in structures.*

Keywords: Fly ash, Recycled concrete aggregate, M25 grade concrete, Compressive strength, Flexural strength, Sustainable concrete

INTRODUCTION

Concrete is the most popular construction material to be used in the world, next only to water in total consumption. This is because it is versatile, strong, and durable, and this has led to its wide usage. Nevertheless, traditional concrete manufacturing depends seriously on natural aggregates and Portland cement, both of which cause harsh environmental impacts. The cement industry alone causes almost 8 per cent of the total carbon dioxide emissions globally, whereas the overall extraction process causes a lot of ecosystem degradation and loss of natural resources.

As the production of solid waste is projected to generate up to 3.88 billion tonnes annually across the world in 2050, there is an increased importance towards a sustainable alternative. Over a billion tonnes of industrial waste (fly ash, slag, and/or demolition waste) are generated each year in India. The use of these by-products in concrete not only encourages the reduction of waste but also the concepts of a circular economy.

Fly ash is a byproduct of thermal power production, and it has been common knowledge that fly ash is an efficient supplementary cementitious material (SCM). Micro-fine particles and the pozzolanic properties they contribute to long-term strength, workability and durability. The fly ash employed in this paper (Fly Ash 1203) has been classified into ultra-fine particles, high fineness (12,000 cm2/g) and a specific gravity of 2.86. Such properties enhance the density of the cement matrix and decrease permeability, and help in augmenting the mechanical performance.

RCA (recycled concrete waste), concrete demolition, and granite cutting have also resulted in a potential substitute for natural coarse aggregates. RCA offers a number of benefits, which include less environmental impact, cheaper and better solid waste management. The study material possessed a specific gravity of 2.64 and good crushing and water absorption values, and was thus good for the construction of concrete.

Past research findings indicate that the partial substitution of cement by SCMs like fly ash enhances the strength in the long run but can compromise the strength at an early age in case of excessive use. Equally, substitution of coarse aggregates with RCA could also reduce density because of adhered mortar, but could also improve bond properties and microstructure at its best. This paper examines the fly ash substitution of 30 per cent and the RCA substitution of 30 to 70 per cent of M25 grade concrete. Mechanical properties- compressive, flexural strength at various curing ages, etc., were examined in order to determine the optimum replacement levels.

1.1 Objectives

- To find out the maximum proportion of fly ash that enhances the strength properties.
- To determine the impact of RCA on compressive strength by using the ideal fly ash dosage.
- To investigate the flexural behaviour of sustainable concrete mixes.
- To propose substitution levels which can be used in structural-grade applications.

The research work will lead to the production of concrete blends of high performance and sustainability that strike a balance between mechanical performance and environmental considerations.

LITERATURE REVIEW

Past literature has always noted the advantages in the use of using industrial by-products in concrete in order to increase their sustainability and mechanical characteristics. The research by Indhya et al. proved that fly ash and recycled aggregate together enhance compressive strength and workability as the particles are packed better, and the pozzolanic activity is more advantageous (2024). Their results go in line with the patterns seen in this study, whereby 25 per cent of fly ash showed the highest strength improvement.

Manasa et al. (2019) investigated the behaviour of recycled concrete aggregate in the M25 mixes and arrived at the conclusion that the replacement of RCA by up to 50 per cent results in compressive strength that is similar to traditional mixes. But elevated replacement levels have a negative influence on strengthening because they cause porosity. Likewise, in the current study, replacement of RCA above 40 per cent led to a decrease in compressive strength.

Prasannan and Deepashri (2018) have documented that the use of demolition waste instead of natural aggregates to a proportion of up to 25 per cent enhanced the concrete strength because of the enhanced interlocking of angular particles. In addition, Sharma et al. (2017) emphasised the perspective of mixed waste aggregates, such as PVC and cast iron, and concluded that concrete with construction waste exhibited greater compressive strength but lower workability.

Various works have highlighted the usefulness of fly ash in improving the mechanical properties. Sinha and Hasan (2016) noted that the higher the fly ash content, the higher the durability and chloride resistance. The authors noted that the best performance can be achieved in the range of 10-15 per cent fly ash in different fibre-reinforced concretes (Magdum and Karjinni, 2016). Jayalakshmi and Basil (2016) also obtained sufficient strength increase using 40-60% RCA and 40% GGBS.

A wider survey by Yadav and Samant (2021) has found that fly ash (especially ultra-fine as Fly Ash 1203) can increase the mechanical and durability properties substantially when being added in the interval of 8-35%.

MATERIALS

3.1 MATERIALS

Cement: The cement type was ordinary Portland Cement (OPC 43 grade), which conforms to IS:12269-1987 and has a specific gravity of 3.12.

Fine Aggregates:

Table 0-1 Properties of Fine Aggregates

Specific Gravity	2.58
Fineness Modulus	2.69
Bulk density (loose)	1514 kg/m^3
Bulk density (compacted)	1674 kg/m^3

Coarse Aggregates:

Table 0-2 Properties of Coarse Aggregates

Nominal Size	20mm
Specific Gravity	2.70
Water absorption	0.9%
Bulk density	1487 kg/m^3 - 1676 kg/m^3
Crushing value	41%

Fly Ash (Type 1203):

Table 0-3 Properties of Fly Ash (type 1203)

Specific Gravity	2.86
Specific surface	11305 cm^2/g
Bulk density	640 kg/m^3
Mean size of the particles	4.4 µm

Recycled Concrete Waste (RCA):

Table 0-4 Properties of Recycled Concrete Waste

Specific Gravity	2.64
Water absorption	0.8%
Bulk density (compacted)	2850 kg/m^3
Crushing value	41%

Water: The mixing and curing were done using potable water.

Mix Design

Table 0-5 Mix Proportion of M25 grade Concrete.

Material	Cement	Fine aggregate	Coarse aggregate	Water
Quantity (kg/m^3)	320	714.66	1223.1	157
Mix proportion	1	2.23	3.82	0.49

1. EXPERIMENTAL PROCEDURE

- Casting: Cubes with dimensions 150×150×150 mm and beams with dimensions 150×150×700 mm were cast.
- Curing: Specimens were water-cured at 27±2°C for 7, 28, 56, and 90 days.
- Tests Conducted:
  - Slump test
  - Compressive strength test
  - Flexural strength test

RESULTS AND DISCUSSION

1.2 Compressive Strength

1.2.1 Effect of Fly Ash

Table 0-1 Compressive Strength with Fly Ash % at 7 and 28 days

Fly Ash %	7 Days (MPa)	28 Days (MPa)
0%	23.3	33.0
15%	24.9	36.8
20%	28.1	37.2
25%	28.4	38.4
30%	23.4	37.7

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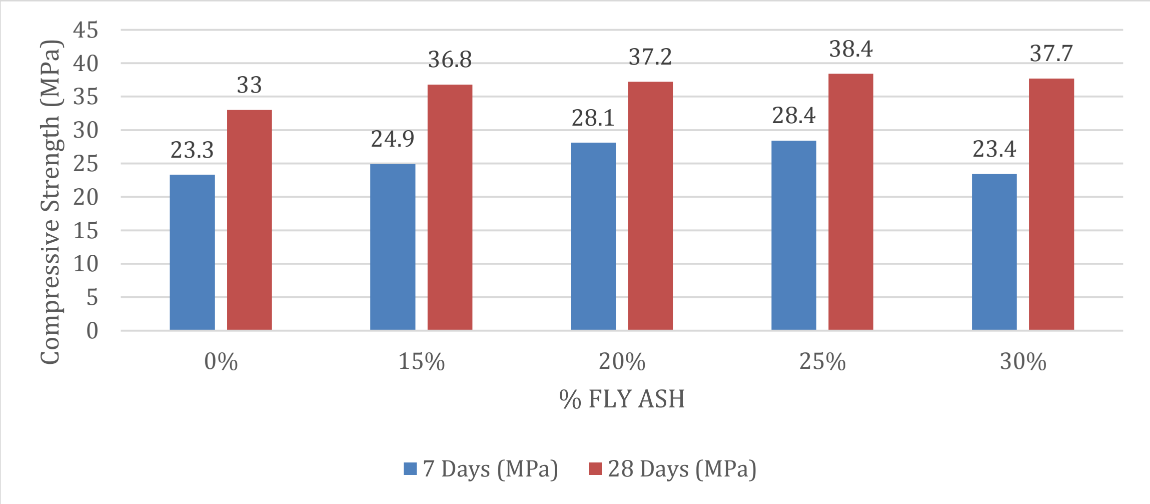

Figure 0-1 Compressive Strength vs Fly Ash(%) at 7 and 28 Day

1.2.2 A combination of optimum fly ash and RCA

Table 0-2 Compressive strength for optimum percentage of Fly ash and recycled coarse aggregate

Concrete mix	Fly ash (%)	Recycled concrete waste (%)	Normal aggregate (%)	Compressive strength (N/mm²)			
				7 days	28 days	56 days	90 days
Control mix	0	0	100	23.3	33	33.5	35.6
Fly ash	25	0	100	28.4	38.66	43.7	47.4
F1	25	30	70	27.4	-	-	-
F2	**25**	**40**	**60**	**32.7**	**40.6**	**45.3**	**48.9**
F3	25	50	50	27.1	-	-	-
F4	25	60	40	25.7	-	-	-
F5	25	70	30	24.6	-	-	-

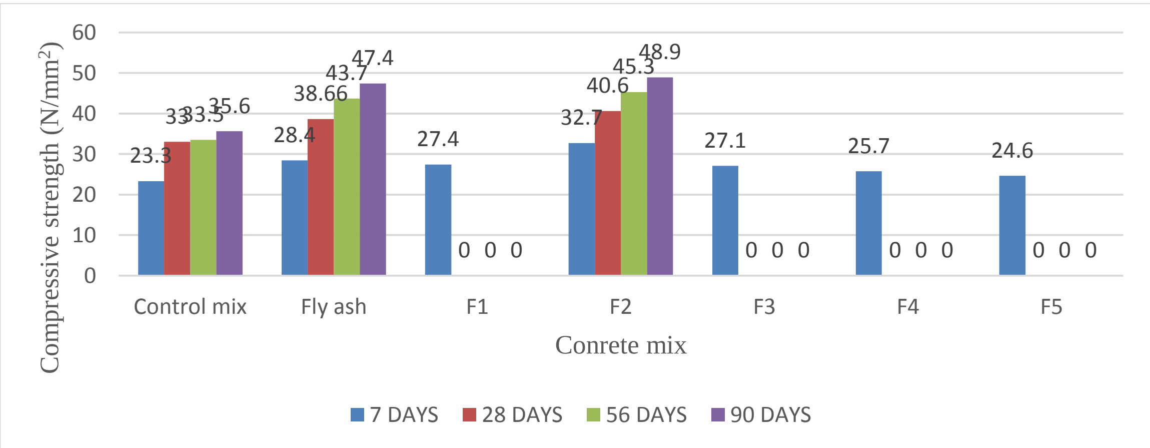

Figure 0-2 Compressive strength Vs % of Recycled concrete waste and Fly ash replacement by coarse aggregate and cement.

1.2.3 Flexural Strength Results

Table 0-3 Flexural Strength of Concrete Mix at 28 days

Mix	28-Day Flexural Strength (MPa)
Control	3.47
25% Fly Ash	3.6
25% Fly Ash + 40% RCA	**3.8**

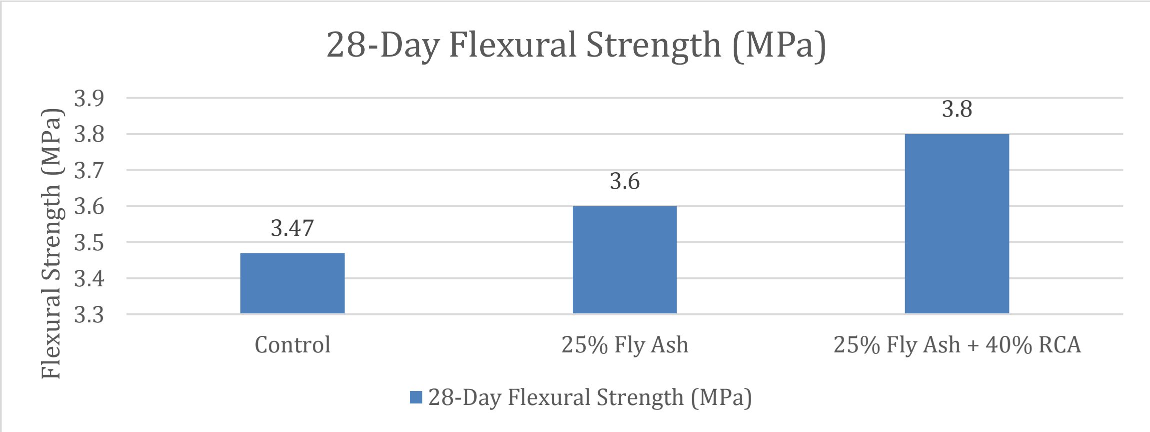

Figure 0-3 Flexural strength of concrete at 28 days

The experimental findings are clear evidence of how fly ash and recycled concrete waste (RCA) can be effectively applied to improve the mechanical performance of the M25 grade concrete at optimum proportions. Adding fly ash resulted in a significant enhancement in compressive strength in both the early and long-term stages, and the replacement level of 25% yielded the best results at all ages of testing. This improvement is explained by the fact that ultra-fine particle size of Fly Ash 1203 contributes to high packing density, fewer microvoids and increases pozzolanic reaction that leads to the formation of more calcium silicate hydrate (C-S-H) gels. The enhanced microstructure facilitated by these reactions goes a long way in enhancing the strength and life span of the concrete. On the other hand, replacement levels of over 25% showed a minor decrease in the strength, probably because of less calcium hydroxide to react with as pozzolana, when higher proportions of fly ash are used.

On the same note, the addition of RCA affected the mechanical properties of concrete, and performance differed according to the percentage replacement. The highest compressive strength of 40.6 MPa at 28 days was achieved by RCA at 40 per cent replacement and optimum 25 per cent fly ash, which is higher than the control mix. This is boosted by the angularity and roughness of the texture of RCA, which enhances the interlocking among aggregate particles and cement matrix. The mortar that is adhered to in RCA can also serve as the source of hydration. Nonetheless, a greater percentage of RCA above 40% resulted in decreased performance because of augmented porosity, diminution of density and poorer interfacial transition zone. Trends in flexural strength were the same as compressive ones, and optimum replacement levels were improved. The mixture of 25/40 fly ash and RCA had the most desired total performance, which implied that such concentrations result in a well-developed and integrated microstructure. Generally, the findings substantiate that reasonable application of fly ash and RCA would effectively lead to the creation of sustainable high-strength concrete that can be utilised in structural works.

CONCLUSIONS

- Fly ash has a tremendous effect on the mechanical properties, with the 25 per cent replacement giving the maximum compressive and flexural strength.
- With 25% fly ash, compressive strength went up by 16.4 per cent as 33 Mpa (control) was improved to 38.4 Mpa.
- RCA replacement increases the performance up to 40% then the strength reduces because of the increased porosity.
- The fly ash-RCA mixture with a 25 per cent fly ash content (40 per cent RCA) had the highest compressive strength (40.6 MPa at 28 days).
- The flexural strength was also found to increase at 3.47 MPa (control) and 3.8MPa of 25% fly ash + 40% RCA mix.

- The performance is improved due to high packing density, improvements in interlocking and pozzolanic activity.
- The high percentages of fly ash or RCA have adverse effects on the strength, as it results in low content of binder and high levels of voids.
- The combination (25 per cent fly ash and 40 per cent RCA) is the most favourable blend that facilitates a sustainable and environmentally-friendly concrete production.

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