

## Combined effect of partial replacement of cement with Alccofine and Fly Ash in M40 Grade Concrete

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### **ABSTRACT**

The excessive use of Ordinary Portland Cement (OPC) production is one of the major contributors to global carbon dioxide emissions and environmental degradation, accounting for nearly 7–8% of global CO<sub>2</sub> emissions [11,23,24,45]. To mitigate the environmental impact associated with cement production, the construction industry has increasingly focused on sustainable alternatives that reduce cement consumption while maintaining the desired mechanical and durability performance of concrete [13,14,26]. Supplementary cementitious materials (SCMs), such as Fly Ash and Alccofine, have demonstrated considerable potential in enhancing concrete properties while minimizing environmental impact [1–3,12,16,19]. This study investigates the combined effect of Alccofine-1203 and Fly Ash as partial replacements for cement in M40 grade reinforced cement concrete (RCC).

A fixed Alccofine-to-Fly Ash ratio of 33.33:66.67 was adopted, and the total cement replacement level was varied from 0% to 50%. The concrete mixes were evaluated for fresh, mechanical, and durability properties, including slump, compressive strength, split tensile strength, flexural strength, and water absorption, in accordance with relevant Indian and ASTM standards [31–33,38,40–42]. The experimental results revealed that workability increased with increasing SCM content due to improved particle packing and lubrication effects. Among all the mixes, the concrete containing 10% Alccofine and 20% Fly Ash exhibited optimum performance, achieving the highest 28-day compressive strength of 43.55 MPa along with improved tensile and flexural strengths and acceptable durability characteristics. At higher replacement levels, a reduction in strength was observed due to dilution effects and delayed pozzolanic reactions [12,20,27,28]. The findings of this study demonstrate that the combined utilization of Alccofine and Fly Ash can effectively reduce cement consumption while maintaining or enhancing the performance of M40 grade RCC.

**Keywords:** Reinforced Cement Concrete, Alccofine, Fly Ash, Workability, Compressive Strength, Split Tensile strength, Flexural Strength.

## **1. INTRODUCTION**

The rapid growth of infrastructure and urban development has led to a substantial increase in the demand for concrete, making it the most widely used construction material worldwide [21,44,45]. Ordinary Portland Cement (OPC), a primary constituent of concrete, is energy-intensive to manufacture and is responsible for a significant portion of global carbon dioxide emissions [11,23,24]. Recent studies indicate that the cement industry contributes approximately 7–8% of total global CO<sub>2</sub> emissions, emphasizing the urgent need for sustainable construction practices [11,23,24,45].

One effective strategy to reduce the environmental impact of concrete is the partial replacement of cement with supplementary cementitious materials (SCMs) [13,14,26,30]. SCMs such as Fly Ash, Ground Granulated Blast Furnace Slag, silica fume, and Alccofine have been widely investigated for their ability to improve workability, strength development, and durability of concrete [5,6,13,17]. Fly Ash, a by-product of coal-fired thermal power plants, exhibits pozzolanic properties that contribute to long-term strength development and improved durability [12,14,20,27]. However, higher Fly Ash replacement levels often result in reduced early-age strength due to slower pozzolanic reactions [12,27,28].

Alccofine-1203 is an ultrafine slag-based SCM characterized by a high specific surface area and rapid reactivity. It enhances early-age strength by accelerating the formation of calcium silicate hydrate (C–S–H) gel and improving particle packing density [1,2,7,15,16,25]. The combined use of Fly Ash and Alccofine has the potential to balance early- and long-term strength development while significantly reducing cement content [3,19]. Despite this potential, limited studies have systematically investigated their combined effect in high-strength reinforced cement concrete. This study aims to address this research gap by experimentally evaluating the combined influence of Alccofine and Fly Ash on the fresh, mechanical, and durability properties of M40 grade RCC.

## **2. REVIEW OF LITERATURE**

Several researchers have reported that partial replacement of cement with Alccofine in the range of 10–15% significantly enhances compressive, split tensile, and flexural strengths due to its ultrafine particle size and high reactivity [1,2,7,15,16]. The incorporation of Alccofine improves particle packing density and accelerates hydration, resulting in reduced porosity and enhanced durability characteristics [16,25].

Fly Ash has been extensively studied as a supplementary cementitious material owing to its economic and environmental benefits [12,14,30]. Studies have demonstrated improved workability, reduced heat of hydration, and enhanced long-term strength in Fly Ash-based concrete [12,14,27]. However, excessive Fly Ash replacement often leads to delayed early-age strength development, limiting its application in high-strength concrete [12,20,27,28].

Recent investigations on the combined use of Fly Ash and Alccofine indicate that Alccofine can compensate for the slow pozzolanic reaction of Fly Ash, resulting in improved early-age strength and refined pore structure [3,19]. Researchers have also reported improved durability performance and reduced water absorption in blended systems containing both materials [10,17,29]. Nevertheless, the optimum proportion of these materials varies depending

on concrete grade, curing conditions, and mix design parameters. Therefore, further experimental studies are required to establish suitable replacement levels for high-strength RCC applications, which forms the basis of the present investigation.

### **3. MATERIALS AND EXPERIMENTAL PROGRAM**

Ordinary Portland Cement (OPC) of 53 grade conforming to IS 12269 was used as the primary binder [35]. Alccofine-1203 and Class F Fly Ash conforming to ASTM C618 were used as supplementary cementitious materials [41]. River sand conforming to IS 383:2016 was used as fine aggregate, while crushed angular aggregates of 10 mm and 20 mm sizes were used as coarse aggregates [32]. Potable water suitable for concrete mixing and curing was used throughout the study. A polycarboxylate-based superplasticizer was incorporated to achieve the desired workability.

The concrete mix was designed for M40 grade in accordance with IS 10262:2019 [33]. A constant water-to-cementitious material ratio of 0.405 was adopted. Six concrete mixes were prepared with total cement replacement levels of 0%, 10%, 20%, 30%, 40%, and 50%, while maintaining a fixed Alccofine-to-Fly Ash ratio of 33.33:66.67. All specimens were cast, compacted, and cured under standard laboratory conditions. Each test result represents the average value of three specimens tested under identical conditions. Tests were conducted as per IS 516:1959 (Reaffirmed 2020) [38].

#### **3.1 Materials**

1. Cement : OPC 53 Grade (SHREE BANGUR): High strength, Faster setting time, good workability and durability.

#### **2. Supplementary Cementitious Materials (SCMs);**

2.1 Alccofine 1203: Ultrafine (1–10 microns), highly reactive GGBS-based SCM. It possesses an extremely fine particle size (typically <10 microns) and high pozzolanic reactivity, which enhances strength, durability, and reduces heat of hydration

2.2 Fly Ash : Class F, low carbon content, specific gravity 2.2.

A fine-particulate byproduct of burning pulverized coal in thermal power plants. Indian coal-based thermal power stations produce a substantial quantity of good-quality Fly Ash with low Sulphur and unburnt carbon. Fly ash is a valuable resource for cement and concrete production.

3. Fine Aggregate : River sand confirming to IS:383-2016.

4. Coarse Aggregate : 20mm & 10mm graded aggregates.

5. Water : Potable, as per IS:456.

6. Superplasticizer : Formaldehyde-based high-range water reducer.

#### **3.2 Mix Design**

The concrete was designed for a target strength of M40 grade. The partial replacement of cement by the combined Alccofine and Fly ash was conducted across six mixed designations (M1 to M6) using a common water-cementitious materials ratio of 0.405 (based on the best trial mix). The replacement proportions were IS 10262:2019 & IS 456:2000 followed.

Best trial mix selected: 1:2.04:3.88, W/C = 0.405.

**Table. 1 The Six mixes (M1–M6) prepared with varying replacement ratios**

Mix	Combined both Alccofine and Fly Ash	Alccofine	Fly Ash	Alccofine % of Replacement	Fly Ash % of Replacement
M1	0%	0%	0%	0%	0%
M2	10%	5%	10%	33.30%	66.70%
M3	20%	10%	20%	33.30%	66.70%
M4	30%	15%	30%	33.30%	66.70%
M5	40%	20%	40%	33.30%	66.70%
M6	50%	25%	50%	33.30%	66.70%

### 3.3 Experimental Program

Each test result represents the average of three specimens tested under identical conditions.

Specimen Details : Cubes (150mm width x 150mm breadth x 150mm height, Cylinders (150 mm dia x 300 mm height), and Beams (100 mm width x 100 mm breadth x 500 mm length).

Tests conducted : 7, 14, and 28 days.

Parameters Tested:

- ✓ Slump Test
- ✓ Water Absorption
- ✓ Compressive Strength
- ✓ Split Tensile Strength
- ✓ Flexural Strength

## 4. RESULTS AND DISCUSSION

### 4.1 Experimental Results

4.1.1 Workability (Slump Test): Slump increased with SCMs content due to improved cohesiveness and with optimum values observed for M3 mix proportion.

**Table. 2 Average results of slump test**

Mix. No.	SCMs Replacement ratios	Avg. Slump Results			
		Batch	Batch	Batch	Average

		Mix-1	Mix-2	Mix-3	Slump
M1	0% of Alccofine & 0 % Fly Ash	93.0	94.0	95.0	<b>94.00</b>
M2	5 % of Alccofine & 10 % Fly Ash	94.5	95.0	97.0	<b>95.50</b>
M3	10 % of Alccofine & 20% Fly Ash	95.5	96.0	97.5	<b>96.33</b>
M4	15 % of Alccofine & 30 % Fly Ash	96.5	97.0	98.0	<b>97.16</b>
M5	20 % of Alccofine & 40 % Fly Ash	97.0	97.5	98.5	<b>97.66</b>
M6	25 % of Alccofine & 50 % Fly Ash	97.5	98.0	98.5	<b>98.00</b>
		95.67	96.25	97.42	<b>96.44</b>

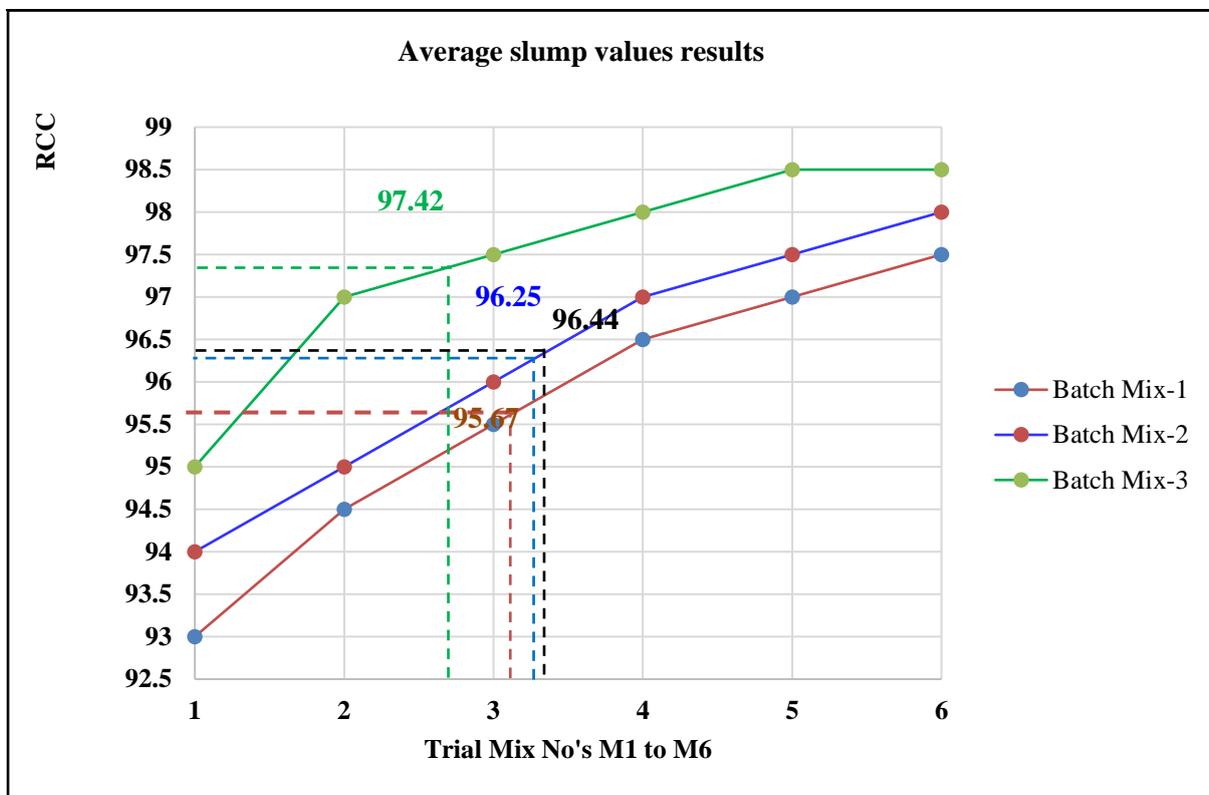


Fig. 1 Average slump values of RCC targeting 100mm slump

4.1.2 Durability (WA – Water Absorption Test): Water absorption marginally increased at higher SCM contents due to the increased specific surface area and associated higher water demand of the mineral admixtures, with values approaching those of the M3 mix proportions

Table. 3 Average water absorption values of Cubes, Cylinders & Beams for 7, 14 & 28 days

Mix. No.	SCMs Replacement ratios	Avg. WA in %age of Cubes	Avg. WA in %age of Cylinder	Avg. WA in %age of Beams	Average WA in %age
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		7, 14 & 28 Days	7, 14 & 28 Days	7, 14 & 28 Days	
M1	0% of Alccofine & 0 % Fly Ash	0.43	0.45	0.47	<b>0.45</b>
M2	5 % of Alccofine & 10 % Fly Ash	0.58	0.56	0.55	<b>0.56</b>
M3	10 % of Alccofine & 20 % Fly Ash	0.73	0.63	0.64	<b>0.66</b>
M4	15 % of Alccofine & 30 % Fly Ash	0.83	0.71	0.75	<b>0.76</b>
M5	20 % of Alccofine & 40 % Fly Ash	0.92	0.81	0.84	<b>0.86</b>
M6	25 % of Alccofine & 50 % Fly Ash	1.04	0.93	0.97	<b>0.98</b>
		0.76	0.68	0.70	<b>0.71</b>

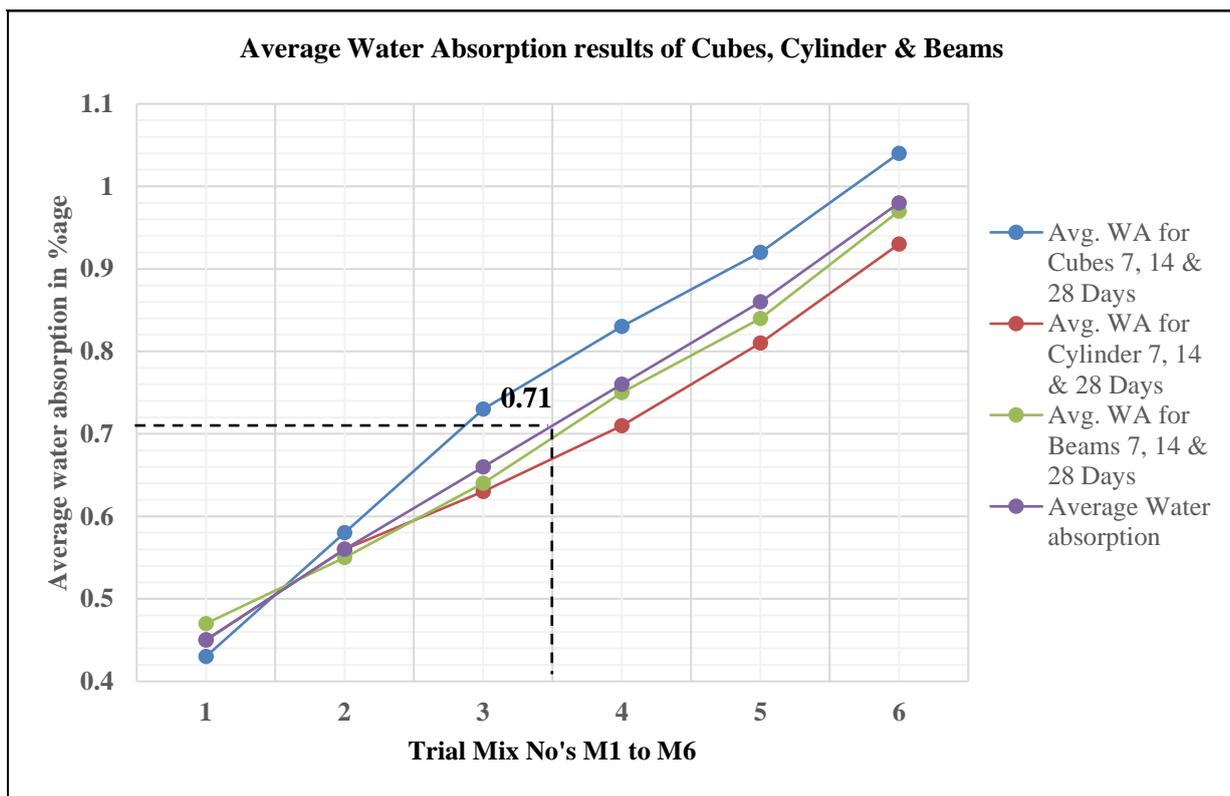


Fig. 2 Average water absorption values of RCC, which must be between 0 to 2%

#### 4.1.3 RCC Strength

##### 4.1.3.1 Compressive strength results of Cubes

**Table. 4 Average Compressive strength values of Cubes for 7, 14 & 28 days**

Mix. No	SCMs Replacement ratios	Compressive Strength Results in MPa		
		7 Days	14 Days	28 Days
M1	0% of Alccofine & 0 % Fly Ash	25.85	33.81	39.78
M2	5 % of Alccofine & 10 % Fly Ash	26.37	34.49	40.58
M3	10 % of Alccofine & 20% Fly Ash	27.65	36.16	<b>43.55</b>
M4	15 % of Alccofine & 30 % Fly Ash	26.66	34.87	41.03
M5	20 % of Alccofine & 40 % Fly Ash	25.93	33.91	39.90
M6	25 % of Alccofine & 50 % Fly Ash	23.11	30.22	35.56

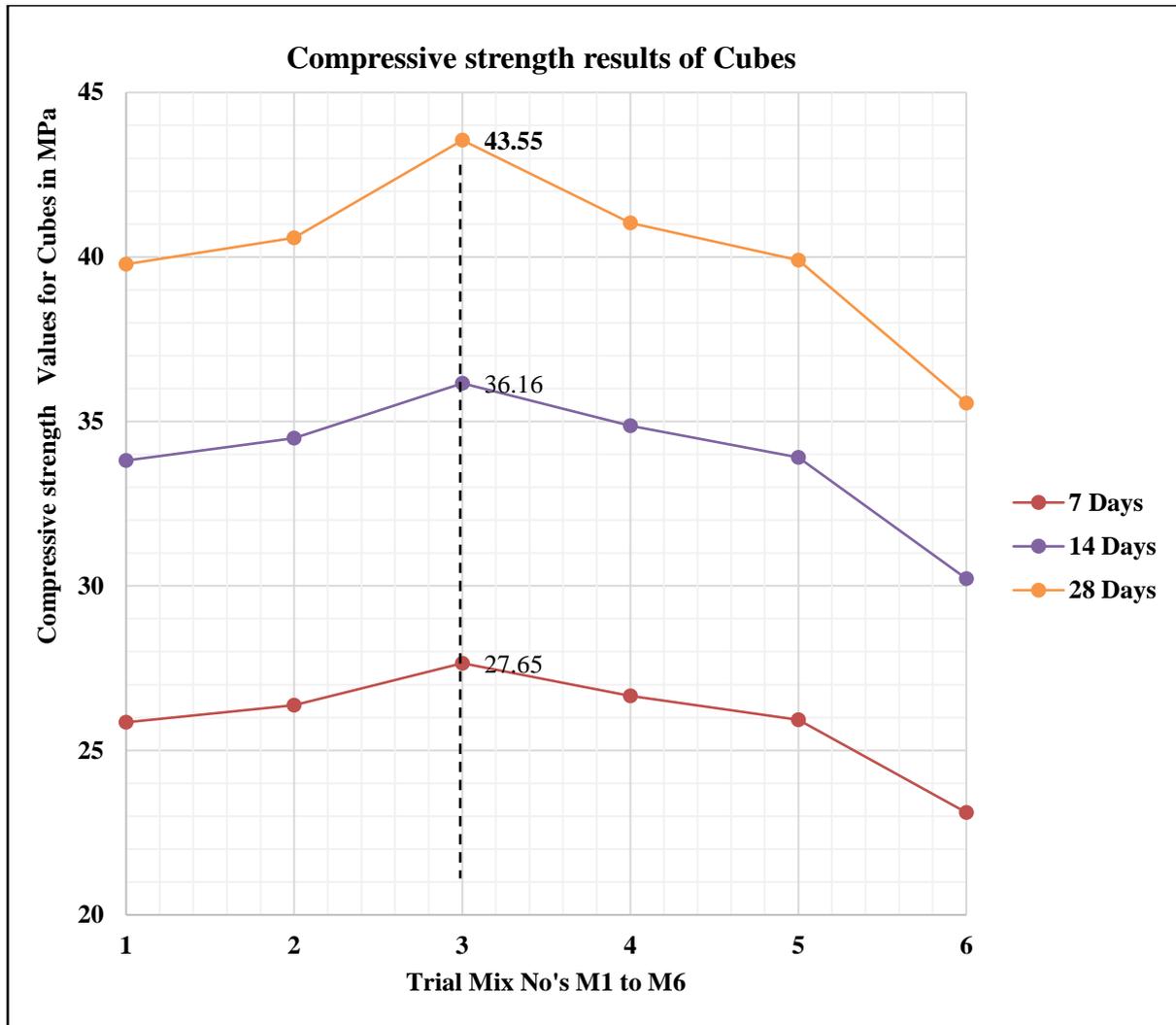


Fig. 3 Optimum compressive strength values of RCC Cubes

4.1.3.2 Split tensile strength results of Cylinders

Table. 5 Average Split tensile strength results of Cylinders for 7, 14 & 28 days

Mix. No	SCMs Replacement ratios	Split Tensile Strength Results in MPa		
		7 Days	14 Days	28 Days
M1	0% of Alccofine & 0 % Fly Ash	2.24	3.12	3.47
M2	5 % of Alccofine & 10 % Fly Ash	2.29	3.14	3.49

M3	10 % of Alccofine & 20% Fly Ash	2.42	3.35	<b>3.73</b>
M4	15 % of Alccofine & 30 % Fly Ash	2.13	2.96	3.29
M5	20 % of Alccofine & 40 % Fly Ash	1.976	2.73	3.04
M6	25 % of Alccofine & 50 % Fly Ash	1.83	2.53	2.82

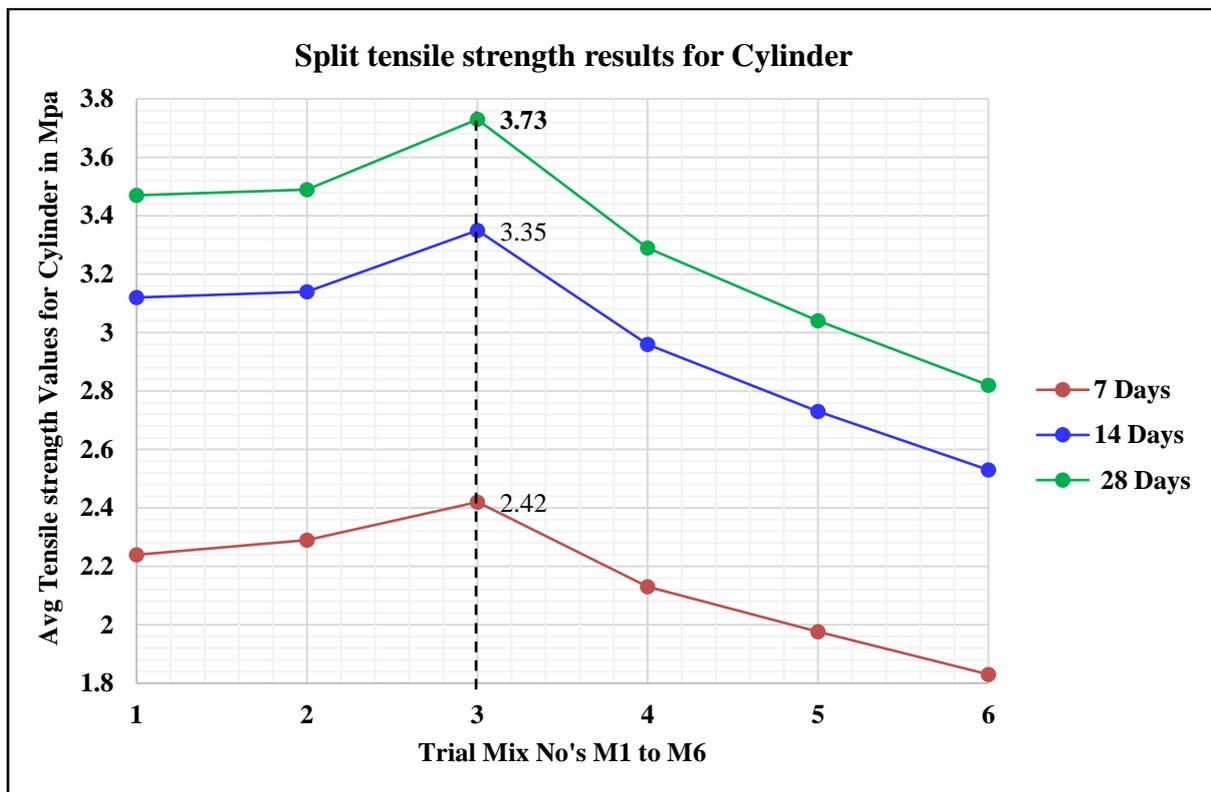


Fig. 4 Optimum Split tensile strength values of RCC Cylinders

4.1.3.3 Flexural strength results of Beams

Table. 6 Average Flexural strength results of Beams for 7, 14 & 28 days

Mix. No	SCMs Replacement ratios	Flexural Strength Results in MPa		
		7 Days	14 Days	28 Days
M1	0% of Alccofine & 0 % Fly Ash	2.54	3.28	3.92

M2	5 % of Alccofine & 10 % Fly Ash	2.6	3.6	4.01
M3	10 % of Alccofine & 20% Fly Ash	2.8	3.88	<b>4.32</b>
M4	15 % of Alccofine & 30 % Fly Ash	2.74	3.78	4.22
M5	20 % of Alccofine & 40 % Fly Ash	2.31	3.22	3.62
M6	25 % of Alccofine & 50 % Fly Ash	2.25	3.09	3.47

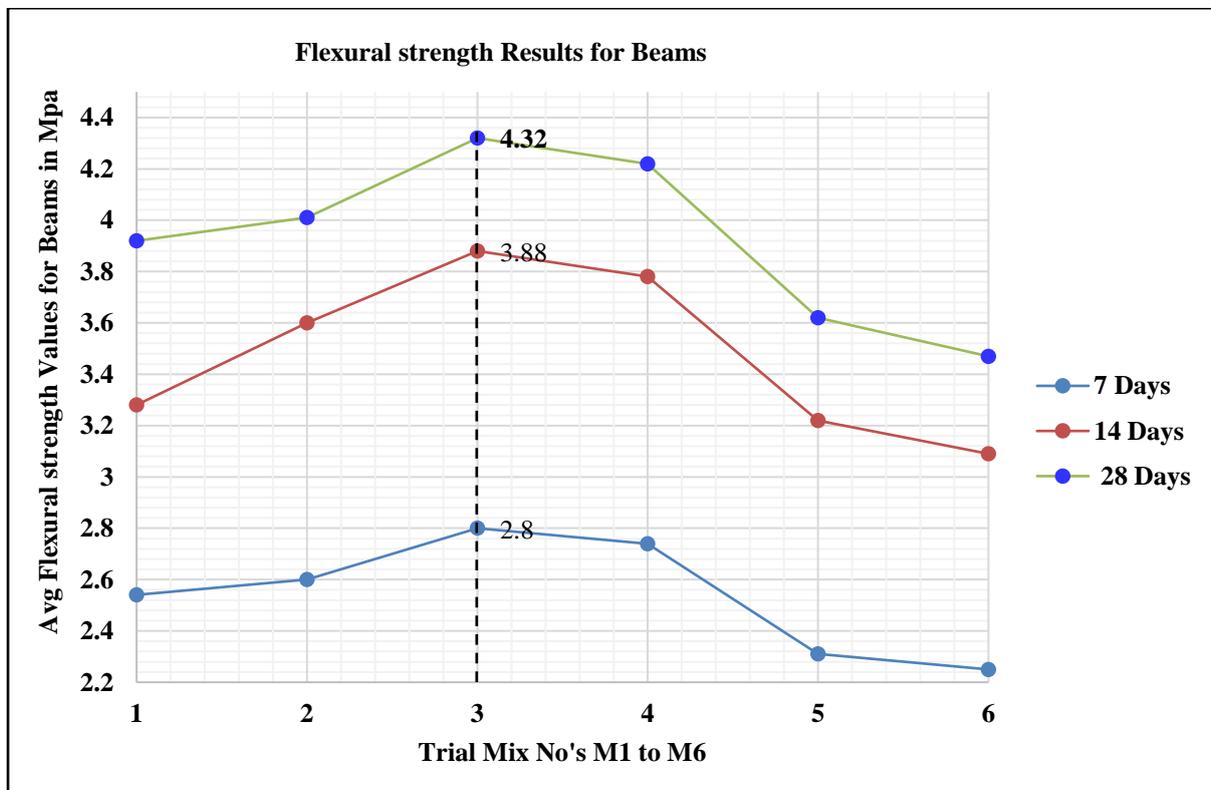


Fig. 5 Optimum Flexural strength values of RCC Beams

#### 4.2 Discussion of Results

The workability of concrete, measured through the slump test, increased with increasing SCM content. This improvement is attributed to the spherical morphology of Fly Ash particles and the micro-filling ability of Alccofine, which together enhance lubrication and reduce internal friction [12,14,16,20]. Mixes with higher SCM content exhibited better cohesion and reduced segregation.

Compressive strength results indicated that the concrete containing 10% Alccofine and 20% Fly Ash achieved the highest 28-day compressive strength of 43.55 MPa. The strength enhancement is attributed to the synergistic effect of Alccofine and Fly Ash, where Alccofine contributes to early-age strength development and Fly Ash enhances long-term strength through pozzolanic reactions [1,3,19, 25]. At higher replacement levels, strength reduction was observed due to dilution of cementitious content and delayed hydration [12,20,27,28].

Similar trends were observed for split tensile and flexural strengths. The optimum mix demonstrated superior tensile performance and improved crack resistance, indicating improved bonding between the cement matrix and aggregates [21,44]. Water absorption results confirmed that mixes with optimum SCM content exhibited acceptable durability due to refined pore structure and reduced capillary porosity [10,17,29]. The reduction in cement content through combined replacement supports sustainability objectives by lowering clinker consumption and associated environmental impact [11,23,24].

## **5. CONCLUSION**

Based on the experimental investigation on M40 grade reinforced cement concrete incorporating Alccofine and Fly Ash, the following conclusions are drawn:

1. The combined use of Alccofine and Fly Ash significantly influences the fresh and hardened properties of concrete.
2. Workability improves with increasing SCM content due to enhanced particle packing and lubrication effects.
3. Optimum performance was achieved at 30% total cement replacement (10% Alccofine + 20% Fly Ash), resulting in improved compressive, split tensile, and flexural strengths.
4. Higher replacement levels led to reduced strength due to dilution effects and delayed pozzolanic reactions.
5. The combined SCM approach effectively reduces cement consumption and promotes sustainable construction through utilization of industrial by-products.

### **Scope for Future Study**

- ✓ Explore higher-grade RCC (M50–M60) with combined SCMs.
- ✓ Microstructural analysis using SEM, XRD, and FTIR.
- ✓ Durability tests such as: Rapid Chloride Penetration Test, Acid Resistance, Freeze–Thaw resistance
- ✓ Required field trial on small-scale RCC segments.

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## **PROJECT GALLERY**

