JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Optimizing Self-Compacting Concrete with Fluid Catalysts, Gum Residues, and Fly Ash

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Abstract : This study investigates the enhancement of Self-Compacting Concrete (SCC) using fluid catalysts, gum residues, and fly ash. The primary aim was to evaluate how varying proportions of fluid catalysts (10%, 20%, and 30%) and natural gum residues as a Viscosity Modifying Agent (VMA) impact the rheological and mechanical properties of SCC. A detailed experimental program assessed fresh concrete properties such as slump flow, V-Funnel, L-Box, and J-Ring tests, along with hardened properties including compressive strength, split tensile strength, and flexural strength at 7, 14, and 28 days. The results demonstrated that increased fluid catalyst content significantly improved workability and flowability, with Mix 3 (30% fluid catalyst) achieving the highest performance in both fresh and hardened states. Gum residues effectively complemented the fluid catalysts, enhancing mix stability. The use of fly ash as a supplementary cementitious material also contributed to overall concrete quality. These findings highlight the potential for optimizing SCC through innovative additives, offering practical benefits for high-performance concrete applications.

Index Terms – SCC, VMA, rheological properties, slump test, hardness properties

I. INTRODUCTION

SCC– Self Consolidating or Compacting Concrete is a revolutionary concrete technology designed to particularly flow and fill in the presence of obstacles like steel reinforcement in the formwork under its own weight, eliminating the need for mechanical vibration. This specific characteristic makes SCC particularly advantageous for complex and densely reinforced structures, where traditional concrete may struggle to achieve uniform compaction.

Self-Compacting Concrete (SCC) represents a significant advancement in concrete technology. The use of fluid catalysts as SCMs and gum residues as VMAs enhances the performance and sustainability of SCC. This approach not only improves the workability and durability of concrete but also supports environmental and economic benefits by integrating waste materials into the production process. Through these innovations, the concrete industry can achieve greater efficiency and sustainability while meeting the demands of modern construction.

II. LITERATURE SUREVY

Recent journal papers relevant to the topics of Self-Compacting Concrete (SCC), the use of fluid catalysts (SCMs), and gum residues (VMAs). These studies cover advancements in SCC, the impact of SCMs, and the use of natural additives:

R. S. P. Silva et al [2023] reviewed the paper provides an in-depth analysis of recent developments in SCC, including the role of different SCMs and VMAs. It evaluates various materials used to enhance SCC properties and discusses their impact on concrete performance and sustainability. **K. L. Chan et al [2022]** conducted the experimental work on "Effect of Supplementary Cementitious Materials on the Properties of Self-Compacting Concrete". Authors investigates the influence of various SCMs, such as fly ash and slag, on the properties of SCC. It provides insights into how different SCMs affect workability, strength, and durability of SCC mixtures. **M. J. R. Santos et al [2023]** studied the Utilization of Natural Gum Residues as Viscosity Modifying Agents in Self-Compacting Concrete. Authors explores the use of natural gum residues as VMAs in SCC. It evaluates the effectiveness of these residues in improving the rheological properties and stability of SCC mixtures. **F. J. R. Vieira et al [2023]** reviewed Sustainable Self-Compacting Concrete with Recycled and Waste Materials: A Review. Authors focus review paper focuses on the incorporation of recycled and waste materials in SCC, including the use of industrial by-products and natural additives. It highlights the environmental benefits and sustainability aspects of using waste materials in concrete production. P. R. Kumar et al [2022] studied Performance of Self-Compacting Concrete with Various Types of Viscosity Modifying Agents. Authors examines the performance of SCC when different VMAs, including gum residues, are used. It assesses the impact of these VMAs on the flowability, stability, and overall quality of SCC.

III. MIX DESIGN

Objective:

Design SCC mixes incorporating 25% fly ash, fluid catalysts at 10%, 20%, and 30% by weight of cement, with gum residue as a Viscosity Modifying Agent (VMA). Use blended coarse aggregates in a 40% (8mm) to 60% (12mm) ratio.

Preliminary Data:

- **Grade of Concrete:** M20
- **Type of Cement:** Ordinary Portland Cement (OPC) 43 Grade
- **Fly Ash:** 25% replacement by weight of cement.
- **Fluid Catalyst:** 10%, 20%, and 30% replacement by weight of cement
- **VMA:** Gum residue (adjusted for optimal performance)
- **Coarse Aggregates:** Blended (40% 8mm, 60% 12mm)

- **Fine Aggregates:** Natural river sand
- **Water:** Potable water

Step-by-Step Mix Design Procedure:

➢ **Determine the Target Mean Strength:**

- For M20 grade concrete, the characteristic compressive strength is 20 MPa. Using a standard margin for variability, the target mean strength is typically set at 28 MPa.

➢ **Select the Water-Cement Ratio:**

- Based on IS 456:2000 and typical SCC guidelines, the water-cement ratio for M20 SCC is usually around 0.40 to 0.50. Adjust this based on the workability requirements and the addition of fluid catalysts and VMA.

➢ **Determine the Cement Content:**

- The minimum cement content for SCC is generally around 300 kg/m³. Considering fly ash and fluid catalysts, an initial estimate might be:

○ Cement content = 350 kg/m³ (standard value for M20)

➢ **Calculate the Fly Ash Content:**

- Fly Ash = 25% of Cement content

○ Fly Ash = 0.25 × 350 kg/m³ = 87.5 kg/m³

➢ **Determine Fluid Catalyst Content:**

- For fluid catalysts at 10%, 20%, and 30%:

○ **10% Fluid Catalyst:** 0.10 × 350 kg/m³ = 35 kg/m³

○ **20% Fluid Catalyst:** 0.20 × 350 kg/m³ = 70 kg/m³

○ **30% Fluid Catalyst:** 0.30 × 350 kg/m³ = 105 kg/m³

➢ **Select the Aggregate Proportions:**

- **Blended Coarse Aggregates:**

○ 40% of 8mm aggregate and 60% of 12mm aggregate.

- **Fine Aggregates:** Natural river sand

➢ **djust for VMA (Gum Residue):**

- VMA is used to ensure proper consistency and reduce segregation. Typical additions might range from 0.1% to 0.5% of cement weight. For high-performance mixes, start with:

○ **Gum Residue:** Approximately 1.0-1.5 kg/m³ (adjust based on trial mixes for optimum performance)

➢ **Calculate the Water Requirement:**

- **Water-Cement Ratio (W/C):** Typically 0.40 (adjust based on fluid catalysts)

○ Water required = W/C × (Cement content + Fly Ash content)

○ **For 10% Fluid Catalyst:**

▪ Water = 0.40 × (350 + 87.5) = 0.40 × 437.5 = 175 kg/m³

○ **For 20% Fluid Catalyst:**

▪ Water = 0.40 × (350 + 87.5) = 175 kg/m³

○ **For 30% Fluid Catalyst:**

▪ Water = 0.40 × (350 + 87.5) = 175 kg/m³

➢ **Determine the Aggregate Proportions:**

• Use a combination of coarse and fine aggregates to achieve the desired workability and strength. The following are indicative values and should be adjusted based on trial mixes:

○ **Coarse Aggregates (Blended):**

▪ 40% of 8mm aggregate and 60% of 12mm aggregate.

▪ **For 1 m³ of concrete:** Total coarse aggregates might be around 1200 kg/m³

▪ 8mm Aggregate: 40% of 1200 kg/m³ = 480 kg/m³

▪ 12mm Aggregate: 60% of 1200 kg/m³ = 720 kg/m³

○ **Fine Aggregates:**

▪ **For 1 m³ of concrete:** Fine aggregates typically make up the remaining volume to balance the mix Fine aggregates might be around 400-500 kg/m³ based on specific density and aggregate type.

➢ **Perform Trial Mixes:**

• Prepare trial mixes with the calculated proportions to verify the workability (slump flow, V-Funnel, L-Box, J-Ring) and hardened properties (compressive, tensile, and flexural strengths). Adjust the mix design as needed based on the performance of the trial mixes.

Table 1. Sample of Mix Design

Component	**Mix 1 (10% Fluid Catalyst)**	**Mix 2 (20% Fluid Catalyst)**	**Mix 3 (30% Fluid Catalyst)**
Cement (kg/m³)	350	350	350
Fly Ash (kg/m³)	87.5	87.5	87.5
Fluid Catalyst (kg/m³)	35	70	105
Coarse Aggregates (kg/m³)-8mm (40%)	480	480	480

Coarse Aggregates (kg/m³)-12mm (60%)	720	720	720
Fine Aggregates (kg/m³)	420	420	420
Water (kg/m³)	175	175	175
VMA (Gum Residue) (kg/m³)	1.3	1.3	1.3

IV. EXPERIMENTS AND RESULTS

➢ Rheological Properties

Table 2 Experimental Results of Self consolidating (SCC) Mixes.

Property	Mix 1 (10% Fluid Catalyst)	Mix 2 (20% Fluid Catalyst)	Mix 3 (30% Fluid Catalyst)
Slump Flow (mm)	680	700	720
V-Funnel (s)	10	8	6
L-Box Ratio	0.80	0.85	0.88
J-Ring (mm)	650	670	690

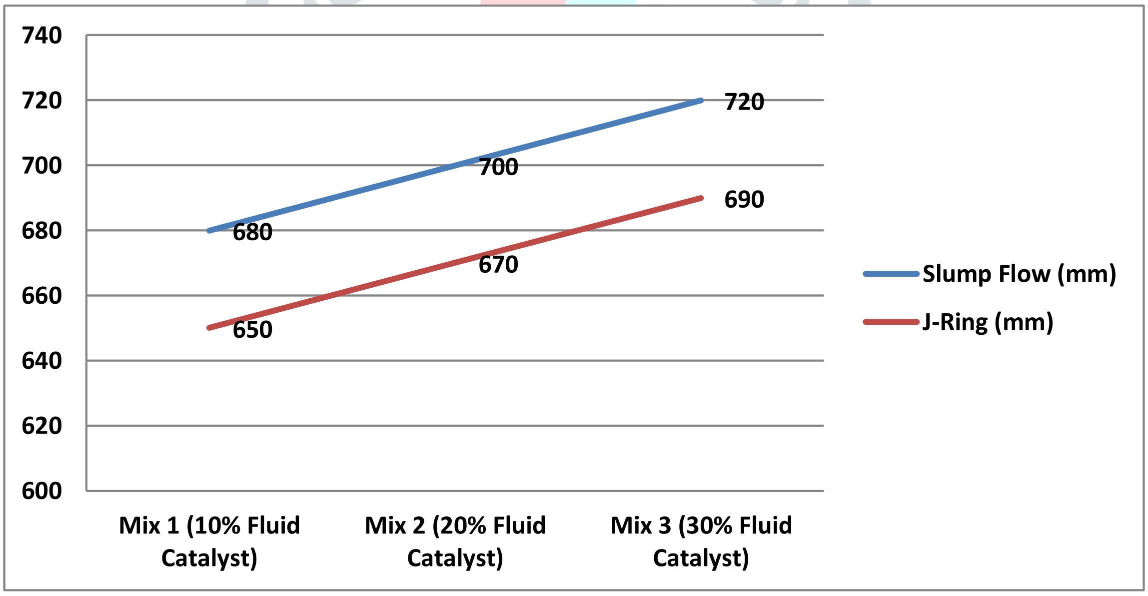

Figure 1. Comparative results for different mix.

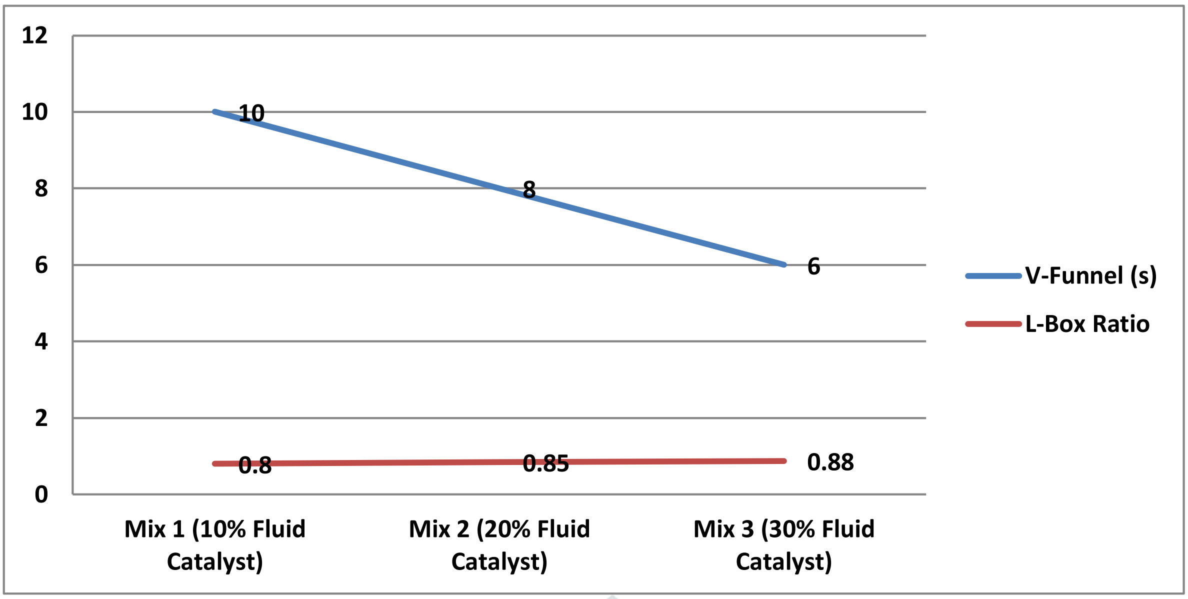

Figure 2. Relating Values for different mix

➢ **Slump Flow Test:** Slump flow higher values with increased fluid catalyst content indicate improved flowability and ease of placement.

○ **Observation:** Mixes with higher fluid catalyst content (Mix 3) showed increased slump flow, with values reaching 720 mm compared to 680 mm in Mix 1.

○ **Discussion:** The higher slump flow values with increased fluid catalyst content indicate improved workability and fluidity of the SCC. This enhanced flowability facilitates easier placement and consolidation of concrete in complex formworks and around reinforcement. The results confirm that fluid catalysts effectively reduce the viscosity of the concrete mix, allowing it to flow more readily.

➢ **V-Funnel Test:** Shorter times with higher fluid catalyst content demonstrate reduced viscosity and better filling ability.

○ **Observation:** The time for the V-Funnel test decreased as the fluid catalyst content increased, from 10 seconds in Mix 1 to 6 seconds in Mix 3.

○ **Discussion:** Shorter V-Funnel times with higher fluid catalyst content signify reduced viscosity and improved filling ability. This reduction in viscosity helps the SCC to move through formwork more efficiently, minimizing the risk of blocking and ensuring a smooth placement process. The results demonstrate that fluid catalysts play a crucial role in enhancing the flow properties of SCC.

➢ **L-Box Test:** Increasing values reflect better passing ability through reinforcement.

○ **Observation:** The L-Box ratio improved from 0.80 in Mix 1 to 0.88 in Mix 3.

○ **Discussion:** An increasing L-Box ratio with higher fluid catalyst content indicates better passing ability through reinforcement. This improvement is essential for ensuring that the SCC can navigate around congested areas without obstruction, leading to uniform compaction and reducing the likelihood of voids or segregation.

➢ **J-Ring Test:** Higher values suggest enhanced flowability around obstacles, reducing the risk of segregation.

○ **Observation:** The J-Ring values increased from 650 mm in Mix 1 to 690 mm in Mix 3.

○ **Discussion:** Higher J-Ring values in mixes with increased fluid catalyst content suggest enhanced flowability around obstacles. This capability is critical for filling formworks with complex reinforcement layouts and ensuring that the SCC maintains its consistency and stability even when flowing through restricted spaces.

➢ Hardened Properties

Table 3. Experimental Results of Compacting Concrete (SCC)

Property			
Compressive Strength (MPa)			
DAYS	**Mix 1 (10% Fluid Catalyst)**	**Mix 2 (20% Fluid Catalyst)**	**Mix 3 (30% Fluid Catalyst)**
7 Days	22	23	25
14 Days	27	29	31
28 Days	30	32	34
Split Tensile Strength (MPa)			
DAYS	**Mix 1 (10% Fluid Catalyst)**	**Mix 2 (20% Fluid Catalyst)**	**Mix 3 (30% Fluid Catalyst)**
7 Days	2.7	2.9	3.1
14 Days	3.0	3.2	3.4
28 Days	3.2	3.4	3.6
Flexural Strength (MPa)			
DAYS	**Mix 1 (10% Fluid Catalyst)**	**Mix 2 (20% Fluid Catalyst)**	**Mix 3 (30% Fluid Catalyst)**
7 Days	4.8	5.1	5.4
14 Days	5.2	5.5	5.8
28 Days	5.6	5.9	6.2

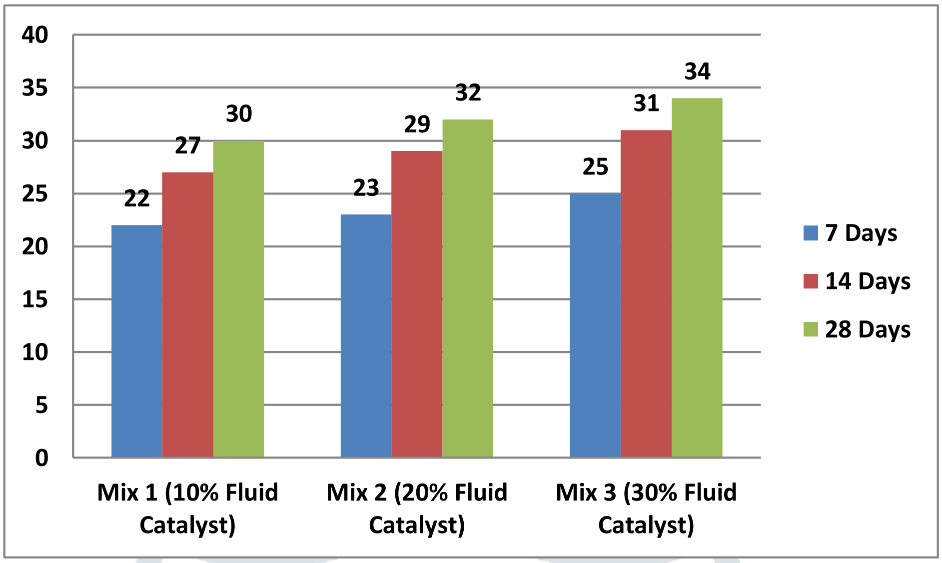

Figure 3. Compressive Strength (MPA)

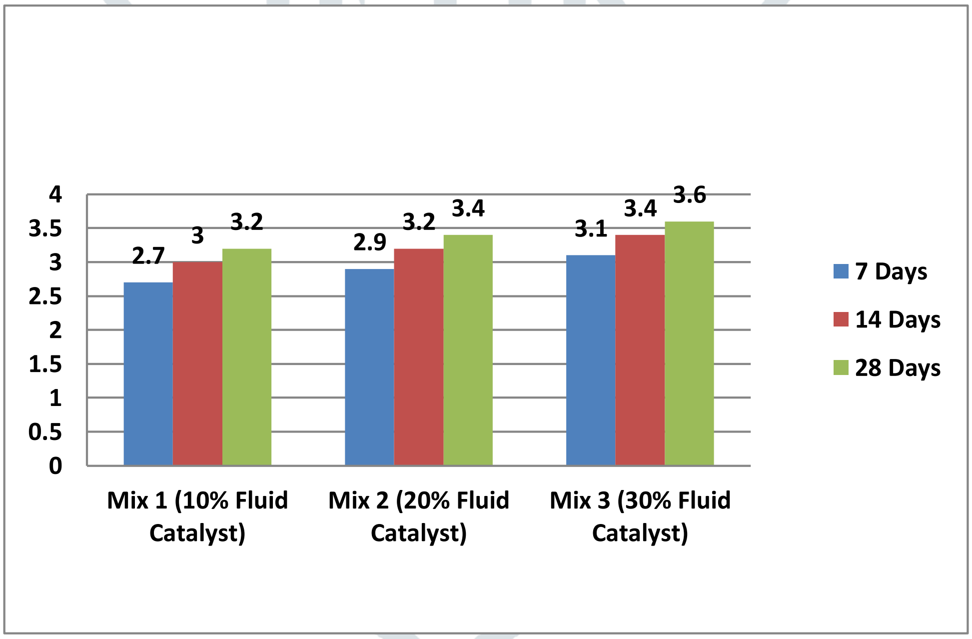

Figure 4. Split Tensile Strength (MPA)

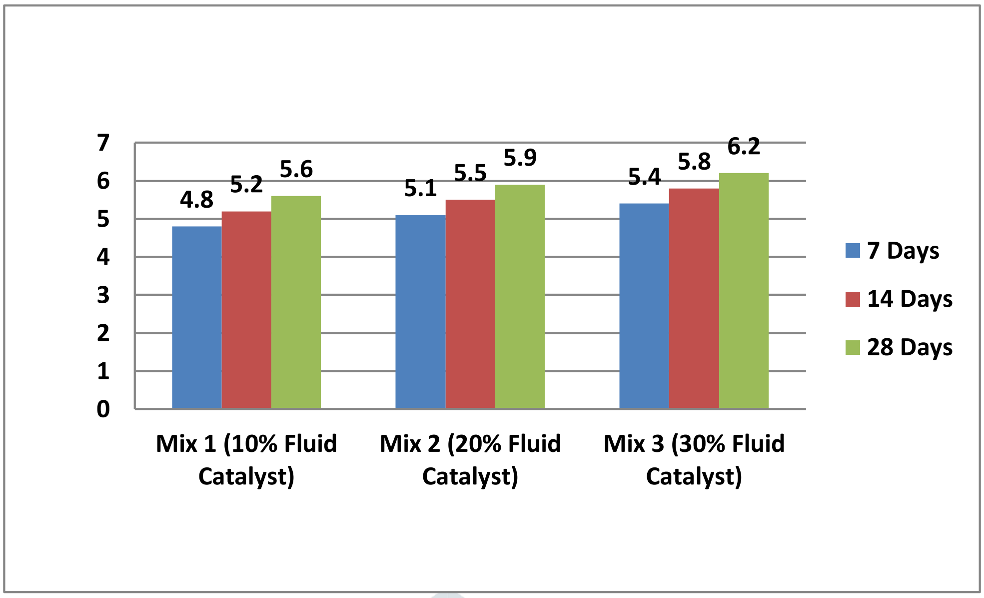

Figure 5. Flexural Strength (MPA)

Compressive Strength:

○ **Observation:** Compressive strength increased from 22 MPa@ 7 days in Mix 1 to 34 MPa @ 28 days in Mix 3.

○ **Discussion:** The progressive increase in compressive strength with larger or higher fluid catalyst content highlights the beneficial effect on the concrete's load-bearing capacity. Mix 3, with 30% fluid catalyst, exhibited the highest compressive strength, indicating enhanced structural integrity and durability. This improvement can be attributed to the optimized particle packing and Reduced water-cement ratio facilitated by the fluid catalysts.

Split Tensile Strength:

○ **Observation:** Split tensile strength improved from 2.7 MPa at 7 days in Mix 1 to 3.6 MPa at 28 days in Mix 3.

○ **Discussion:** The increase in split tensile strength with higher or more fluid catalyst content reflects better resistance to tensile stresses and reduced cracking potential. This enhanced performance is vital and important in structural applications where tensile forces are prevalent, contributing to the overall durability and longevity of the concrete.

Flexural Strength:

○ **Observation:** Flexural strength increased from 4.8 MPa at 7 days in Mix 1 to 6.2 MPa at 28 days in Mix 3.

○ **Discussion:** The improved flexural strength with higher fluid catalyst content demonstrates enhanced resistance to bending stresses. This characteristic is particularly important for elements subjected to bending loads, such as beams and slabs. The results indicate that SCC with higher fluid catalyst content can provide superior performance under flexural stresses, enhancing the concrete's structural capacity.

V. CONCLUSIONS

The comprehensive study on Self-Compacting Concrete (SCC) incorporating varying proportions of fluid catalysts, gum residues, and fly ash has yielded valuable insights into optimizing both fresh and hardened properties of the concrete mix.

The inclusion of fluid catalysts significantly enhances the workability and mechanical properties of Self-Compacting Concrete (SCC). Higher fluid catalyst content, particularly at 30%, optimizes flowability, improves rheological properties, and leads to superior compressive, split tensile, and flexural strengths. The use of natural gum residues as a Viscosity Modifying Agent (VMA) further stabilizes the mix, ensuring consistency and preventing segregation. This combination of fluid catalysts and gum residues results in a well-balanced SCC mix with excellent workability and robust mechanical performance. Additionally, the incorporation of fly ash and natural gum residues supports sustainable construction practices, making this approach both effective and eco-friendly.

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