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Investigation of the Ternary Blended Self-Compacting Concrete with Fiber's Strength and Durability Properties

Pawar Priyan[1], C. Venkata Siva Rama Prasad[2], B. Sudharshan Reddy[3]

[1]M. Tech Student, Department of Civil Engineering, Malla Reddy Engineering College, Secunderabad-500100, Telangana, India

[2]Associate Professor, Department of Civil Engineering, Malla Reddy Engineering College, Secunderabad-500100, Telangana, India.

[3]Professor, Department of Civil Engineering, Malla Reddy Engineering College, Secunderabad-500100, Telangana, India

*__Correspondence Author:__

Pawar Priyan,

Email ID: Priyanpawaar@gmail.com

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ABSTRACT

This study investigates the effect of ternary blended self-compacting concrete (SCC) mixes incorporating fly ash and silica fume on the compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity over different curing periods (7, 14, 28, and 56 days). The results revealed that the compressive strength increased with up to 20% fly ash substitution, with an optimal improvement of 13.64% at 28 and 56 days in the mix with 20% fly ash and 10% silica fume (TBC9). Similarly, splitting tensile strength and flexural strength exhibited significant improvements in mixes TBC9 and TBC10, particularly at 28 and 56 days, while the addition of glass fibers further enhanced tensile strength. The modulus of elasticity showed an increase in stiffness, with TBC9 demonstrating the highest value at 31.04 GPa. The study emphasizes the potential of ternary blends with fly ash and silica fume in enhancing the mechanical and physical properties of SCC, particularly with 20% fly ash and 10% silica fume

Keywords: *Ternary Blended Concrete, Self-Compacting Concrete, Fly Ash, Silica Fume, Compressive Strength, Splitting Tensile Strength, Flexural Strength, Modulus of Elasticity, Glass Fiber Reinforced Concrete.*

1. INTRODUCTION

Concrete is one of the most commonly used construction materials worldwide, made by mixing cement, fine and coarse aggregates, and water. However, inconsistencies in its fresh and hardened properties can lead to durability issues. Proper compaction is crucial for achieving optimal strength, yet manual compaction using vibrators is often inadequate in practice. To address this, Self-Compacting Concrete (SCC) was developed, which flows and consolidates under its own weight without external vibration.

SCC was first introduced in Japan to overcome compaction-related defects and reduce the need for skilled labor. It has high flowability, allowing it to pass through congested reinforcement and intricate architectural designs without segregation. According to Paulo Ricardo et al., SCC must meet three key criteria: filling ability, which enables the concrete to flow under its own weight; passing ability, which allows it to move easily through reinforcement; and segregation resistance, ensuring a uniform consistency during mixing and placement.

Based on composition, SCC can be categorized into three types: Powder-type SCC, which has a high powder content (550-650 kg/m³) and offers superior performance; Viscous Modifying Agent (VMA) SCC, with a lower powder content (350-450 kg/m³), mainly used in underwater structures; and Combination-type SCC, which balances flowability and mechanical strength with a moderate powder content (450-550 kg/m³). SCC provides several advantages, including eliminating the need for mechanical vibration, making it ideal for complex and reinforced structures, enhancing construction speed, reducing labor dependency, improving concrete strength, and minimizing noise pollution.

To improve SCC's properties and reduce costs, Supplementary Cementitious Materials (SCMs) such as metakaolin, rice husk ash, fly ash, silica fume, and ground granulated blast furnace slag (GGBS) are incorporated. These materials refine the concrete's pore structure, improving strength and durability. Fly ash, a byproduct of coal-fired power plants, is one of the most commonly used SCMs, significantly reducing environmental concerns related to its disposal. It enhances the long-term strength of concrete while lowering early-age strength due to its alumina and silica content. Silica fume, another byproduct of the silicon industry, has high pozzolanic reactivity and significantly improves the compressive strength and durability of SCC by reducing pore size.

Additionally, Fiber-Reinforced Self-Compacting Concrete (FR-SCC) has been developed to enhance SCC's mechanical properties. Concrete is inherently weak in tension, making it prone to shrinkage cracks. The inclusion of fibers, such as natural (coir, jute, cotton) or synthetic (steel, glass, polypropylene), helps control cracking, improve tensile strength, and increase impact resistance. Glass fibers, for example, enhance durability and reduce crack propagation, though excessive fiber content may affect SCC's flowability. The optimal fiber dosage can improve both the strength and performance of SCC in structural applications.

2. LITERATURE REVIEW

Jones et al. (1997)

Jones and colleagues studied the durability of ternary blended concrete and found that it exhibited superior resistance to chloride ion penetration compared to standard concrete.

Thomas et al. (1999)

Thomas investigated the durability properties of ternary blended concrete with silica fume and Class C and F fly ash. Class C fly ash reduced sulfate resistance, but the addition of silica fume mitigated this issue. The combination of Class F fly ash and silica fume improved mechanical properties and durability while significantly reducing chloride ion penetration.

Path et al. (1999)

Path examined the effects of alkali-silica reaction (ASR) on ternary blends containing fly ash, silica fume, and slag. The study found that ternary mixtures exhibited higher resistance to ASR compared to binary mixes of OPC + fly ash or OPC + slag. Additionally, ternary blends achieved higher early strength and improved durability.

Bleszynski et al. (2002)

Bleszynski assessed the mechanical and durability properties of ternary mixes containing ground granulated blast furnace slag (GGBS) and silica fume. The study found that ternary blends resisted chloride penetration, ASR, and saltwater exposure better than conventional concrete.

Ghrici et al. (2006, 2007)

Ghrici studied ternary mixes incorporating natural pozzolana, silica fume, and limestone powder. The research demonstrated enhanced early-age compressive strength, increased resistance to acid and sulfate attacks, and reduced chloride permeability.

Medhat and Michael (2006)

Medhat and Michael analyzed the durability of ternary concrete containing silica fume and fly ash with varying calcium content. Their study showed that low-calcium fly ash reduced expansion due to alkali-silica reaction.

Mullick et al. (2007)

Mullick explored the effects of granulated slag, fly ash, and silica fume in ternary blends. The study concluded that ternary mixes improved mechanical properties, corrosion resistance, and durability compared to conventional concrete.

Chindaprasirt and Rukzon (2008)

Chindaprasirt and Rukzon focused on incorporating fly ash and rice husk ash into mortar. They observed that early-age strength was lower, but 28-day compressive strength improved significantly. They also noted that pozzolanic reactions of fly ash and rice husk ash were delayed.

Murthi et al. (2008)

Murthi investigated M20, M30, and M40 ternary mixes with OPC (72%), fly ash (20%), and silica fume (8%). The study showed that weight loss due to acid attacks was lower in ternary mixes compared to conventional concrete.

Sharfuddin et al. (2008)

Sharfuddin examined the chloride permeability of ternary mixes containing silica fume and fly ash. The study found that chloride penetration was significantly reduced, with ternary mixes requiring only seven days of curing.

Elahi et al. (2010)

Elahi assessed high-performance ternary concrete containing silica fume, fly ash, and GGBS. The study found that ternary blends exhibited superior durability, particularly in resisting chloride penetration.

Robert et al. (2010)

Robert found that ternary mixes containing metakaolin and Class C fly ash reduced alkali-silica reaction expansion, outperforming conventional and binary concrete.

HAF et al. (2012)

HAF studied self-compacting concrete (SCC) with quarry dust, silica fume, and fly ash. The ternary blends showed improved compressive strength, flexural strength, and durability properties.

Ali et al. (2012)

Ali explored ternary concrete containing GGBS and silica fume. The study concluded that silica fume contributed significantly to early-age strength and reduced water demand. The ternary mix also demonstrated superior durability compared to binary and conventional concrete.

Kannan and Ganesan (2012)

Kannan and Ganesan investigated the effects of fly ash and metakaolin in SCC. Their study revealed that ternary blends improved both fresh concrete properties and mechanical performance.

Satish et al. (2013)

Satish examined ternary blends with fly ash and rice husk ash. The study found that while 28-day compressive strength was slightly lower than control concrete, flexural strength increased by 4.5%.

Bode Venkata Kavyateja et al. (2019)

Bode Venkata Kavyateja studied self-compacting concrete incorporating fly ash and alccofine. The research concluded that the optimal alccofine replacement was 10%, which significantly improved workability and compressive strength.

3. MATERIALS AND METHODOLOGY

3.1 Materials Used

3.1.1 Cement:

The 53-grade OPC concrete used in this review followed IS 12269-2013. The real properties, including specific gravity, consistency, and setting times, were determined as per IS 12269-2013 standards. The specific gravity and density were measured using a Le Chatelier flask, while the fineness was assessed using a Blaine-type variable air permeability device according to IS: 4031 (P2)-1999.

3.1.2 Fine Aggregate:

River sand with a specific gravity of 2.62 and a fineness modulus of 2.6 was used in the SCC mixes. The physical properties were determined as per IS: 383-2016. The fine aggregate was graded in accordance with Zone II as specified in IS: 383-2016.

3.1.3 Coarse Aggregate:

Crushed granite with a maximum size of 12.5 mm was used as the coarse aggregate in SCC, following IS: 383-2016. The specific gravity, fineness modulus, and bulk density were determined as per relevant IS codes. Additionally, the aggregate impact and crushing values were measured in accordance with IS: 2386 (P4)-1963.

3.1.4 Water

Ordinary potable drinking water available in the laboratory was used for mixing the SCC. The pH value, chloride content, total hardness, and total dissolved solids were within permissible limits as per IS: 456-2000.

3.1.5 Fly Ash:

Class F fly ash, a byproduct of coal-fired power plants, was used in this study. The chemical composition met ASTM C 618-1992 requirements, with a high $SiO_2 + Al_2O_3 + Fe_2O_3$ content and low calcium oxide content. The specific gravity and density were determined using a Le Chatelier flask, and fineness was measured using a Blaine-type air permeability device as per IS: 4031 (P2)-1999.

3.1.6 Silica Fume:

Silica fume, a byproduct of the silicon industry, was incorporated due to its high pozzolanic reactivity. It has a fineness of 20,000 m^2/kg, significantly higher than OPC. The chemical composition showed a high percentage of SiO_2, with minor amounts of Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, and Na_2O.

3.1.7 Chemical Admixture:

A poly-carboxylic ether-based superplasticizer was used to improve the fresh properties of SCC. It was a liquid admixture with a specific gravity of 1.22 at 30°C, a light brown color, and a recommended dosage of 0.6–1.5 liters per 100 kg of cement. It contained no chloride as per IS: 456-2000.

3.1.8 Glass Fiber:

Alkali-resistant glass fiber with an aspect ratio of 857.14 was used in this investigation. The fibers were included to enhance mechanical properties and durability.

3.2 Workability and Mechanical Properties

3.2.1 Workability

Compaction Factor Test: The workability of concrete mixes was evaluated using the compaction factor test, conducted in accordance with IS 1199 (1959). The compaction factor apparatus consists of two hoppers with hinged bases and a cylinder positioned below them. The concrete sample was filled in the top hopper, and after releasing the hinge, the concrete fell into the lower hopper. The lower hopper's hinge was then opened, allowing the concrete to fall into the cylinder. The weight of the cylinder with the concrete was recorded. The weight of the empty cylinder (W1) was subtracted from this, and the cylinder was placed on a vibrating table for full compaction.

Fresh Bulk Density: The fresh density of concrete mixtures was determined following IS 1199 (1959). Freshly prepared concrete was placed in a cylindrical mould (150 × 300 mm), compacted using a table vibrator, and weighed along with the cylinder. The fresh density was calculated in kg/m³ using the volume of the cylinder.

3.2.2 Mechanical Properties

Compressive Strength Test

The compressive strength test was conducted on 150 × 150 × 150 mm concrete cube specimens at four different curing ages, following IS: 516-1959 standards. The specimens were subjected to a compression testing machine with a capacity of 2000 kN, applying a constant loading rate. The failure load of each cube was recorded, and the compressive strength was calculated based on the failure load and surface area of the cube. The average of three specimens for each mix proportion and curing period was used to determine the experimental results.

Splitting Tensile Strength Test

Cylindrical specimens of 150 mm diameter and 300 mm height were cast and cured in water for 7, 28, and 56 days. The splitting tensile strength test was conducted in accordance with IS: 5816-1999, using a compression testing machine with a capacity of 2000 kN. The cylinders were placed horizontally, and the load was applied gradually until failure. The splitting tensile strength was then calculated based on the failure load, cylinder diameter, and length. Three specimens were tested for each curing period to determine the average experimental results.

Flexural Strength Test

Prismatic specimens of 100 × 100 × 500 mm were cast and cured in water for 28 days before undergoing the flexural strength test. The test was performed using a flexural testing machine under a two-point loading system at a specific loading rate, in line with IS: 516-1959. The flexural strength was obtained by measuring the load at failure and the dimensions of the prism. The average result from three specimens was used to compute the flexural strength.

Modulus of Elasticity Test

For the modulus of elasticity test, cylindrical specimens of 150 mm diameter and 300 mm height were cast and cured in water for 28 days. A compressometer was attached to measure longitudinal strain at two-thirds of the cylinder height. The stress-strain curve was plotted for each specimen, and the secant modulus of elasticity was determined from the experimental data.

Impact Strength Test

The impact strength test was conducted on cylindrical specimens of 150 mm diameter and 63.5 mm height, cured in water for 28 days. A thin layer of oil was applied to the specimens before placing them on a base plate. A steel ball, weighing 4.54 kg and with a diameter of 63.5 mm, was dropped repeatedly from a height of 457 mm onto the specimen. The number of drops required to cause the first crack and the total number of drops leading to complete failure were recorded. The impact energy was calculated based on the number of drops, ball mass, acceleration due to gravity, and drop height.

These mechanical tests helped in assessing the strength, durability, and overall performance of ternary blended self-compacting concrete for potential structural applications.

4. RESULTS AND DISCUSSIONS

4.1 Compressive strength test results

The compressive strength of ternary blended self-compacting concrete (SCC) mixes was tested at different curing periods (7, 14, 28, and 56 days). The results indicated that the compressive strength of conventional mixes (NM) at 7 and 14 days reached 45% and 65% of the target mean strength, respectively. The strength increased moderately with up to 20% fly ash substitution. However, higher fly ash substitution levels (greater than 20%) did not achieve the ideal early-age strength. The optimal strength at 28 and 56 days was observed in mixes with a fly ash substitution of 20% (TBC9), with a 13.64% increase in compressive strength. In contrast, higher levels of fly ash substitution (TBC12 – TBC15) showed a reduction in strength after 28 days.

4.2 Splitting Tensile Strength Test Results

The splitting tensile strength of ternary blended SCC mixes was measured at 7, 28, and 56 days. At early ages (7 days), a slight increase in splitting tensile strength was observed for the mix TBC10. However, starting from TBC11 to TBC15, a decline in splitting tensile strength was noted. At 28 days, mixes TBC9 and TBC10 achieved higher splitting tensile strengths than the conventional mix (NM), with increases of 28.13% and 31.25%, respectively. At 56 days, the potential tensile strength benefits for all TBC mixes were higher than those of the NM mix, except for TBC14 and TBC15, which showed a decrease. The addition of glass fiber (GFTBC) mixes resulted in further improvements in splitting tensile strength, particularly in GFTBC4, which outperformed TBC9 and GFTBC1 by 17% and 11%, respectively.

4.3 Flexural Strength Test Results

The flexural strength of ternary blended SCC mixes was evaluated at 28 days. The highest flexural strength was achieved in TBC9 (34.38% higher than NM). Other mixes also showed significant improvements, with TBC8 and TBC7 demonstrating flexural strength increases of 32.81% and 29.69%, respectively. The results indicate that the flexural strength of ternary blends closely follows the pattern of their compressive strength, with TBC9 outperforming the conventional mix. Glass fiber reinforcement further enhanced the flexural strength, with GFTBC4 achieving a 12% higher flexural strength compared to TBC9.

4.4 Modulus of Elasticity Test Results

The modulus of elasticity of ternary blended SCC mixes was determined at 28 days. The results indicate that the inclusion of fly ash and silica fume in the SCC mixes initially increased the modulus of elasticity. TBC9 showed the highest modulus of elasticity at 31.04 GPa, which was 17.84% higher than the NM mix. However, mixes with higher levels of fly ash substitution (TBC12 and beyond) experienced a decrease in the modulus of elasticity. The incorporation of these supplementary cementitious materials contributed to an improvement in the overall stiffness of the concrete, which was especially evident in the earlier-age results.

These findings highlight the performance variations between the ternary blended SCC mixes and the conventional mix, with the optimal blend containing 20% fly ash and 10% silica fume (TBC9) showing significant improvements in both strength and elasticity properties.

5. CONCLUSIONS

The performance of ternary blended self-compacting concrete (SCC) mixes demonstrates the significant benefits of incorporating fly ash and silica fume, especially at 20% fly ash substitution and 10% silica fume. The results indicate a marked increase in compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity compared to conventional concrete. The addition of glass fibers further enhances the tensile and flexural properties of SCC. These findings suggest that ternary blends with fly ash and silica fume can be an effective strategy for improving the mechanical and physical properties of SCC, offering potential benefits in construction applications where higher strength and durability are required.

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