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STRENGTH AND DURABILITY ASSESSMENT OF TERNARY BLENDED CONCRETE CONTAINING CORN ASH AND SILICA FUME

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Abstract - Concrete is a fundamental material in modern infrastructure, but its primary binder, Ordinary Portland Cement (OPC), is associated with significant environmental drawbacks, including high carbon dioxide (CO_2) emissions and depletion of natural resources. To address these concerns, this study explores the use of Supplementary Cementitious Materials (SCMs), specifically silica fume and corn ash, as partial replacements for cement in M20 grade concrete. Silica fume, an industrial by-product with high pozzolanic reactivity, and corn ash, an emerging agricultural waste material rich in silica, were combined in varying proportions to evaluate their synergistic effects on concrete performance. Five concrete mixes were prepared, ranging from a control mix with 100% cement to blends with up to 10% silica fume and 9% corn ash. The mixes were tested for compressive strength, split tensile strength, and water absorption at 7, 28, and 90 days of curing. Results indicated that a 6% replacement of cement with corn ash, in combination with 10% silica fume (Mix SC3), achieved the best overall performance, balancing strength and durability enhancements with sustainability benefits. This study highlights the potential of integrating industrial and agricultural waste in concrete production to reduce environmental impact, conserve natural resources, and support low-carbon construction practices.

***Key Words*:** Blended Concrete, Corn Ash, Silica Fume, compression strength, Split Tensile Strength, Water Absorption Percentage.

1.INTRODUCTION

Concrete is one of the most widely used construction materials globally due to its excellent strength, durability, versatility, and cost-effectiveness. It serves as a critical component in the development of infrastructure such as buildings, bridges, roads, and dams. At the core of concrete's binding ability is Ordinary Portland Cement (OPC), which plays a crucial role in the material's performance. However, cement production presents significant environmental concerns, particularly regarding carbon dioxide (CO_2) emissions and the depletion of natural resources.

According to the Intergovernmental Panel on Climate Change (IPCC, 2014), the cement industry alone accounts for approximately 8% of global CO_2 emissions, primarily due to the calcination of limestone and the combustion of fossil fuels in cement kilns. In addition, producing one ton of cement requires about 4 to 5 GJ of energy, predominantly sourced from non-renewable fuels such as coal and petroleum (Mehta and Monteiro, 2014). Furthermore, the extraction of raw materials like limestone, clay, and gypsum contributes to the rapid depletion of natural reserves. This growing environmental footprint, driven by increased urbanization and infrastructure development, necessitates an urgent shift toward sustainable alternatives.

In response, researchers and engineers have explored the use of Supplementary Cementitious Materials (SCMs) as partial replacements for cement in concrete. SCMs possess pozzolanic or latent hydraulic properties, allowing them to react with calcium hydroxide in the presence of water to form additional calcium silicate hydrate (C-S-H), the primary binder in concrete. Common SCMs include industrial by-products such as fly ash, ground granulated blast furnace slag (GGBS), and silica fume, as well as agricultural waste ashes like rice husk ash, bagasse ash, and corn ash. These materials not only reduce the dependency on OPC but also promote sustainable construction by recycling waste that would otherwise contribute to environmental degradation.

Silica fume, a by-product of the silicon and ferrosilicon alloy industry, is rich in amorphous silica and is known for its ultrafine particle size and high pozzolanic reactivity. Its inclusion in concrete enhances strength, durability, chemical resistance, and overall performance, particularly in high-performance applications (ACI 234R-06). On the other hand, corn ash, derived from the controlled combustion of corn cobs and stalks, is an emerging pozzolanic material with promising potential. It contains significant amounts of silica and other beneficial oxides, making it suitable for partial cement replacement, especially in combination with other SCMs.

In this study, we investigate the combined use of silica fume and corn ash as partial replacements for cement in M20 grade concrete. The primary objective is to evaluate the mechanical and durability characteristics of concrete using different replacement levels. Five concrete mixes were prepared for this experimental study:

- Mix 1 (CM): 100% cement (control mix)
- Mix 2 (SC1): 90% cement + 10% silica fume
- Mix 3 (SC2): 87% cement + 10% silica fume + 3% corn ash
- Mix 4 (SC3): 84% cement + 10% silica fume + 6% corn ash
- Mix 5 (SC4): 81% cement + 10% silica fume + 9% corn ash

These mixes were tested for compressive strength, split tensile strength, and water absorption at curing intervals of 7, 28, and 90 days. Based on literature and preliminary hypotheses, Mix SC3 was anticipated to yield the best performance due to an optimal balance between pozzolanic contribution and filler

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effect. Higher corn ash content beyond 6% was expected to reduce strength due to dilution and potential increases in porosity (Neville, 2011; Ramezanianpour et al., 2009). This research contributes to the broader goals of sustainable construction and resource conservation. By utilizing agricultural and industrial waste as SCMs, the study demonstrates the potential for reducing environmental impact, promoting circular economy principles, and supporting low-carbon development in the construction sector. The outcomes of this investigation are expected to guide civil engineers, builders, and policy-makers toward greener construction practices. As future engineers, embracing such innovative and sustainable solutions is not only a responsibility but a necessary step toward addressing the environmental challenges of the modern world.

2. MATERIALS AND MIX DESIGN

M20 grade concrete was designed using Ordinary Portland Cement (OPC) as per IS 12269:2013. The cement used had a specific gravity of 3.12, a fineness of 6.5%, initial setting time of 50 minutes, final setting time of 420 minutes, soundness of 1.2 mm, and a specific surface area of 290 m²/kg. Corn ash (CA), obtained by burning agricultural corn waste, was processed and used as a partial replacement for cement. It had a specific gravity of 2.4 and good pozzolanic properties. Nano-silica (CNS), collected from Beechems Pvt. Ltd., Kanpur, was used in liquid form with very fine particles (10–20 nm), a purity of 99.8%, and a specific gravity of 1.21, to improve strength and reduce porosity. Class F fly ash, collected from NTTPS – IBPM and confirming to IS 3812:2013, was used in some mixes for better durability, with a specific gravity of 2.3 and fineness modulus of 1.19%. River sand passing through a 4.75 mm sieve was used as fine aggregate, as per IS 383:2016, having a specific gravity of 2.6 and fineness modulus of 2.71%. Crushed granite stone of 20 mm size was used as coarse aggregate, also as per IS 383:2016, with a specific gravity of 2.7 and fineness modulus of 7.2%. Tap water available on campus was used for mixing and curing as per IS 456:2000. A polycarboxylic ether-based superplasticizer, confirming to IS 9103:1999, was added to improve workability. The mix had a water–binder ratio of 0.45. Cement was partially replaced with 10% corn ash and 2% nano-silica. The total binder content was 336 kg/m³ (300 kg cement, 30 kg corn ash, 6 kg nano-silica). This ternary mix was tested for strength and durability as a sustainable alternative to traditional concrete

MIX DESIGN

Mix design is the process of determining the right proportions of cement, water, fine and coarse aggregates to achieve the desired strength and workability. For M20 grade concrete, the target is 20 MPa at 28 days. Using materials like silica fume and corn ash as partial cement replacements improves strength, durability, and sustainability.

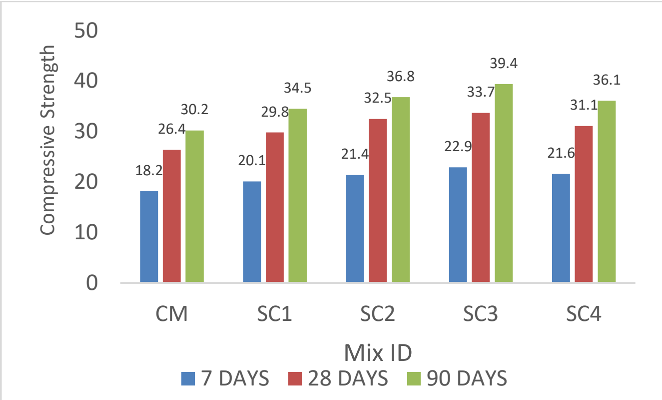
Table 1: Mix Design of M20 grade concrete

Material	Ratio (by volume)	Quantity (per 1 m³)	Unit
Cement	1	320 – 400	kg
Fine Aggregate (Sand)	1.5	600 – 700	kg
Coarse Aggregate	3	1100 – 1200	kg
Water	—	160 – 180	Liters
Water-Cement Ratio	—	0.45 – 0.55	—
Concrete Grade	—	M20	—
Target Strength	—	26.6 MPa (approx.)	—

3. RESULTS

1. Compressive Strength Result

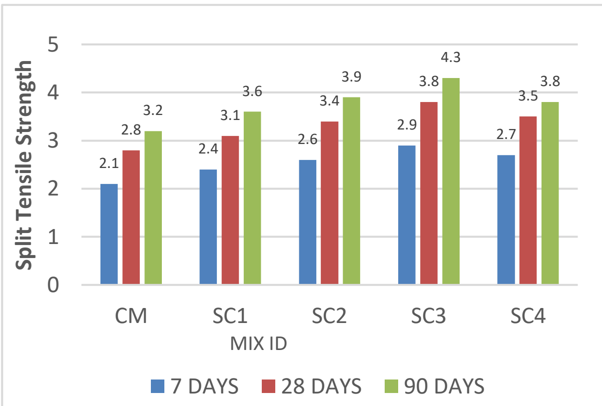
Standard cubes of size 150 mm × 150 mm × 150 mm were cast and tested for compressive strength at 7, 28, and 90 days as per IS 516:1959.



The study revealed that Mix SC3 (84% cement, 10% silica fume, 6% corn ash) achieved the highest compressive strength at 7, 28, and 90 days. This improvement is due to the synergistic effect of silica fume and corn ash, which enhance pozzolanic reactions and densify the concrete matrix. Silica fume reacts rapidly with calcium hydroxide to form additional C-S-H gel and fills micro-voids, increasing strength and reducing porosity. Corn ash, rich in reactive silica and alumina, further contributes to C-S-H formation. The 6% corn ash level in SC3 provided optimal reactivity without excessively reducing cement content. However, increasing corn ash to 9% in Mix SC4 led to reduced strength due to dilution of cement, lower pozzolanic activity, and higher water demand. These findings align with earlier research, highlighting those optimal partial replacements, around 10% silica fume and 5 to 7% corn ash, can significantly enhance strength while supporting sustainability in concrete design.

2. Split Tensile Strength Test Results (MPa)

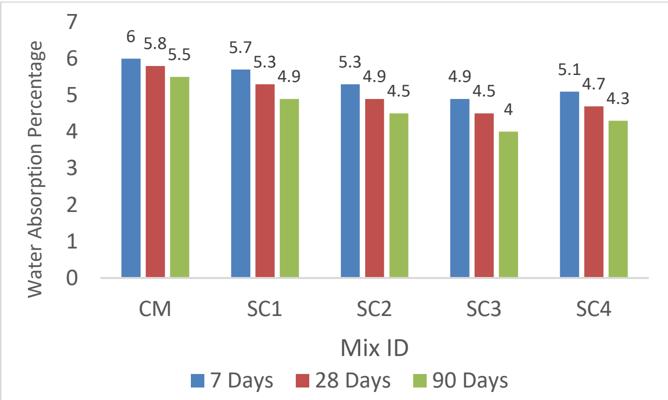
Standard cylinders of size 300 mm × 150 mm were cast and tested for Split Tensile strength at 7, 28, and 90 days as per IS 516:1959.



Mix SC3 (84% cement, 10% silica fume, 6% corn ash) achieved the highest split tensile strength at 7, 28, and 90 days. The enhanced performance is due to the combined pozzolanic activity of silica fume and corn ash. Silica fume, rich in reactive silica and ultrafine in size, reacts with calcium hydroxide to form additional C-S-H gel and fills micro-voids, reducing porosity and improving bond strength. Corn ash, containing reactive silica and alumina, also contributes to C-S-H formation and densifies the microstructure. At 6%, corn ash offers optimal strength gain without excessive reduction in cement content. However, increasing corn ash to 9% in Mix SC4 led to a slight strength decline due to lower cement availability, reduced reactivity, and potential porosity from unreacted ash. These findings are consistent with previous studies (Ramezanianpour et al., 2009; Neville, 2011), confirming that balanced replacement levels enhance concrete performance while promoting sustainability**.**

3. Water Absorption (%) Test Results

Standard cubes of size 150 mm × 150 mm × 150 mm were cast and tested for **water absorption** percentage at 7, 28, and 90 days as per IS 516:1959.



The study found that Mix SC3 (84% cement, 10% silica fume, 6% corn ash) exhibited the lowest water absorption at 7, 28, and 90 days, indicating a denser, less porous, and more durable concrete matrix. This improvement is attributed to the synergistic effects of silica fume and corn ash. Silica fume, due to its ultrafine particles and high pozzolanic activity, reacts with calcium hydroxide to form additional C-S-H gel and acts as a micro-filler, reducing pore connectivity. Corn ash, at an optimal 6% replacement, also contributes reactive silica and alumina, enhancing microstructural densification. However, increasing corn ash to 9% (Mix SC4) led to higher water absorption due to reduced cement content, lower reactivity, and potential increase in water demand. These results align with findings by Ramezanianpour et al. (2009) and Neville (2011), confirming that moderate levels of agricultural and industrial waste can significantly improve concrete durability by reducing permeability.

4. CONCLUSION

This study demonstrates the effectiveness of using silica fume (SF) and corn ash (CA) as supplementary cementitious materials (SCMs) in the development of sustainable and durable ternary blended M20 grade concrete. Through comprehensive testing of compressive strength, split tensile strength, and water absorption across different curing periods (7, 28, and 90 days), the findings reveal several key insights:
Mix SC3, containing 84% cement, 10% silica fume, and 6% corn ash, consistently outperformed all other mixes, including the control mix, in terms of mechanical strength and durability. The compressive strength and split tensile strength of SC3 showed notable improvement due to the synergistic pozzolanic reactions of SF and CA, along with their micro-filling properties, which refined the concrete's pore structure. Water absorption was lowest in SC3, indicating enhanced density and reduced porosity, critical for improving the long-term durability of concrete in aggressive environments, such as coastal and sulfate-prone areas. However, increasing corn ash beyond 6% (as in Mix SC4) resulted in reduced performance, highlighting the importance of optimal SCM proportions. In conclusion, the incorporation of 10% silica fume and 6% corn ash presents a promising solution for producing high-performance, durable, and environmentally friendly concrete, paving the way for more sustainable construction practices. Future research may focus on long-term performance under real environmental conditions and explore the behavior of such blends in structural applications.

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