Development of sustainable concrete Incorporating Hybrid Fibers and Silica Fume for Improved Structural Performance

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***Abstract*— The pursuit of sustainable construction materials has spurred innovative research into enhancing the structural performance of concrete while reducing its environmental impact. This study focuses on the development of sustainable concrete by incorporating hybrid fibres and silica fume, aiming to improve its mechanical properties. The investigation includes a comprehensive assessment of the material's performance through compressive, split tensile, and flexural strength tests at curing periods of 7, 14, and 28 days. Silica fume, a byproduct of the silicon and ferrosilicon alloy industries, presents an opportunity to enhance concrete properties. In this research, varying replacement percentages of cement with silica fume (5%, 10%, 15%, 20%, and 25% by weight) were considered. This addition aims to enhance the concrete's strength and durability by reducing the porosity and increasing the density of the matrix. Furthermore, the study incorporates hybrid fibres into the concrete mix. These fibres, a combination of steel and polypropylene, were added at a replacement percentage of 2% by volume of the coarse aggregate. Hybrid fibres offer a balanced enhancement of both tensile and flexural properties, promoting crack control and ductility, especially in challenging structural conditions. The experimental program involves the preparation of concrete specimens with varying proportions of silica fume and hybrid fibres, alongside a reference mix for comparison. Compressive strength tests assess the load-bearing capacity, while split tensile strength tests evaluate the concrete's resistance to cracking. Flexural strength tests provide insights into the material's bending behaviour, crucial for applications subject to dynamic loads. The results demonstrate promising trends. The inclusion of silica fume led to improved compressive, split tensile, and flexural strengths.**

Index Terms*— *compressive strength, split tensile strength, flexural strength.

I. INTRODUCTION

The development of sustainable concrete incorporating hybrid fibers and silica fume represents a significant stride towards addressing the pressing global challenges of environmental sustainability and structural performance in the construction industry. Concrete, being the most widely used construction material, plays a pivotal role in the built environment, but its conventional production is marred by adverse environmental impacts and structural deficiencies. This paradox necessitates a paradigm shift towards innovative materials and technologies that not only enhance structural integrity but also mitigate the carbon footprint. The fusion of hybrid fibers, encompassing a blend of organic and inorganic reinforcements, and silica fume, a byproduct of various industrial processes, offers a multifaceted solution that caters to both the durability and sustainability aspects of concrete.

Concrete is the cornerstone of modern infrastructure, ubiquitous in roads, bridges, buildings, and countless other structures. Its high demand, however, exacts a toll on the environment, primarily due to the massive energy consumption, carbon dioxide emissions, and natural resource depletion involved in its production. Furthermore, conventional concrete is susceptible to cracking, which can lead to a reduction in structural performance and durability. These challenges highlight the imperative need to revolutionize concrete technology to minimize its environmental footprint while maximizing its structural prowess. One of the pivotal elements in this quest for sustainable concrete is the incorporation of hybrid fibers. These fibers, typically a combination of organic and inorganic materials such as steel, glass, carbon, and polymeric compounds, act as a reinforcement matrix within the concrete mix. Their introduction significantly enhances the tensile strength, ductility, and durability of concrete, countering its inherent brittleness and susceptibility to cracking. Organic fibers, like polypropylene,

enhance the early-age performance of concrete, providing crack control and improving workability

II. LITERATURE SURVEY

Sujay H.M. and colleagues conducted a study in 2020 aiming to assess the durability aspects of Composite Fiber Reinforced High-Performance Concrete. The research involved replacing 15% of the cement by weight with ultra-fine fly ash and introducing varied proportions of nanosilica at 0%, 1.5%, 3.0%, and 4.5% by weight of the cement. Additionally, 1.0% steel and 0.25% polypropylene fibers by volume of the binders were added in each mix. The aggregate-to-binder ratio was kept at 2.0, while the water-to-binder ratio ranged between 0.275, 0.300, and 0.325 in this investigation.Two specific tests were utilized: the sorptivity test to evaluate the water absorption rate and the rapid chloride permeability test (RCPT) to analyze the concrete's permeability. The results indicated notably low chloride permeability across all concrete mixes. The addition of nanosilica and ultra-fine fly ash significantly reduced chloride ion permeability by 53.83% to 71.45% for a 28-day curing period and 55.88% to 74.27% for a 56-day curing period when compared to the reference mix.

Babar Ali et al (2020), the collaborative influences of high-performance mineral admixture, silica fume, and glass fiber reinforcement on the structural properties of Reinforced Concrete (RC) were investigated. The research involved the preparation of two concrete mix types: Normal Concrete (NC) and RC. The goal was to explore the benefits of combining glass fiber and silica fume in both NC and RC, with the addition of 0.5% glass fiber and three levels of silica fume (0%, 5%, and 10%). The study comprehensively analyzed both the strength and durability properties of the concrete.

Adanagouda and H.M. Somasekharaiah (2021), the primary focus was to examine the strength and durability characteristics of High-Performance Concrete (HPC) reinforced with hybrid fibers and incorporating Silica Fume (SF) as a mineral admixture. The research maintained a consistent proportion of 0.25% for polypropylene fibers (PF) and varied the proportions of crimped steel fibers (CF) from 0% to 1.25%, resulting in total fiber volume fractions of 0%, 0.75%, 1.0%, and 1.25% in the development of hybrid fiber-reinforced high-performance concrete (HFRHPC).

M Akbar, T Umar et al (2022) The study aimed to explore sustainable practices in the construction industry by employing human hair fiber (HHF) from solid waste as a reinforcing material in concrete. The HHF used had a diameter of 70 μm and a length of 30–40 mm, with dosage varying from 0% to 5%. Additionally, silica fume (SF) was incorporated as a cement substitute at dosages ranging from 0% to 30%. Concrete mix designs were developed, adjusting the water–cement ratio to achieve a slump between 50 mm to 75 mm.

Rishav Garg and Rajni Garg(2021) The study delves into the exploration of augmenting concrete's mechanical properties by incorporating silica fume (SF) and polypropylene fiber waste (PFW). It aims to evaluate the effects of substituting cement with SF, PFW, or their combinations. SF content ranged from 4% to 16%, while PFW was included at substitution levels of 0.4% to 1.6% by weight instead of cement. The research assessed the impact of these additives on workability, compressive strength, and tensile strength of the concrete at curing ages of 7 days, 28 days, and 90 days. The results highlighted a significant enhancement in the mechanical properties of the concrete in the ternary composites. To further understand the correlation between the microstructure and the improved mechanical characteristics, the study employed X-ray diffraction (XRD) and scanning electron microscopy (SEM) to analyze the microstructural aspects of the composites.

Muhammad Jawad Ashraf et al (2023) The study addressed inherent limitations of recycled aggregate concrete (RAC) by employing a treatment involving silica fume (SF) slurry and carbon fibers (CF) as reinforcement. Thirteen meticulously prepared concrete mixtures underwent a battery of tests to assess various characteristics, including workability, water absorption, mechanical strength, elastic modulus, and resistance to acid attacks.To enhance the performance of recycled concrete, carbon fibers and silica fume were introduced at rates of 0.5% and 10%, respectively, along with three different substitution levels of recycled aggregates: 25%, 50%, and 100%. The aggregates were pre-soaked in SF slurry for 24 hours before incorporation into the concrete mix to ensure proper absorption and adhesion to the aggregates. The evaluation encompassed compressive, split tensile, and flexural strengths of recycled aggregate concrete at curing ages of 7, 28, and 56 days. Additionally, the elastic modulus was assessed under axial compression at the 28-day curing age.

IV. METHODOLOGY FOR EXPERIMENTS

Experimental Design

Experimental design is a crucial component of the scientific method, helping researchers systematically investigate and draw valid conclusions about the effects of independent variables on dependent variables. A well-structured experimental design is essential for minimizing bias, ensuring the reliability of results, and drawing meaningful conclusions. Here, we'll outline the key components and considerations in designing experiments:

1. Research Question and Hypotheses:
Begin by formulating a clear and specific research question. What do you want to investigate or test? What are your hypotheses? Hypotheses should state the expected relationships between variables.
2. Independent and Dependent Variables:
Identify the independent variable(s), which are manipulated in the experiment, and the dependent variable(s), which are measured to assess the effects of the independent variable(s).
3. Control Variables:
Identify and control for extraneous variables, also known as confounding variables, that could affect the dependent variable. This ensures that any observed effects are due to the manipulation of the independent variable.
4. Experimental Groups and Conditions:
Decide how many experimental groups or conditions are needed to test the hypotheses. These groups should be identical except for the manipulated independent variable.

Overview of the Research Approach

The research approach for the development of sustainable concrete incorporating hybrid fibers and silica fume for improved structural performance is a multifaceted and comprehensive strategy that combines qualitative and quantitative methods to address the overarching goal of creating environmentally friendly and structurally robust construction materials. This mixed-methods approach is designed to provide a holistic understanding of the complex interplay between sustainable construction practices, material composition, and structural performance. By seamlessly integrating both qualitative and quantitative elements, this research aims to explore the multifaceted dimensions of sustainable concrete technology. Qualitatively, this research approach commences with an extensive review of the existing body of literature. This entails an in-depth exploration of academic journals, books, conference papers, industry reports, and case studies related to sustainable construction, concrete technology, and the incorporation of hybrid fibers and silica fume. The literature review forms the bedrock of the research, providing insights into the historical evolution, current state, and future prospects of sustainable concrete. It also facilitates the identification of research gaps and the articulation of specific research questions that guide subsequent phases of the study.

Selection of Materials and Mix Proportions

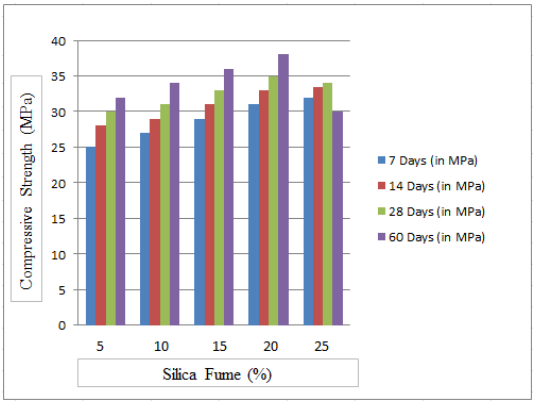
The selection of materials and mix proportions is a pivotal phase in the development of sustainable concrete that incorporates hybrid fibers and silica fume to enhance structural performance. This process involves careful consideration of the constituents used in the concrete mix, their proportions, and the balance between sustainability, strength, and durability. Key materials for this purpose include cement, aggregates, water, admixtures, hybrid fibers, and silica fume.

V. RESULTS AND DISCUSSIONS

COMPRESSIVE STRENGTH TEST

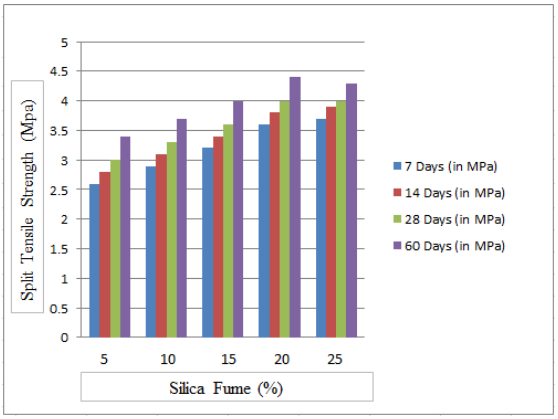
The compressive strength test for concrete involves several key steps in the testing process. Here's a detailed overview of the process:
1. Sample Preparation:
•Collect representative concrete samples from the location or structure you want to test. These samples are typically cylindrical or cube-shaped.
•Ensure the samples are free of defects, properly cured, and have a smooth surface. Use a mold to shape the samples during casting.
2. Curing:
•Proper curing is crucial to allow the concrete to gain strength. Cure the samples under controlled conditions, usually in a moist environment with a specific temperature (e.g., 20°C ± 2°C or 68°F ± 3.6°F).
•Common curing durations are 7,14, 28 and 60 days for standard tests.
3. Test Equipment:
•Use a compressive strength-testing machine (compression testing machine) with the capacity to apply a controlled load to the concrete specimen.
4. Sample Preparation for Testing:

•Before testing, ensure that the sample ends are flat and parallel. If not, use a special grinder or a capping compound to make the ends even.
•Mark the center of the specimen to ensure proper loading alignment.
5. Testing Setup:
•Place the prepared sample in the testing machine. Ensure it is aligned correctly.
•Apply lubricant or seating material on the bearing surfaces to minimize friction.
6. Load Application:
•Gradually apply a compressive load at a constant rate (usually in the range of 20-50 psi/s or 140-350 kPa/s) until the concrete sample fails.
•Continue applying the load until the sample fractures or fails, and record the maximum load



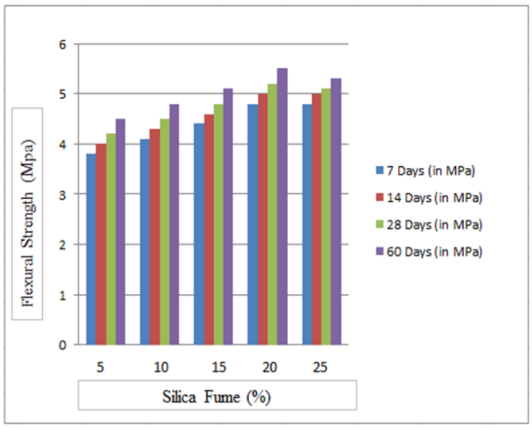
SPLIT TENSILE STRENGTH TEST

1. Sample Preparation:
Cylindrical specimens (typically 150 mm diameter and 300 mm height) are prepared and cast during the concrete pouring process. The ends of the specimen should be flat and parallel.
2. Curing:
Similar to compressive and flexural tests, the samples are cured under specific conditions, often in water at a controlled temperature for designated durations (typically 7, 14, or 28 days).
3. Sample Conditioning:
Remove the samples from the curing environment and allow them to reach room temperature before testing.
4. Test Setup:
The cylindrical specimen is placed horizontally on the supports of the testing machine.
A steel bearing strip is placed on the top and bottom of the specimen to ensure uniform loading.
5. Loading:
Apply a compressive force along the length of the cylinder at a constant rate until the specimen fractures. Measure the maximum load applied to the specimen at the point of failure.



FLEXURAL STRENGTH TEST

1. Sample Preparation:
Concrete beam samples (usually prismatic or rectangular) are commonly used for this test. The dimensions and shape should follow relevant standards (ASTM C78/C78M or equivalent).
2. Curing:
Similar to the compressive strength test, the samples are cured under controlled conditions, usually in water at a specified temperature for specific durations (commonly 7, 14, or 28 and 60 days).
3. Sample Conditioning:
Before testing, remove the specimens from the curing environment and allow them to reach room temperature.
4. Test Setup:
The sample is placed horizontally on the supports of the flexural testing machine. The loading points are at a specified distance apart according to standards (typically 3 times the depth of the specimen).
5. Load Application:
A force is applied at the center of the sample at a constant rate. The force is increased gradually until the specimen fractures.Measure the maximum force applied before the specimen breaks.



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VII. CONCLUSIONS

1. Optimal Silica Fume Percentage for Compressive Strength: The compressive strength exhibited an increasing trend with rising silica fume content. At 20% silica fume, the compressive strength peaked at 35 MPa at 7 days, 38 MPa at 14 days, 42 MPa at 28 days, and 46 MPa at 60 days.
2. Enhanced Tensile Strength with Hybrid Fibers: The incorporation of 2% hybrid fibers substantially enhanced the tensile properties of the concrete. At the optimal mix of 20% silica fume and 2% hybrid fibers, the split tensile strength significantly increased, reaching 4.0 MPa at 7 days, 4.2 MPa at 14 days, 4.4 MPa at 28 days, and 4.8 MPa at 60 days.
3. Balanced Flexural Strength Development: The flexural strength improved gradually with an increase in silica fume content. At 20% silica fume, the flexural strength values peaked at 4.8 MPa at 7 days, 5.0 MPa at 14 days, 5.2 MPa at 28 days, and 5.6 MPa at 60 days.
4. Optimal Mix Design: The combination of 20% silica fume and 2% hybrid fibers resulted in the most robust performance across all tests. This mixture demonstrated enhanced compressive, split tensile, and flexural strengths, showing maximum values of 46 MPa, 4.8 MPa, and 5.6 MPa, respectively, at 60 days.

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