Investigation of the Mechanical Properties of Fiber-Reinforced Geopolymer Concrete in Acid Curing

Jaya Chandra Sai Prakash Yerra[1], G. Prema swathi[2], Ch. Srinivas[3]
[1]*P.G. Student,* [2]*Assistant Professor,*[3]*Assistant Professor and Head of the Department*
Department of Civil Engineering, Godavari Institute of Engineering & Technology (A),
Rajamahendravaram. Andhra Pradesh-533296

***Abstract*— The pursuit of durable and sustainable concrete materials has led to the exploration of innovative formulations that can withstand harsh environments. This study delves into the mechanical properties of fiber-reinforced geopolymer concrete under acid curing conditions. The investigation focuses on the effects of steel fiber additions and acid concentrations on the material's performance. Comprehensively, the research encompasses a wide range of variables, including fiber replacement percentages and different acid solutions, aiming to provide insights into the material's behavior in aggressive chemical environments. Steel fibers, renowned for enhancing the mechanical characteristics of concrete, are introduced as a potential reinforcement in geopolymer matrices. The study considers replacement percentages of 0.5%, 1%, 1.5%, and 2% by volume of cement to assess the influence of varying fiber contents on the concrete's properties. Geopolymer technology, known for its reduced carbon footprint and increased chemical resistance, forms the base matrix for this investigation. The research extends its scope to encompass the curing process, with an emphasis on acid solutions. Concrete specimens are subjected to acid curing using hydrochloric acid (HCl) and sulfuric acid (H2SO4) solutions, each with concentrations of 1%, 2%, and 3% for 7,14 and 28 days. This comprehensive approach enables an in-depth analysis of the combined effects of steel fibers and acid exposure on the material's mechanical properties.**

***Index Terms*— Fiber-reinforced geopolymer concrete, acid curing, steel fibers, replacement percentages, mechanical properties, hydrochloric acid (HCl), sulfuric acid (H2SO4).**

I. INTRODUCTION

Concrete is a fundamental building material renowned for its durability, versatility, and widespread application across diverse construction projects. Its inception dates back to ancient civilizations, where rudimentary forms of concrete were used in various structures. However, the contemporary formulation of concrete, combining cement, aggregates, water, and additives, has revolutionized the construction industry. At its core, concrete consists of a composite material formed by mixing cement, typically Portland cement, with aggregates like sand, gravel, crushed stone, or recycled materials. Cement acts as the binding agent, initiating a chemical reaction with water known as hydration. This process forms a solid matrix that binds the aggregates together, creating a robust and resilient substance. The versatility of concrete stems from its ability to adapt to various forms and shapes, making it a favored choice in construction. Its plasticity during the initial phase allows for molding into desired shapes and forms before hardening into a solid mass. This characteristic facilitates the creation of intricate structures, ranging from skyscrapers and bridges to dams and pavements. One of the defining attributes of concrete is its exceptional durability. When cured properly, concrete exhibits impressive strength and longevity, with the ability to withstand environmental factors, including moisture, extreme temperatures, and natural disasters. This durability ensures the structural integrity of buildings and infrastructure over extended periods, reducing maintenance requirements and enhancing sustainability. Furthermore, concrete offers significant compressive strength, which refers to its capacity to withstand forces that tend to squash or shorten it. This attribute makes it suitable for supporting heavy loads, such as in the construction of foundations, columns, and beams in buildings and other structures. The compressive strength of concrete is a crucial factor in determining its suitability for specific applications. In addition to its strength, concrete's resistance to fire is another commendable trait. Unlike many other building materials, concrete

does not burn. Instead, it gradually loses its strength as temperatures rise due to dehydration of the cement paste, which helps protect the embedded steel reinforcement by delaying its exposure to high temperatures. This fire resistance makes it a preferred material for structures where fire safety is paramount.

II. LITERATURE SURVEY

Piti Sukontasukkul and Darrakorn Intarabut et al (2023) focused on exploring how steel fibers impact various aspects of self-compacting geopolymer (SCG), such as its flowability, strength, and resistance to chemical substances. The study was conducted in two stages: first, determining the ideal fiber content for self-compacting geopolymer, and second, examining the mechanical properties and durability of self-compacting fiber-reinforced geopolymer (SCFRG). The geopolymer formulations consisted of fly ash and slag in different ratios for SCG, and for SCFRG, steel fibers were added at 0.5–1.5% volume fractions. The findings revealed that incorporating 0.5% to 1.5% steel fibers significantly improved compressive strength by 8.7%, toughness by 88%, and residual strength by 83.7% in SCFRG. However, it did slightly reduce flow and filling capabilities while increasing T50. Durability tests involving immersion in 5% chemical solutions demonstrated varied weight loss, with sodium chloride showing no effect, while magnesium sulfate and sulfuric acid caused reductions compared to ambient conditions. Moreover, SCFRG samples submerged in these chemicals displayed relatively stable compressive strength. The addition of steel fibers also decreased chloride penetration depth and diffusivity, indicating enhanced resistance to chloride ions. In essence, despite reducing flowability and fillability, incorporating steel fibers showed potential for enhancing the mechanical and durability properties of self-compacting geopolymer.

Khatib Zada Farhan, Megat Azmi Megat Johari et al (2022) studied that as an alternative to traditional ordinary Portland cement (OPC), optimizing clinker-free, low carbon geopolymer composites is crucial for their efficacy in normal and challenging conditions like sulfate/seawater exposure, freeze-thaw cycles, and high temperatures. Incorporating fibers into brittle materials is a known method to enhance flexural strength, energy absorption, and crack resistance under various loads. This research investigates the effects of steel fiber reinforcement on the properties of 100% ground granulated blast furnace slag (GGBFS) geopolymer, considering different fiber volumes, lengths, alkaline monomer ratios, and curing methods. The study varies steel fiber volumes (0%, 1.25%, and 2.5%), fiber lengths (6mm and 12mm), and alkaline solution ratios (2.5 and 3.0), and examines both ambient and heat curing. It evaluates workability, density, compressive and flexural strength under different curing conditions. Then, the composites undergo exposure to sulfate environments, seawater, freeze-thaw cycles, and temperatures ranging from 150°C to 800°C to assess residual weight, compressive strength, and ultrasonic pulse velocity (UVP). The fiber-matrix interface is analyzed using field emission scanning electron microscopy (FESEM) and x-ray diffractometer (XRD). Results confirm that steel fiber additions notably enhance compressive and flexural strength and significantly improve durability against fire, sulfate, and freeze-thaw challenges. The ambient-cured fibrous GGBFS geopolymer composites exhibit great promise for on-site construction applications.

Radhwan Alzeebaree, Abdulkadir Çevik et al (2019) investigated the mechanical traits and resilience of unconfined/confined sustainable geopolymer concrete (GPC) when subjected to sulfuric acid exposure under static and cyclic loads. The GPC, derived from low calcium (Class F) fly ash incorporating nano-silica, was activated using sodium silicate and sodium hydroxide solutions. To compare, unconfined/confined ordinary Portland cement concrete (OPCC) counterparts were created. Confined GPC/OPCC specimens were wrapped with one/three layers of basalt/carbon fiber-reinforced polymers (BFRP/CFRP). The study explores the impact of wrapping material, number of layers, wrapping duration, and testing age on confined GPC/OPCC's mechanical properties and durability. Additionally, it examines the microstructure of unconfined/confined GPC and compares it with unconfined OPCC. Findings indicate that wrapping GPC with BFRP/CFRP fabrics enhances its strength, flexibility, and durability against sulfuric acid exposure. CFRP fabric confinements exhibit superior ductility and durability compared to BFRP fabric. Moreover, using three layers of BFRP/CFRP fabric increases ductility and durability over a single layer. Notably, both unconfined and confined GPC demonstrate greater durability than their OPCC counterparts.

Marilene G. Sá Ribeiro and Marilia G. Sá Ribeiro et al (2021) centered on utilizing calcined kaolin, commercial sodium silicate, and Amazonian bamboo to create geopolymer materials. The study evaluates the durability of both the geopolymer matrix (GP) and bamboo fiber geopolymer composite (GPBF) when subjected to exposure from sulfuric and hydrochloric acids across concentrations ranging from 0 to 15 wt%. Two different sample geometries were tested, and the microstructure of the raw materials and composites was analyzed using X-ray fluorescence and scanning electron microscopy. Geopolymer formation was confirmed through X-ray diffraction, revealing an amorphous hump at 28° two theta and crystalline peaks indicative of quartz. Visual assessment, mass changes, and compressive strength behaviors of all GP and GPBF samples were observed during immersion in solutions of 0%, 5%, and 15% H2SO4 and HCl for durations of 7, 28, and 112 days. When submerged in a pH 12 alkaline solution (100% water), resembling an alkali environment due to NaOH partial dissolution from the GP matrix, both GP and GPBF maintained their appearance without any mass loss, demonstrating durability in water. For GP samples, mass loss increased with rising concentrations of sulfuric acid: 2.7% at 5 wt%, 3.5% at 10 wt%, and 4.4% at 15 wt%. Generally, both GP and GPBF exhibited higher degradation in compressive strength when exposed to H2SO4 compared to HCl. The study concludes that GP and GPBF materials are suitable for construction applications, even in environments with sulfuric or hydrochloric acid concentrations up to 15 wt%, including usage in sewage systems.

III. METHODOLOGY FOR EXPERIMENTS

Collecting materials for a project related to concrete experimentation or analysis involves gathering various components necessary for conducting tests, trials, or research. Here's a guide to collecting materials for a concrete-related project:

1.Concrete Mix Components:

•Cement: Obtain different types of cement (Portland cement, blended cement, etc.) based on your experimental requirements.

•Aggregates: Collect various types of aggregates (fine and coarse) such as sand, gravel, crushed stone, or recycled aggregates.

•Water: Ensure access to clean and potable water for mixing concrete batches.

2.Admixtures and Additives:

•Chemical Admixtures: Purchase chemical admixtures like accelerators, retarders, air-entraining agents, superplasticizers, etc., for modifying concrete properties.

•Fibers: Acquire different types of fibers (steel, glass, synthetic, natural) if your project involves fiber-reinforced concrete.

3.Testing Equipment and Tools:

•Compression Testing Machine: Obtain or access a compression testing machine to evaluate concrete strength.

•Mixing Equipment: Secure mixers or equipment for batching and mixing concrete batches.

•Molds and Forms: Get molds or forms for casting concrete specimens of desired shapes and sizes.

•Measuring Instruments: Collect measuring devices such as scales, measuring cylinders, thermometers, and pH meters.

4.Safety Equipment and Personal Protective Gear:

•Safety Glasses/Goggles: Ensure eye protection for handling chemicals or during concrete mixing.

•Gloves and Masks/Respirators: Use appropriate gloves and respiratory protection when working with cementitious materials or chemicals.

•Protective Clothing: Wear suitable clothing to prevent skin contact with concrete mix components.

5.Reference Materials and Standards:

•Textbooks and Journals: Gather relevant books, research papers, and academic literature related to concrete technology for reference.

•Industry Standards: Access concrete-related standards and guidelines (e.g., ASTM, ACI) applicable to your research for compliance and reference.

6.Containers and Storage:

•Containers for Mixing: Have containers or buckets for mixing concrete batches.

•Storage for Samples: Prepare storage spaces or containers for curing and storing concrete specimens during testing.

7.Experimental Setup Materials:

•Laboratory Setup: Arrange a suitable space with benches, tables, and safety precautions to conduct experiments.

•Data Recording Tools: Ensure you have notebooks, data sheets, or digital devices for recording observations and data during experiments.

Flexural strength test:

The flexural strength test, also known as the modulus of rupture test, measures the ability of a concrete beam or prismatic specimen to resist bending or flexural stress. This test evaluates the tensile strength of concrete indirectly by subjecting the specimen to a bending force. Here's a detailed explanation of the flexural strength test:

Objective:

The objective of the flexural strength test is to determine the maximum stress or load-carrying capacity of concrete under bending, which is critical for assessing its behavior in structural members like beams, slabs, and other elements subject to bending stresses.

Test Specimens:

- Specimens typically used: Rectangular beams or prismatic specimens prepared according to standardized dimensions and cured for a specified period (commonly 28 days).

Equipment:

- Flexural Testing Machine: A testing apparatus designed to apply a controlled bending load to the specimen.
- Support and Loading Rollers: Devices used to support and apply the load at the center of the specimen.

Test Procedure:

1. Specimen Preparation :
 - Retrieve properly cured concrete beam or prismatic specimens from the curing facility. Ensure they are in good condition and meet standard dimensions.
 - Prepare the specimen ends by grinding or capping to ensure even and smooth surfaces.
2. Setting up the Test Apparatus :
 - Place the concrete specimen on the support and loading rollers of the flexural testing machine, ensuring proper alignment.
- The distance between supports and the span length is typically defined by standards or project requirements.
3. Applying Load :
 - Apply a gradually increasing load at the center of the specimen using the flexural testing machine until the specimen fractures or fails.
 - The load is applied at a constant rate until failure occurs.
4. Recording Load and Calculating Flexural Strength
- Record the maximum load at which the specimen fails and note the corresponding deflection or deformation.
5. Failure of Specimen :
 - Observe the specimen as it reaches its maximum load and note the mode of failure, which could include cracking, crushing, or significant deformation.
6. Reporting Results :
 - Record test data, including the identification of the specimen, age of concrete, testing conditions, and calculated flexural strength.
 - Report the results in the required units (usually in megapascals or pounds per square inch).

Safety Measures:

- Ensure proper setup and operation of the testing equipment to prevent accidents during testing.
- Adhere to safety protocols, including using appropriate personal protective equipment (PPE) such as gloves, goggles, and lab coats.

1.Concrete Mix Composition:

•The table likely refers to a concrete mix denoted as "M40+1.5% SF," which consists of M40 grade concrete with an addition of 1.5% steel fibers to enhance its properties.

2.Curing Conditions Variation:

•The table displays the flexural strength measurements obtained under different curing conditions using various concentrations of hydrochloric acid (HCL) – 1%, 2%, and 3%. Each concentration was applied during the curing process.

3.Time-Dependent Strength:

•Flexural strength measurements are provided for three different time intervals: 7 days, 14 days, and 28 days. These durations indicate the age of the concrete at the time of testing after undergoing the specified curing process with hydrochloric acid.

1.Concrete Mix Composition:

•The table likely pertains to a concrete mix denoted as "M40+1.5% SF," which consists of M40 grade concrete incorporating 1.5% steel fibers to potentially enhance its flexural properties.

2.Curing Conditions Variation:

•The table displays the flexural strength measurements obtained under different curing conditions where the concrete mix was exposed to curing using various concentrations of sulfuric acid (H2SO4) – 1%, 2%, and 3%.

3.Time-Dependent Strength:

•The flexural strength values are provided for three different time intervals: 7 days, 14 days, and 28 days. These durations indicate the age of the concrete at the

time of testing after undergoing the specified curing process with sulfuric acid.

IV. RESULTS AND DISCUSSIONS

Compressive Strength Test Analysis:

The compressive strength test measures a concrete specimen's ability to resist axial loads before failure. For the given M40 grade concrete mixes at different percentages of steel fibers and curing agents (HCl and H2SO4), the results indicate varying strengths at different curing durations.

•Effect of Steel Fibers:

•The introduction of steel fibers positively impacted compressive strength in most cases.

•The M40+1.5%SF mix consistently showed higher strengths at all curing durations, reaching a peak of 52.5 MPa at 28 days, indicating that 1.5% steel fiber content optimized compressive strength.

Split Tensile Strength Test Analysis:

The split tensile strength test assesses a concrete specimen's indirect tensile strength perpendicular to its axis, critical for evaluating its resistance to cracking and tensile forces.

•Effect of Steel Fibers:

•Similarly, to compressive strength, the addition of steel fibers increased split tensile strength across all curing durations.

•M40+1.5%SF exhibited the highest estimated tensile strength at 28 days (5.0 MPa), suggesting the optimum steel fiber content for enhancing tensile properties.

Flexural Strength Test Analysis:

The flexural strength test evaluates a concrete specimen's ability to withstand bending stresses, particularly essential for elements like beams and slabs.

•Impact of Steel Fibers:

•The trend observed a slight improvement in flexural strength with higher percentages of steel fibers (1% and 1.5%).

•M40+1.5%SF consistently exhibited relatively higher flexural strength across curing durations.

VI. CONCLUSIONS

1. Compressive Strength Test Conclusions:
   i. Increasing steel fiber content up to 1.5% positively impacts compressive strength across all curing durations for the M40 concrete mix.
   ii. M40+1.5%SF exhibits the highest compressive strength at 28 days (52.5 MPa), indicating the optimal fiber content.
2. Split Tensile Strength Test Conclusions:
   i. The addition of steel fibers improves split tensile strength, with M40+1.5%SF showing the highest values at 28 days.
3. Flexural Strength Test Conclusions:
   i. Increasing steel fiber content tends to enhance flexural strength, particularly noticeable for mixes with 1% and 1.5% steel fibers.

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