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Strength Evaluation of Carbon Fiber Reinforced Flexural Members

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ABSTRACT: High Strength Concrete (HSC) is a dense, homogeneous material with improved engineering properties and durability compared to conventional concrete. In recent years, HSC has gained wide application in the construction industry. HSC is composed of similar ingredients as conventional concrete, such as cement, fine aggregate, coarse aggregate, and water. However, the paste of HSC requires a high volume of cement content and a low water-to-binder ratio to achieve its desired properties.

The stability and flowability of HSC are typically achieved by increasing the cement content or employing mineral admixtures. Nevertheless, increasing the cement content can lead to higher costs, elevated heat of hydration, and greater drying shrinkage. These issues can be mitigated by incorporating mineral admixtures such as fly ash and ground granulated blast furnace slag.

In the present investigation, the cement content in the HSC mix is partially replaced with fixed percentages of fly ash. Additionally, Carbon Fiber Reinforced Polymer (CFRP) strips, each with a width of 80 mm, are placed in varying layers (single, double, and triple layers). The hardened concrete properties of HSC were studied through experimental investigation. The study concludes that carbon fibers can be effectively used as a reinforcing material in HSC.

KEYWORDS: HSC (High Strength Concrete), CFRP (Carbon Fiber Reinforced Polymer), Flexural Strength etc.

I. INTRODUCTION

Carbon Fiber, also known as graphite fiber, is a polymer characterized by its exceptional strength and lightweight properties. It is five times stronger and twice as stiff as steel while being significantly lighter. High Strength Concrete (HSC) is a specialized concrete type with a specified compressive strength of 60 N/mm² or greater. HSC is particularly economical when used in columns of high-rise buildings, parking garages, bridge decks, and other structures requiring enhanced compressive strength and density.

For optimal performance, HSC typically employs selected pozzolanic and chemical admixtures and necessitates a low water-to-cementitious material ratio. Identifying the optimal mixture proportions often requires numerous trial mixtures. Despite its strength under compression, HSC is relatively brittle, exhibiting weakness under tension or flexure. Carbon fibers, characterized by high tensile strength (2110 to 2815 N/mm²) and Young's modulus, are inert, medically safe, chemically stable, and low in density, with one of the highest strength-to-density ratios among fiber types. When used as reinforcement in cement composites, carbon fibers significantly enhance the modulus of elasticity and flexural strength, improving the material's structural properties.

Incorporating discontinuous carbon fibers into concrete transforms it into a homogeneous and isotropic material, converting its brittle nature into ductile behaviour. Upon cracking, the randomly oriented fibers arrest micro-cracking and impede its propagation, thereby enhancing both strength and ductility. These carbon fibers are produced by carbonizing polyacrylonitrile yarn at high temperatures and aligning the resulting graphite crystallites through a process

called hot stretching. Initially, polyacrylonitrile-based carbon fibers were not commonly used in Fiber Reinforced Concrete (FRC) due to their high cost. However, the development of less expensive short pitch-based carbon fibers in the early 1980s made their use more feasible.

Mixture proportioning is more critical for HSC than for normal strength concrete, typically involving selected pozzolanic and chemical admixtures and requiring a low water-to-cementitious material ratio. Numerous trial mixtures are often necessary to identify the optimum mixture proportions, generating essential data for HSC formulation.

Carbon fibers, characterized by their inertness, medical safety, chemical stability, low density, and high strength-to-density ratio, significantly enhance the specific strength and stiffness of HSC. The addition of carbon fibers to cement composites improves structural properties, particularly tensile and flexural strengths. Incorporating discontinuous fibers into concrete transforms it into a homogeneous and isotropic material, converting its brittle nature into ductile behaviour. When concrete cracks, the randomly oriented fibers arrest micro-cracking and impede its propagation, thereby enhancing both strength and ductility.

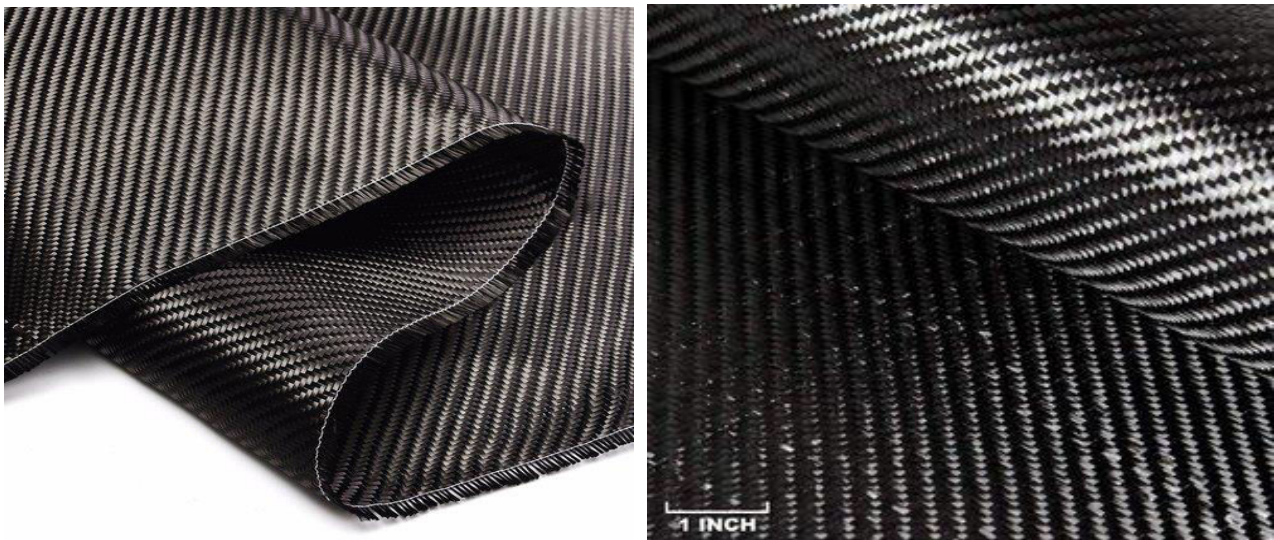


Fig. 1 CFRP (Carbon Fibre Reinforced Polymer)

Principle of CFRP:

Carbon Fiber, also known as graphite fiber, is a polymer that is both extremely strong and lightweight. It is five times stronger than steel and twice as stiff, yet significantly lighter, making it an ideal material for many manufacturing applications. These attributes contribute to its popularity among engineers and designers.

Advantages of CFRP

- CFRP is stronger than steel.
- CFRP exhibits high tensile strength.
- CFRP has excellent binding properties with concrete.
- It is lightweight.
- CFRP is primarily used for wrapping purposes.

Disadvantages of CFRP

- The primary disadvantage of CFRP is its high cost.
- It is manufactured in only a few selected countries.
- The manufacturing cost is high.

Comparison between Conventional Concrete and HSC

HSC is more expensive compared to conventional concrete.

HSC has superior strength properties compared to conventional concrete.

HSC has a significantly shorter initial and final setting time compared to conventional concrete.

Objectives

To compare the flexural strength properties of CFRP-reinforced beams with plain beams.

To determine the strength properties of CFRP-reinforced concrete.

Scope

Rapid construction activities have increased the demand for concrete, leading to the overuse of natural resources in concrete element manufacturing. Industrialization has also resulted in the generation of large amounts of waste, posing disposal challenges.

This study aims to establish the acceptability of various eco-friendly concrete alternatives. An experimental study was conducted to investigate the flexural strength of HSC with and without carbon fiber reinforcement. CFRP beams were cast and tested with different layers of reinforcement to evaluate their performance.

II. METHODOLOGY

Material specification

The basic material used for manufacture of HSC is cement, Course aggregate, Fine aggregate etc.

Table 1. Material Specifications

Sr. No.	Material	Specification
1	Cement	53 <u>grade</u>
2	<u>Course aggregate</u>	Less than 12.5 mm
3	Fine aggregate	Passing through 2.36mm
4	Concrete	M60 Grade

Materials

Cement: Ordinary Portland cement (OPC) (53 grade) with specific gravity of 3.15 and fineness of 292 m²/kg confirming to IS 8112:1989 is being used.

Fine aggregate: The sand used for the experimental program was locally procured and was confirming to zone-III. The specific gravity of fine aggregate was 2.58 and bulk density 1600 kg/m³.

Coarse aggregate: Locally available crushed angular coarse aggregate having maximum size of 12.5 mm were used in the present work. The specific gravity of coarse aggregate was 2.90 and bulk density 1553kg/m³.

Fly ash (FA): Fly ash from Raichur thermal power station, Karnataka has been used as cement replacement material with a specific gravity of 2.2 and blains fineness of 229 m²/kg.

Carbon fiber: The carbon fiber used is obtained from engineering India, Pune. The density of carbon fiber is about 1800 kg/m³ and tensile strength of fiber is 4137 N/mm².

Glass fiber: waste broken glass pieces are used as glass fibers. (Passing through 10mm IS sieve and retained on 4.75mm IS sieve.)

Water: Potable tap water was used for the preparation of specimens and for the curing of specimens.

Superplasticizer: The super plasticizer used is Conplast SP430, which is obtained from FOSROC chemicals, Bangalore.

Hydroxy Ethyl Cellulose (HEC): The Hydroxy Ethyl Cellulose used as in this experiment was obtained from FOSROC chemicals, Bangalore. The viscosity of HEC is 4.75 % in water at 20°C

Epoxy: Epoxy is the resin based bonding agent, which is obtained from FOSROC chemicals, Bangalore.

Mixture Proportions

In the present investigation 10% cement is replaced by fly ash, this is optimised by trial workability test which is kept constant. ACI Method (ACI 211.4R-93) of mix design is adopted for designing M60 grade of concrete. Mix proportion for cubic meter of concrete is presented in Table 2.

Table 2. Mix Proportion for cubic meter of concrete

Particulars	Quantity (kg/m ³)
Cementitious material (90% Cement + 10 % FA)	546
Fine aggregate	694
Water	169
Coarse aggregate	1050
Superplasticizer	8.19

Table 3. Mix Proportions

Cement	Fine Aggregate	Coarse Aggregate	Fly ash	Water Content	Super Plasticizer
492 kg/m ³	694kg/m ³	1050kg/m ³	54kg/m ³	169 litres	8.19 litres
1.00	1.41	2.13	0.10	0.31 (w/c ratio)	1.50 %

Concrete mix short procedure: After obtaining the dry mix we selected W/C ratio as 31%. The W/C can be increased if proper consistency is not obtained. After adding the water, proper mixing of the concrete is done and care should be taken that lumps of the concrete are not formed. beam specimens of size 500×100×100 mm are casted in laboratory.

III. EXPERIMENTAL RESULTS

Flexural test: Place the specimen in UTM. Then press the run key. Machine will start. The test when the specimen is breaking i.e. when it reached to maximum load. The failed specimen shows cracks and ultimately broken down then the machine will automatically stop and the results will be shown on the screen. Flexural strength test is carried out on UTM by applying two-point loading system on beams as per IS 516-1959.

Table 4. Flexural strength test results for 28 days of curing

Width of CFRP strip (mm)	Fiber content in layers (Nos)	Flexural strength (N/mm ²)
40	0	1.55
	1	2.14
	2	2.65
	3	3.17

Photos for Testing Work



IV. CONCLUSION

The hardened concrete properties of High Strength Concrete (HSC) were studied through experimental investigation. The design mix, as per ACI 211.4R-93, provides the most economical concrete, as HSC can be produced using locally available standard ingredients. This study focuses on the manufacture of HSC using conventional concrete components. The strength and effects of fiber-reinforced HSC were evaluated using various laboratory tests.

The experimental investigation revealed that the addition of carbon fiber as a reinforcing material in HSC, with 10 percent fly ash, results in improved mechanical properties. High strength concrete incorporating 40 mm wide CFRP strips exhibited a significant increase in flexural strength and deflection. The design mix (ACI 211.4R-93) yielded satisfactory results for High Strength Concrete (HSC), demonstrating that HSC is dense, homogeneous, and possesses enhanced engineering properties and durability compared to conventional concrete. The results indicate that the use of chemical and mineral admixtures in HSC has significant beneficial effects, making HSC the most economical concrete when designed using ACI Committee 211.4R-93 guidelines with locally available ingredients.

HSC is ideally suited for use in the columns of high-rise buildings, parking garages, bridge decks, and other installations requiring enhanced compressive strength and density. Typically, selected pozzolanic and chemical admixtures are employed in HSC, and achieving a low water-to-cementitious material ratio is essential. Numerous trial

mixtures are often necessary to generate the data required to determine the optimal mixture proportions, as reported by ACI Committee 211.4R-93.

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