Structural Behaviour of Ultra High Performance Fibre Reinforced Concrete

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Abstract - Recent advancements in building materials technology have led to the creation of novel cementitious composites, such as Ultra-High Performance Fibre Reinforced Concrete (UHPFRC). UHPFRC is a cement-based material with exceptional mechanical characteristics. UHPFRC is attractive for reinforcing applications because to its superior mechanical properties over conventional concrete and its ease of preparation and application. Compared to typical concrete, Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC) is a more durable concrete material. This current study explores the behaviour of compressive strength and load bearing capacity of ultra-high performance concrete (UHPC) with the addition of steel fibres, as well as silica fume and quartz powder to the concrete mix. Steel fibres are added to concrete in varying amounts (0 to 2%) by volume. The test results showed that UHPFRC produced the greatest strength compared to traditional concrete.

Key words: Ultra-High Performance Fibre Reinforced Concrete (UHPFRC), silica fume, quartz powder, steel fibres

1. INTRODUCTION

Concrete technology has advanced in a new approach to overcome the constraints of ordinary concrete, such as High-Performance Concrete (HPC). HPC is distinguished not only by its superior strength, but also by its enhanced durability, resistance to a variety of external agents, and fast rate of hardening. The primary drawbacks include brittleness, low tensile strength, and poor resistance to fracture initiation and propagation **[Tayeh et al., 2012].** Ultra-High Performance Concrete (UHPC), one of the most recent innovations in concrete industry, blends high-strength concrete with fibers to overcome many of the issues with conventional concretes. In order to make a super plasticized concrete that is fiber-reinforced and has higher homogeneity, fine sand is used in place of typical coarse particles.

High performance concrete possesses the following performance characteristics: freeze-thaw resistance, scaling resistance, abrasion resistance, chloride penetration, compressive strength, elastic modulus, minimum shrinkage, and creep. The first four are commonly referred to as durability characteristics. Binder components such as cement, silica fume, quartz powder, and fine aggregates such as river sand and quartz sand are combined with steel fibre and a super plasticizer to create UHPC. It was developed in Europe and was first used in specialty applications requiring exceptional strength and corrosion resistance, such as earthquake buildings or marine applications. Lately, UHPC has seen significant application for narrow profiles requiring high strength, such as bridge spans and building facades, where the material's strength, wear resistance, less weight, and lower life cycle costs have been deciding considerations.

2. LITERATURE REVIEW

Spyridon et al. (2020) investigated the possibility that UHPFRC is desirable for reinforcing applications due to its superior mechanical properties compared to standard concrete, as well as its ease of preparation and application. The strategy appears to be promising, since the performance of the reinforced portions increased in every example evaluated. Moreover, significant interface connection between concrete and UHPFRC was discovered, with minimal slip values.

Wei Fan et al. (2020) performed the experimental testing on fiber-reinforced ultra-high-performance concrete. Experimental data demonstrates that ultra-high-performance fiber-reinforced concrete (UHPFRC), one of the most innovative concrete materials, provides excellent strength, durability, impact resistance, and energy-absorption capacity. To assess the performance of UHPFRC-reinforced columns subjected to vehicle collisions, high-resolution finite element (FE) models were developed. The impact resistances of RC and UHPFRC-reinforced columns were fully investigated using the suitable simplified model.

The research conducted by **Muhammad Safdar et al. (2018)** on the flexural behaviour of reinforced concrete beams retrofitted with UHPFRC compares experimental results to 3-D finite element analysis. The tests were done on reinforced concrete beams that had been repaired in the tension and compression zones with UHPFRC of varying thicknesses. According to the research, UHPFRC improves the resistance and durability of repaired beams by increasing their stiffness and delaying the appearance of localized fractures.

Tanarslan (2019) evaluated the UHPRFC as a laminated plate in order to acquire consistent results while utilising UHPRFC and enhance the efficacy of its use on site. In addition, multiple methods of applying UHPFRC laminates were investigated to determine which method enhanced the flexural integrity of RC beams the most. In light of this, seven specimens were reinforced using 50 mm thick UHPFRC laminates, one of which served as the control specimen and the remaining six as the under-reinforced test specimens. The load bearing capacity of the UHPFRC-reinforced specimens improved by at least 32% and as much as 208%.

Tanarslan et al. (2019) analyzed the impacts of reinforced concrete (RC) beams using UHPFRC laminates. First, a preliminary analysis at the material scale was undertaken to assess the effect of fibre volume on the mechanical characteristics of UHPFRC and to establish the optimal fibre reinforcement ratio for laminate production. In the second step, actual-sized laminates were subjected to material testing to assess their fundamental properties and analyse the size effect prior to their use as a reinforcement material. The last phase entailed fortifying flexurally weak RC beams with 30 mm thick UHPFRC laminates using two distinct bonding methods: epoxy glue and mechanical anchoring.

It was highlighted by **Ramachandra Murthy et al. (2019)** that RC beams were statically preloaded to about 70%, 80%, and 90% of the maximum load of control beams, The model accounts for the severity of any existing damage, the particular fracture energy and stress-crack opening correlations of concrete and UHPFRC, and the elasto-plastic behaviour of the reinforcing steel.

Behaviour of ultra-high performance fibre reinforced concrete columns subjected to blast loading was examined by **Juechun Xu et al. (2018).** Four UHPFRC columns measuring 0.2 m by 0.2 m by 2.5 m were subjected to different explosions at a standoff distance of 1.5 m. To determine how the four high strength reinforced concrete (HSRC) columns would react under the same stress circumstances as the UHPFRC columns, blast tests were conducted on the HSRC columns. The failure mechanisms of flexural, shear, and concrete spalling, which constitute the three primary damage modes, were identified. In terms of blast loading resistance, UHPFRC columns outperformed HSRC columns, as indicated by post-blast fracture patterns, permanent deflections, and various levels of damage.

Lampropoulos et al. (2018) examined the fortifying of reinforced concrete beams with extremely high performance fibre reinforced concrete (UHPFRC). This research examines the behaviour of UHPFRC-reinforced reinforced concrete (RC) beams. To obtain extraordinary performance considerably beyond that of normal concrete, an intense matrix and customised fibre and aggregate phases are required. A three-sided jacket with a 50 mm thickness, a 50 mm layer on the compressive side, and a 50 mm layer on the tensile side were produced as models

3. EXPERIMENTAL PROGRAMME

3.1 Materials utilised in this work

In this investigation, grade OPC 53 cement was employed. As fine aggregate, M sand that passed through an IS sieve of 4.75mm was utilised. This research made use of 20mm crushed stone aggregate that was locally accessible.

Bars of Fe500-grade steel were utilised for reinforcement. As a binding substance, silica fume and quartz powder were employed. The addition of steel fibres improves the flexural behaviour. The superplasticizer conplast SP 430 is utilised. Regular potable water is utilised according to **IS 456:2000.**

3.2 Material properties

The different materials employed in this study and the testing on their material properties were done in accordance with IS specifications. The materials used in this study are ordinary Portland cement with a specific gravity of 3.14, M sand as a fine aggregate with a specific gravity of 2.65, and crushed granite with a particle size of 20 mm as a coarse aggregate with a specific gravity of 2.85. The flexural reinforcement of each beam taken into consideration consists of two steel bars, one on each of the tension and compression sides, each with a diameter of 8 mm. The use of 6 mm steel bars with 120 mm spacing is made for shear reinforcement. M30 grade concrete was taken for this research work. The proposed mix design has done as per the guidelines **IS: 10262-1982**. Material proportion for mix design of conventional concrete ; cement to fine aggregate to coarse aggregate mass proportions were 1:1.56:2.72 and the water to cement ratio was 0.45. Table 1 displays the proportion of UHPC materials.

Table 1 Proportion and quantity of materials by the weight of cement

Constituent	Mix proportion by weight of cement	Quantity of materials (kg/m³)
Cement	1	438
Silica fume	0.25	109
Quartz powder	0.25	87
W/C ratio	0.2	-
Steel fiber	0.5%,1% 1.5% and 2% by Volume	-
Super plasticizer	0.05	
River sand	0.8	350
Quartz sand	0.5	219

3.3 Casting of specimen

Cubes of sizes 150x150x150 mm were used to investigate the compressive strength of concrete. The size of beam specimen was 1.5mx0.15mx0.2m. The conventional RC beam labelled as CB and the beam consists of steel fibres as designated as (SFB) ; Cast RC beam specimens are illustrated in Figure 1.

Figure 1 Casting of RC beam specimen.

3.4 Testing of specimen

The comparison to be done with control beam and SFB. The two-point loading condition used to test all the beams. A hydraulic jack was employed to provide the monotonic load, and a proving ring was utilised for accurate data collection. Load was applied to the beam progressively, with each increase in force equal to 5kN. The beams were stressed to their breaking points, and the loads at the on set of cracking and total collapse were recorded. Color coding the cracks helped to highlight the various failure patterns in the beam.

3.5 Compressive strength of specimens

The compressive strength test was performed as per **IS 516-1959**. After 7 and 28 days of curing, cube specimens' compressive strength was measured; the results are shown in Figure 2 and Table 2. After 28 days of curing, the control beam's compressive strength was 34.56 MPa. The specimen ID UHPSF3 produced the best results. In comparison to the control mix, the strength was raised by 25%.

Table 2 Compressive strength of UHPSF and CM specimen

MIX ID	Compressive strength, MPa	
	7 days	28 days
CM	18.32	34.56
UHPSF1	21.03	39.84
UHPSF2	22.12	41.2
UHPSF3	23.25	43.2
UHPSF4	22.1	42.12

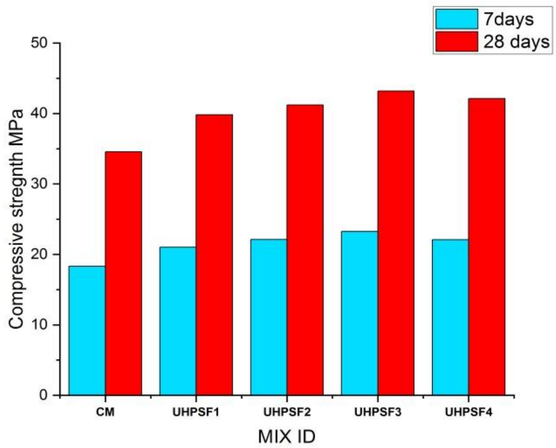

Figure 2 Variation in compressive strength of UHPSF and control specimens

3.6 Load carrying capacity of RC beam

Table 3 depicts the load carrying capability of control beams and other ultra-high performance steel fibre reinforced beams; Figure 3 depicts the ultimate load and first crack load of CB and SFB. CB's initial crack load and ultimate load were, respectively, 37 kN and 62 kN. The UHPSFB2 beam specimen achieved the greatest ultimate load among all other beam specimens.

Table 3 First crack load and ultimate load of beam specimens

MIX ID	First crack load kN	Ultimate load kN
CB (Control beam)	37	62
UHPSFB1(0.5% SF)	52	72
UHPSFB2 (1%SF)	58	76
UHPSFB3(1.5%SF)	48	70
UHPSFB4(2%SF)	43	60

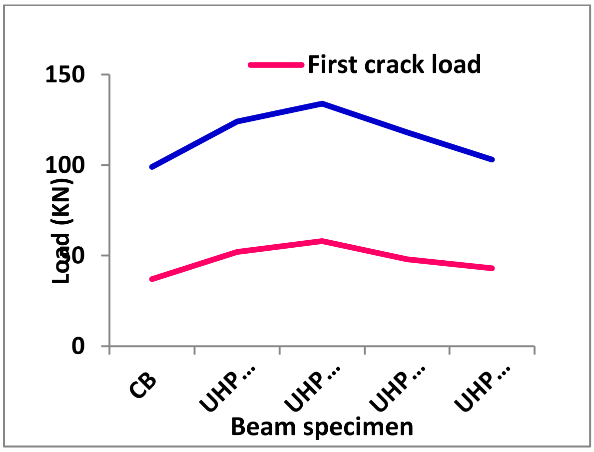

Figure 3 first crack and ultimate load of beam specimens

4. Conclusion

On the basis of the experimental analysis, the following findings may be drawn:

After 28 days of curing, the control beam's compressive strength was 34.56 MPa. The specimen ID UHPSF3 produced the greatest results. When compared to the control mix, it enhanced the strength by 25%. It was observed that the incorporation of fibrous elements improves mechanical performance, particularly flexural strength.

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