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Impact Behavior Of Ultra-High Performance Fiber-Reinforced Concrete: A Critical Review Of Experimental And Finite Element Approaches

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Abstract:
Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) is an advanced construction material known for its exceptional strength, durability, and resistance to extreme loading conditions. The incorporation of fibers into Ultra High Performance Concrete (UHPC) significantly enhances its mechanical properties, particularly under impact loading. This study focuses on the impact behavior of UHPFRC and reviews various experimental techniques used to evaluate its performance under dynamic loads. Furthermore, the role of Finite Element Analysis (FEA) in simulating impact conditions and predicting structural response is highlighted. The findings indicate that UHPFRC exhibits superior impact resistance, energy absorption capacity, and crack control compared to conventional concrete, making it highly suitable for high-performance structural applications.

Keywords: Concrete, FRC, UHPFRC, Finite Element Analysis.

1. Introduction

Image Ultra-high performance concrete (UHPC) is one of the high strength concrete invented in the last decade of 20th century. It is characterized by cement weight higher than 600Kg, fine aggregate size less than 6mm, pozzolanas and the water/cement ratio less than 0.2 per cubic meter volume [1]. The mixture of above constituents in correct proportion leads in a dense and low interconnected pores with compressive strength higher than 150MPa.

With the advancement of technology, researchers added fibre in UHPC to arrest the crack propagation in the concrete arising specially during the impact loads. It results in better properties than UHPC such as higher compressive and tensile strength, toughness and other parameters. The concrete thus obtained was termed UHPFRC (Ultra high performance fibre reinforced concrete). UHPFRC includes better durability properties like low permeability, low creep strain, and higher service period.

The primary problem in concrete is its brittle failure and strain softening behaviour. The strain softening behaviour in concrete is observed due to pull out resistance of fibre which leads to the stable propagation of crack. The fibre bridging effect in UHPFRC makes it suitable for higher load applications without loss of considerable strength. Fibre bridging results in lesser crack width, hence UHPFRC helps in fulfilling the “Limit state of serviceability” criteria [1].

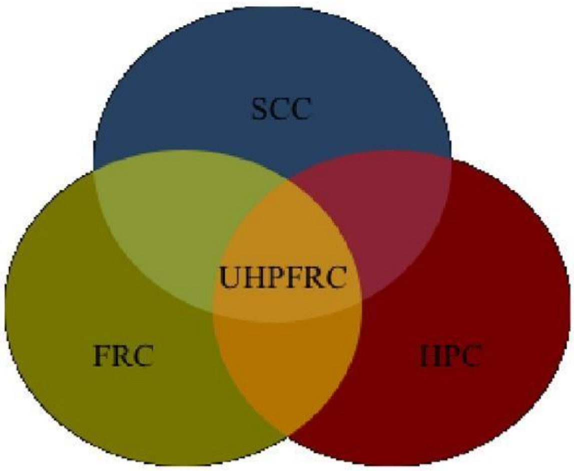

Figure 1: UHPFRC as a contribution of Special concretes [2]

One of the main advantages of UHPFRC over the conventional plain concrete and high performance concrete is the lesser shrinkage. Due to its promising properties, it can be uses in the severe environmental conditions.

2. Types of Impact Test

There are no recommended methods to determine the impact resistance of concrete, therefore every other researcher have investigated through different kind of method. And because of the variability in results obtained from two different methods and the results obtained from same method over two different specimen, no statistical analysis is available to make any method as standard method. However 'ACI Committee 544' has proposed 'drop weight impact test' to measure the impact resistance parameters of concrete.

Some of the impact test methods are as given below [11]-

- Drop-weight impact test (single or repeated impact)
- Split-Hopkinson Pressure Bar (SHPB) test
- Pendulum impact test
- Constant strain-rate test
- Projectile impact test
- Explosive test

Split Hopkinson Pressure Bar Test

SHPB is a specific type of instrument used to determine the dynamic properties of the concrete. The concrete specimen used in this test is in the form of cylinder with diameter of 70mm and height 35mm (as shown in figure 2). A pressure pulse is imparted at one circular face of the specimen and the reactions histories and deflection histories are measured at the other circular face and then used to find the impact properties of concrete specimen.

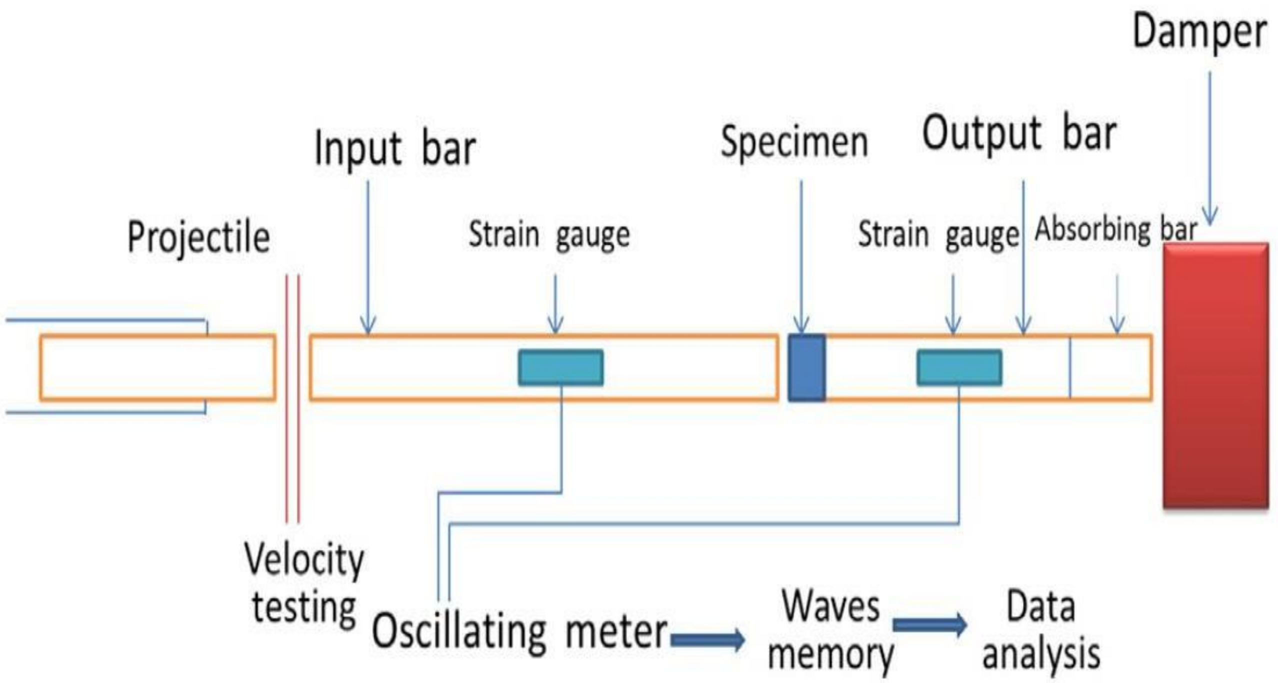

Figure 2: Split Hopkinson Pressure Bar test [12]

Drop weight impact test

Drop weight impact test is one of the most famous and worldwide used method to determine the impact resistance of concrete. The cheap availability of instrument comparative to other dynamic strength measuring instrument and simplicity in performing the experiment, make this method more appropriate for researchers. The concrete specimen is supported over rigid supports because a high magnitude of impulse load act over supports during the impact. A free falling weight is dropped over the concrete specimen and the time histories for impact force, reaction forces and deflection are measured. Sometimes the strain gauges are also introduced to measure the strain in specimen before failure. The accelerometer and the force transducers are attached to the surface of the specimen to measure the inertial acceleration and impact forces in the concrete specimen. However some alloy materials are also stick together with the force transducer and accelerometer to avoid damage to them.

Figure 3: Drop impact test [13]

Pendulum Impact Test

This test is somewhat similar to Charpy impact test. The difference is that the metallic specimen is fixed in Charpy impact test but the concrete specimen is kept freely over the surface in pendulum impact test, and the specimen also rotates after the rotating pendulum mass strikes with the specimen. But the primary limitation in conducting this test is the correct measure of transferred energy. The potential energy of Hammer is transferred to the strain energy of hammer, kinetic energy of hammer and the residual kinetic component in the striking pendulum.

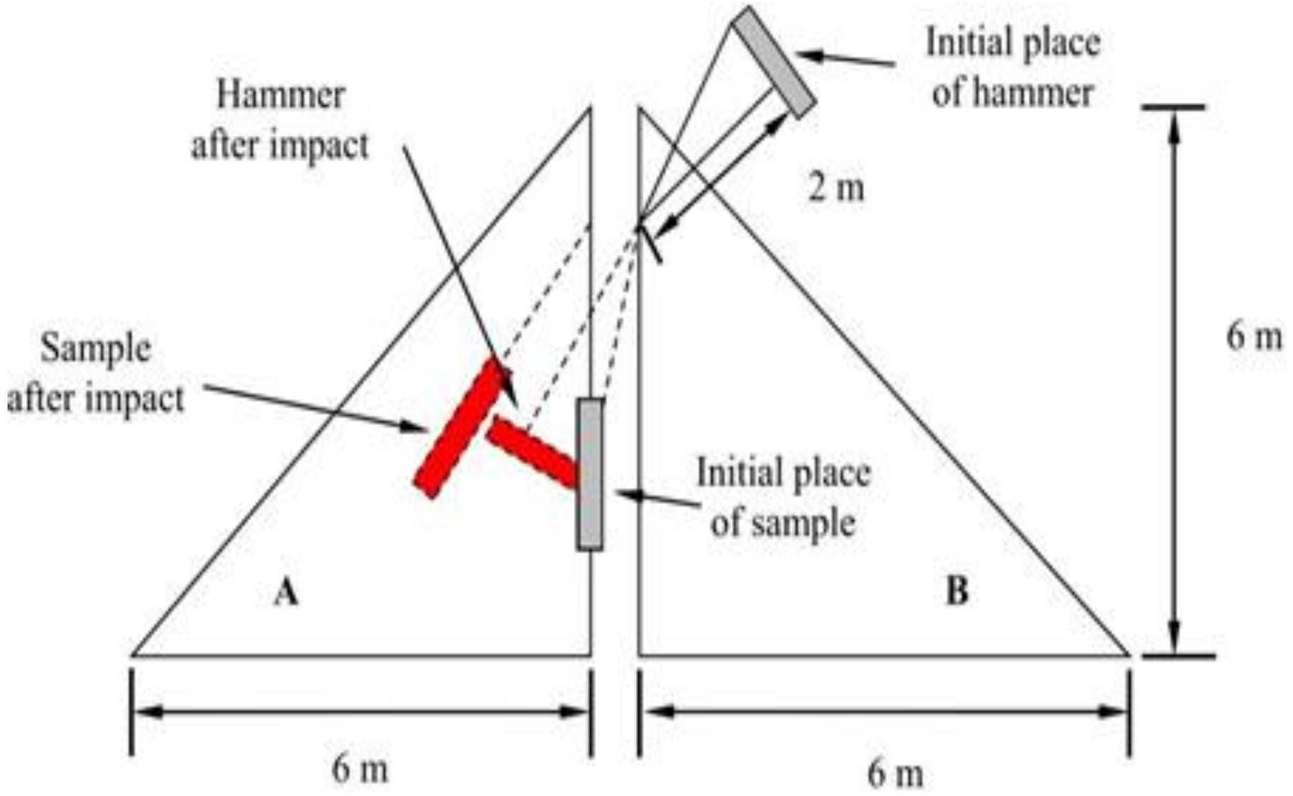

Figure 4: Pendulum impact test [14]

Projectile Impact Test

A high velocity projectile generally the bullet fired from a gun with a velocity generally in the range of 200-500 m/s is fired over the concrete specimen [15]. The presence of fibers in UHPFRC prevents the spalling and scabbing of concrete ear the faces of concrete specimen, because a high velocity projectile try to carry the impact surface area shearing from the concrete specimen [16].

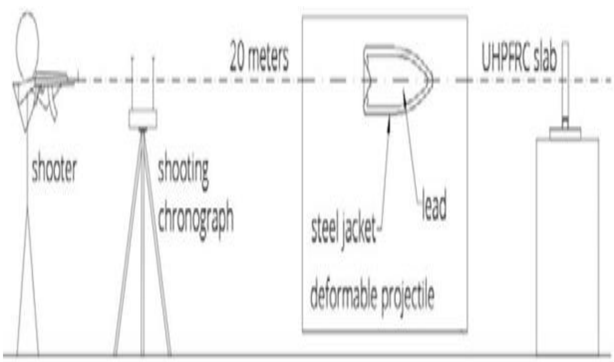

Figure 5: Projectile impact over UHPFRC slab [15]

3. Role of Finite Element Analysis (FEA)

Finite Element Analysis (FEA) plays a crucial role in understanding the impact behavior of UHPFRC. It allows researchers to simulate complex loading conditions and analyze stress distribution, deformation, and failure mechanisms without extensive experimental trials. FEA models incorporate material properties, boundary conditions, and loading scenarios to predict structural performance. For UHPFRC, advanced material models such as damage plasticity and strain-rate dependent behavior are used to accurately simulate impact responses. The integration of experimental data with numerical modeling enhances the reliability of results and provides deeper insights into material performance.

4. Conclusion

This study highlights the impact behavior of Ultra High Performance Fiber Reinforced Concrete and the various experimental methods used to evaluate its performance under dynamic loading. The incorporation of fibers significantly improves the mechanical properties of UHPC, resulting in enhanced impact resistance, ductility, and energy absorption capacity. Among the different testing methods, the drop-weight impact test remains the most widely used due to its simplicity and cost-effectiveness, while advanced techniques such as SHPB and projectile testing provide deeper insights into high strain-rate behavior. Furthermore, Finite Element Analysis serves as a powerful tool for simulating impact conditions and understanding the structural response of UHPFRC. Overall, UHPFRC demonstrates superior performance compared to conventional concrete, making it an ideal material for structures subjected to extreme loading conditions such as impacts, blasts, and collisions. Future research should focus on optimizing material composition, improving cost efficiency, and integrating experimental and numerical approaches for enhanced structural design.

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