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Attributes of Ultra-High Performance Fibre Reinforced Concrete (UHPFRC)

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Abstract—*Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) is a futuristic material emerged over last few decades, in recent years the term UHPFRC has gained an intensive popularity in construction field. A bunch of specific terminologies, which include all aspect of concrete as durability, raw material characteristics, simplicity in design and application, draws attention of researchers towards the improvement of concrete and implementations in construction field. Tensile characteristics of concrete is almost nil, generally render with propagation of cracks on the surface because of shrinkage, introduction of fibre into concrete prevents the propagation of cracks in concrete and improves the tensile strength but there is a large domain of effect of fibre in UHPFRC on the properties of fresh as well as hardened concrete. This review paper aims to provide a comprehensive review on the UHPFRC pertaining to, its mechanical, physical and durability related features. It summarises the results of UHPFRC deployments and focuses on the area of structural improvement, most widely used international recommendations for structural design of UHPFRC, suitable curing methods and a large scale of global applications of UHPFRC is also overviewed*

Keywords: *UHPFRC, Fiber, Mechanical strength, Durability.*

INTRODUCTION

Numerous forms of concrete are frequently used in huge amounts and are a material that is widely used around the world. Many researchers are looking into this material's specific qualities because of how widely it is used. Modern civil engineering construction field has increased the demand for new types of concrete that must have improved features like strength, toughness, and durability. High-Performance Concrete (HPC) is one of the solutions that address the former demand and this specific term i.e HPC had been developed by concrete technology Together with superior strength, toughness and long lasting properties .HPC shows its improved durability, resistance to a variety of external threats , and quick setting and early gaining strength .The main drawbacks of High performance concrete(HPC) is that is it brittle and has almost nil tensile strength it cannot resist the propagation of cracks in the structure ,to overcome these threats the concept of addition of fibre in the concrete came into existence. Self-Compacting Concrete (SCC) has been formulated to solve a number of issues such as difficulties in small specimen casting, in addition by showing advantages such as, less noise level on construction regions, speedier casting, especially in rapidly varying environment conditions, and extremely high mechanical qualities[1] . Ultra-high performance fibre reinforced concrete (UHPFRC) is the special sort of novel composite, flourished by France, which is characterized by greatly flowing smoothly, ability to gain strength easily and early as compared to normal concrete, higher ultimate strength and supercilious durability.

EXPANSION OF UHPC

Concrete being primarily available, most widely used fabricated material to be used globally, and a huge demand for it can be presumed to continue high for the foreseeable future. Because of its magnificent qualities, including its mechanical characteristics and durability, flexibility ,having plenty of application, and relatively cheaper, concrete material is the most popular and essential material in the construction sector[2]. Concrete's great compressive strength makes it frequently used in construction. Significant advancements have been observed in the domain of development of construction material over the past few decades. Early in 1930s, several researchers began looking for every feasible scientific and experimental approach to improve compressive strength and enduringness of concrete. Fig. 1[3] shows important enhancement of compressive strength over the years.

The graph in the figure is clearly depict the gradual advancement of concrete technology over the year in 1960s, while the maximum compressive strengths varying between 15 MPa and 20 MPa. Concrete's compressive strength increased from 45 MPa to 60 MPa during a period of around 10 years. Concrete's compressive strength could only reach up to 60Mpa in the early 1970s due to a lack of chemical development in the early water reducer that was in use at the time. for this reason The then-existing water reducer was unable to further reduce the water to binder ratio (W/B)[4].In the 1980s, it was found that superplasticizers (SP), high-range water reducers, could be used to gradually lower W/B down to 0.30. one of the researchers demonstrated that it was possible to lower the W/B below 0.16 using high doses of superplasticiser (SP) and silica fume, but it was not the feasible way to enhance the strength of the concrete mix reason being the hydration lack of cement thus the W/B below a certain limit was assumed to be unlawful. Concrete compressive strength of up to 280 MPa was achieved utilising compacted granular materials by regulating the grain size distribution of the granular skeleton. In order to attain maximum strength and durability, a material with a minimal number of flaws—such as microcracks and interconnected pore spaces—was developed.

These technological developments have led to the creation of ultra-high-performance Portland cement-based materials with exceptional mechanical properties, along with fundamental knowledge of low-porous materials.

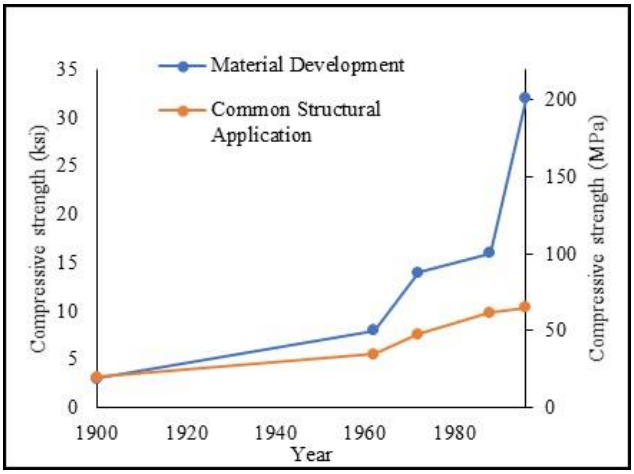

Figure 1: Improvement of compressive strength of concrete for over 100 years [2]

Since the year 2000, significant advancements in the development of UHPC have been made. As concrete technology matured, engineers realised that advanced concrete should have other beneficial features beyond high strength, leading to the names UHPC and UHPFRC. To suit an expanding range of needs, numerous inventive concrete concepts have been evolving. Several researchers are actively proposing environmentally friendly UHPC conceptualisation in an effort to lower startup and material expenses...

Table 1: UHPC, a regular proportion

Ingredients (kg/m^3)	UHPFRC[4]	RPC800[5]
Ordinary Portland cement	1015	1000
Fine Sand	609	500
Silica Fume	254	230
Ground Quartz	-	390
Steel Fibre	316	630
Total water	211	190
Superplasticiser	49	19

PRINCIPLES OF UHPC PRODUCTION

UHPC has a compressive strength that could reach 200 MPa. The fundamental conception of fabricating concrete with a thick microstructure and extraordinarily high strength was first put forth in the 1980s. The useful innovation, however, came with the formulation of efficient SP, which made it possible to fabricate easily-flowing concrete with a significant portion of ultra-fine particles that were effectively packed to reduce composite porosity while using extraordinarily lower water/binder.

According to some authors, [5][6][7][8][9] the core design principle of UHPC is as follows:

a) Enhancing diverse raw material sizes in the mixture to optimise w/b ratio and ultimately diminishing the combined porosity.
b) Improving mechanical characteristics and microstructure employing a better option of heat treatment to catalyze the reaction of pozzolanic component of silica fume(SF).
c) eliminating coarse aggregate to increase homogeneity and alleviate the mechanical consequences of heterogeneity.
d) Adding sufficient volume proportions of small steel fibres to increase ductility.

Concrete developed according to the aforementioned principles has a very high compressive strength, and introducing steel fibres increases the material's tensile strength and ductility.

Table 2: Summary of various researchers and their findings in the field of ultra-high performance fibre reinforced concrete (UHPFRC)

Rechard 1995[5]	Brought the concept of making homogeneous mixture after totally forbidding coarser particles in the mix, which ultimately helped in optimization of compacted mix, enhanced density which would contribute in enhancement of strength of composite. In addition, stated that compressive strength could reach up to the the value of 680, soliciting appropriate pressure confining the concrete.
A.Cwirzen 2008[10]	Theoretically and experimentally investigated for ultra-high strengths fundamental mechanical characteristics, lastingness, bonding strength was also given the importance in the study to predict the characteristics. 28-day strength as compression resistance found to be within 170 and 202 MPa, when they were subjected to steamed type curing set up, specimens which were cured under normal water curing showed strength in between 130 and 150 MPa,. The outcome demonstrated that reactive powder concretes' principles and packing theories might be used to create ultra-high strength concrete. Additionally, it was shown that adding steel fibres only increased flexural strength

Graybeal 2014 [11]	Study demonstrated, UHPC pertains greater tensile strength compared to traditional concrete, and it may display both a peak cracking strength and sustained tensile strength after the initial crack. As a result, tensile strength becomes a more crucial quality to take into account when designing. Graybeal recorded a stress strain curve as a response in tensile properties, using a readily accessible UHPC with 2% by volume steel fibre reinforcing
Kay Wille 2011[12]	UHPC generally requires special curing method namely thermal curing, for large scale projects it is not feasible to employ heat curing to the structure, in this study it was intended to examine the response of the mix without any special curing method rather subjecting normal water curing , results advocated that it is possible to obtain such a great extent of strength as high as 292MPa
Zhidan Rong 2011[13]	It has been discovered that it can withstand deformation under dynamic loads and absorb a lot of energy. UHPFRC is a material that is suitable for impact-resistant constructions such blast walls, barriers, and bridge piers because of its high tensile strength and ductility, which enable it to endure high strain rates and prevent rapid brittle failure
Shah and Ribakov 2011	examined experimental findings in the areas of non-destructive testing and steel fibre reinforced high strength concrete. Additionally, it covered the characteristics of fresh and hardened concrete, as well as the characteristics of durability and the structural behavior of UHPFRC parts.
Parham Aghasi 2016[14]	The goal of this study is to create a remarkable, high-performance composite containing fibres for massive structural applications in the building sector. This unique mixture has a significant number of cementitious components, which causes an outstanding hydration of heat that is inappropriate for large-scale engineering projects. Fly ash was substituted for the conventional solution to this problem, which eventually assisted in minimising excessive heating conditions and also improved flowability. Test on the same context indicated., fly ash can be replaced up to 30% with fine aggregate
Frederic Lachance 2016[4]	Conducting a lot of experimental set up Lachance delivered, if slabs are constructed employing UHPFRC, the coating of reinforcement which is to be provided at top of slab thickness can be avoided to such an extent of 55%,additionally quoted dead weight of the structure is also reduced to an extent 36%
Ali Alsalman 2017[15]	Made an attempt to formulate high strength composite adopting raw material which were available in the locality, and successfully was able to gain 155MPa strength after 90days testing, concluded and reported that finer sand revealed a slightly greater response to compression loading in comparison with concrete prepared using natural grading sand.
B.Luccioni 2018[16]	For this study, high performance composite concrete was used with reinforcement in the form of fibre of varying length, small, medium, and large. Experimental results were in favour of small length fibre, because specimen with smaller fibre length responded very well against blast impacts
Jae-jin Kim 2020[17]	In order to determine the bond characteristics of the fibres in the construction, comparisons between smooth, straight fibres and those with curvilinear textures, consisting of curvatures between 0.02 and 0.1mm, were made. Greater binding strength was indicated by fibres with a curved structure
Amin K.Akhoukh 2021	UHPFRC has a number of typical qualities that make it suitable for use in particular kinds of construction, such as multistorey buildings, bridge girders with greater spans, structures in maritime environments, nuclear reactor chambers, etc
Raju Sharma 2022	Quoted in regard of this special composite, since this composite is made of finer particles and a high range of water reducer, it affects the workability of fresh mix and makes it difficult to use in some special structures. UHPC is a special type of concrete that is prepared using mineral admixture in the recommended proportion. If these minerals exceed their limit, however, there has been a negative impact. Additionally, adding fibre has been a significant hassle and significantly decreases workability

CONCLUSION AND DISCUSSION

Subsequent outcomes could be drawn following the recent and former literature available on UHPFRC

- With water cement ratio of less than 0.2, the best mechanical properties in the majority of UHPFRC were attained. In the UHPFRC mixture, the highest compressive strength was observed when steel fibres added in the mix in proportion 2% of total fraction of volume and have linear measure of roughly 13 mm, hooked end type in the mixture.

- Best mechanical strength was observed when the specimens were subjected to steam curing, when specimens were exposed to a heat curing environment having temperature ranging 90-100 degree centigrade.

- The most important factor that affects the fresh and hardened UHPFRC is observed to be the fibre, fibre type, its orientation, fibre volume proportion in the specimen as well as its geometry .it was found that twisted steel fibres exhibited highest mechanical strength and greater bond strength, followed by hooked end steel fibre and then smooth straight steel fibre.

- This innovative concrete material responds well to impact-type loading; testing evidence supported this and led to the conclusion that this concrete can endure conditions with severe impact loading.

- Reduced porousness, ameliorate microstructure, greater homogeneity, and enhanced rigidness are the cornerstones of this material design. Raw materials, method of preparation, and curing regimens all have a big impact on UHPC's properties.

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