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A Review on the Composition, Microstructure and Properties of Ultra-High Performance Concrete

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Abstract
Concrete being the most widely used building material, plays a vital role in the performance of many industrial, commercial, and residential structures. Consequently, as concrete quality improved, one of the most effective and useful type, Ultra-High Performance Concrete (UHPC) was created. Ultra-high performance concrete, a novel cement composite, has received significant attention and is used in the bridge engineering field, due to its superior mechanical performance and durability. A thorough literature review was undertaken in this report to demonsrate the development concepts and properties of UHPC. The compositional content, water-binder (w/b) ratio, and design mix strategy of UHPC all add to denser and more homogeneous particle packaging. Numerous research studies from around the world were used to compile a database on UHPC mechanical and durability properties. This review mainly focuses on the composition, microstructure, mechanical and durability properties of UHPC. This study aims to aid architects, builders, and other construction stakeholders better grasp UHPC's fundamental characteristics and capabilities, which will help them to learn more on this durable and long-lasting building material.

Keywords: *Ultra-high performance concrete, Mechanical properties, Durability properties, Composition, Microstructure*

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I. INTRODUCTION

Concrete is one of the most universally adopted material in the present world. Still, it has number of drawbacks in terms of extreme loading, high permeability, and carbon dioxide emission. To overcome this, an ample of research work has been conducted within the last decades to obtain a concrete having higher strength, enhanced durability, and better impermeability along with lesser CO_2 emission. UHPC is one of the latest advances in concrete technology and it achieves extraordinary strength characteristics through optimization of the particle packing density of the cementitious matrix [1]. The dense matrix also promotes exceptional durability properties and is the biggest benefit of the material [2, 3]. A durable concrete results in long lasting structures, reduced maintenance cost and it helps to achieve a more sustainable infrastructure. In 1970s, Yudenfreund et al. [4] had developed the first ultra-high strength cement paste having a compressive strength of 240MPa in 180 days, in which water-to-cement ratio was taken as 0.2. Later in 1980s, Bache [5] and Birchall [6] tried to make some improvements in ordinary conventional concrete. With the use of superplasticizers and pozzolanic admixtures, they introduced densified with small particle (DSP) and macro defect free (MDF) concretes having ultra-high strength and very low porosity, respectively. However, the main drawback of these concretes was their ductility as the enhancement of strength reduces the ductility property. Hence, Richard and Cheyrezy [7] developed the new reactive powder concrete (RPC), the antecedent of ultra-high performance concrete (UHPC), by using highly fine-grained reactive admixtures (i.e. silica fume and fine quartz), fibers and superplasticizers while having more binder content and low water-to-binder ratio. The mechanical characteristics such as tensile strength, flexural strength, toughness, ductility, and the impact resistance was enhanced by providing fiber reinforcement.

The newfangled UHPC is a special type of concrete having a minimum compressive and tensile strengths of 150 and 8MPa, respectively, while fulfilling the specified criteria of better ductility, durability, and toughness requirements along with far better permeability resistance to chemicals as compared to ordinary concrete [8]. These excellent properties of UHPC results in the weight reduction of structures, due to which more slender structures can be constructed. In spite of all these advantages, it has some drawbacks also. The production of UHPC requires very high amount of binder content which affects its heat of hydration along with its production cost [9]. It's complicated mix design and very high manufacturing cost has limited its use to the mass structures only. Hence, studies are required to overcome these drawbacks and to make it an economical and efficient construction material. The main purpose of this article is to summarize various progress done in the past years to provide an insight knowledge regarding this ultra-beneficial material. This article mainly focuses on the constituents, microstructure, mechanical and durability properties of UHPC

II. COMPOSITION OF MATRIX

UHPC is composed of aggregates, cement, water, additives, admixtures and fibres. The difference between UHPC and conventional concretes mix design lies in the amount of binder, the size of the aggregate and the presence of fibres. Use of large amount of super-plasticizers to obtain an acceptable workability is also a characteristic of the UHPC. The matrix of the UHPC is much denser compared to a conventional concrete. The matrix phase includes cement, pozzolanic materials and the filler fraction of the aggregates. Hence, the matrix consists of both inert and chemically reactive materials, having some packing density enhancer property also [10]. To increase the packing density of concrete matrix, different size classes of binders and aggregates has to be increased, so that the voids in between the larger particles can be filled by the smaller ones [11]. The incorporation of this well graded system will also help to improve the workability of the fresh concrete to some extent by introducing ball bearing effect between the finer and coarser particles and reducing the cement paste requirement for lubricating the particle's surface. But it has been noticed that a completely dense packing is not benefitting as the fresh concrete needs to flow to certain degree before it gets placed [10]. Hence, addition of water-reducing agents in the mix will oppose the effect of low water–binder ratio and fiber's addition to maintain minimum required workability [10, 11].

2.1 MATERIALS

2.1.1 Binder

Generally, cement content required for the production of UHPC (600-1000kg/m3) is approximately twice the amount of cement required in ordinary concrete [10]. Low water-to-binder ratio is required in UHPC and there is always the risk of secondary ettringite formation. As all the cement particles do not react due to low water–cement ratio, the unhydrated cement which is leftover behaves inertly and will be used in particle packing [10]. Other materials with cementitious properties like silica fume (SF), fly ash (FA), metakaoline, etc. can be used as a replacement (partially or completely) for cement. Compared to cement particles, silica fume particles are very small and hence can be used as an excellent filler material, increasing the packing density of the matrix [12]. Also, it produces denser CSH gel on reaction with CH leading to higher strength and lesser porosity. Fly ash particles are mainly spherical in shape having ball bearing effect. Cement replacement with fly ash helps in enhancing the flowability of fresh concrete, increasing the setting time, decreasing the permeability, and reducing sulfate attacks [13]. Metakaolin when used as a cement replacement will reduce autogenous shrinkage, increases flexural strength but with a slight decrease in the compressive strength [14]. Rice husk ash (RHA), ground granulated blast furnace slag (GGBFS), and nano-particles are some other cement replacement materials which can improve the properties of UHPC. RHA have greater specific surface area and higher amorphous silica content like SF but have porous and angular particles [10]. Shrinkage reduces with increasing the RHA content [15]. GGBFS is produced from molten iron slag which is a by-product of iron and steel factories and is mainly composed of alumina, silica, lime, magnesia, and iron oxide [10]. The durability of structures gets enhanced as it provides greater resistance to sulfate attack and chloride penetration along with reduction in the damage risk due to alkali-silica reaction [16]. Nano-particles (nano-silica, nano-iron, nano-$CaCO_3$, etc.) have the ability to densify the microstructure by acting as a filler material and also promotes further cement hydration because of their high reactivity by acting as cement phase nucleus [17].

2.1.2 Aggregates

Normally, aggregate is considered as an inert material but it plays a very crucial role in deciding the dimensional stability of the concrete along with its elastic and thermal properties. The best aggregates which should be used for UHPC are characterized by high mechanical strength (hard, durable, etc.), well-graded size distribution and free from any harmful contaminants (clay, silt, chemicals, etc.) so that it may not affect the hydration process, strength, density, and porousness of the concrete matrix. Various aggregates which are currently in use for the production of UHPC are silica sand, natural sand, quartz sand, recycled glass cullet, crushed basalt, and iron ore tailings [18]. Adding these materials as fine aggregates in the concrete composite will enhance packing density, increases strength, and improve durability.The silica sand is considered to be expensive for UHPC. Natural sand and recycled glass cullet can be the better option as it does not affect its mechanical performance [19]. Iron ore tailing which is relatively inert and having particle size bigger than cement, can be used efficiently as a fine aggregate in UHPC production [20]. Moreover, Collepardi et al. [21] and Shi [22] have founded crushed basalt as a promising material which can be used as fine aggregates in UHPC by getting similar better results. Generally, apart from fine aggregates, coarse aggregates are rarely used in

UHPC production from strength point of view. But, addition of coarse aggregates in the concrete mix have the ability to reduce autogenous shrinkage, cement quantity and hence the cost of UHPC [23].

2.1.3 Superplasticizers

According to the principle of production, UHPC requires a very high binder content at a very low water–cement ratio of 0.14–0.20 [18]. Hence, superplasticizers like polycarboxylate are to be added so as to provide the required workability to the concrete mix. The amount and type of superplasticizer to be used, should be chosen on the basis of the quality of UHPC to be obtained. Marsh cone test is usually done to determine the optimum dosage of superplasticizer. Generally, SP dosages of 1.4–2.4 % by cement weight are recommended [24].

2.1.4 Fibers

Fibers are used as a reinforcement in UHPC to reduce its brittle nature and to increase its mechanical properties. The fibers provide better resistance against the crack generation and its propagation within the concrete matrix. Fibers' (i) geometry and type, (ii) length, (iii) volume content with dispersion homogeneity, and (iv) orientation are some of the important factors which affect the properties of UHPC. Steel fibers are commonly used in UHPC matrices [25]. The deformed fibers [twisted (TF), hooked end (HF), triangular, polygonal, square shapes, etc.] are much better than straight fibers (SF) in terms of strength and post-cracking strain [25].

III. MICROSTRUCTURE

From material science point of view, the macro properties of a material are determined by its microstructure, which is the same for UHPC. The microstructure of UHPC can be observed by Scanning Electron Microscope (SEM). The main aspect of the microstructure of UHPC is the pore structure, i.e. pore size distribution and the total porosity.

Another difference of NC and UHPC in microstructure lies in the interfacial transition zone (ITZ) between the paste and aggregate particles. Figure 1 is a Backscattering Scanning Electron (BSE) image of a UHPC paste containing FA and SF. Because of the low w/b, large amount of unreacted cement and FA particles can be seen in the image. No visible capillary pores and cracks can be found, as well as the portlandite (Ca(OH)2) crystals [26]. Figure 2 shows the pore size distribution of UHPC, HPC and NC, determined by mercury intrusion porosimetry (MIP). It can be seen that, compared with HPC and NC, the main features of UHPC pore structure are the absence of capillary pores and lower total porosity. The fine pore structure is the reason why UHPC has a particularly high resistance to chloride penetration, carbonation and freezing-thawing attack [27]. The thickness of ITZ in NC is normally in the range of 20 to 100 μm, whereas the thickness of this zone in UHPC is found to be very small (2 μm), or even none [28]. Figure 3 shows ITZ between the paste and sand particles in UHPC. It seems that ITZ almost disappears [26]. Figure 4 shows the bond between the steel fiber and the UHPC matrix. It can be seen that the steel fiber is closely wrapped up by the matrix, showing a strong bond between them. Hence, the fibers could effectively bridge the cracks and thus improve the ductility of UHPC [26]. UHPC's microstructure mainly consist of quartz sand, unhydrated particles of cement clinker, and hydration products i.e. calcium silicate hydrate (CSH) gel. Compared to conventional concrete, it has an extremely dense, less porous, and highly compact ITZ. It is due to the use of low water–cement ratio and pozzolanic chemical reactions between CH and reactive admixtures, because of which maximum CH crystals get converted into dense CSH gel [29]. The very dense and compact microstructure of UHPC results in outstanding mechanical properties and durability.Thus, UHPC is characterized by an advance microstructure because of the close packing of solid particles and improved ITZ.

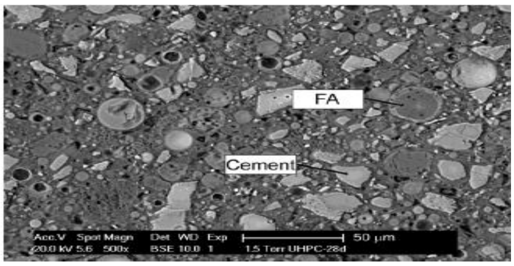

Figure: 1 Microstructure of UHPC paste containing FA and SF, w/b = 0.18, 28d [25]

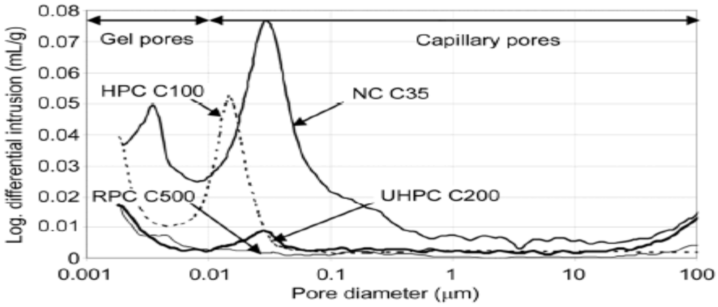

Figure: 2 Pore size distribution of UHPC, HPC and NC [26]

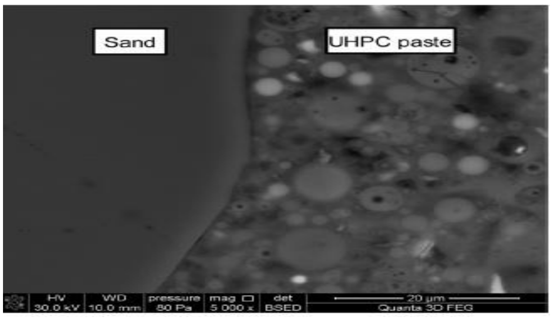

Figure: 3 ITZ between sand and paste in UHPC [25]

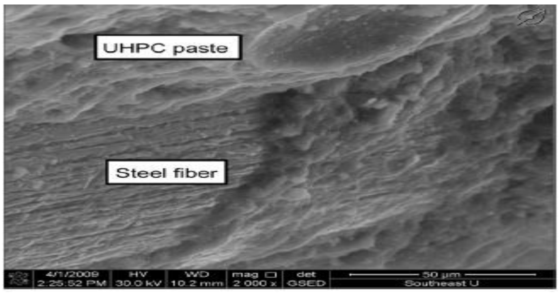

Figure: 4 ITZ between steel fiber and paste in UHPC [25]

IV. MECHANICAL PROPERTIES

Some of the major conclusions of renowned researchers regarding various mechanical properties of UHPC has been delivered under this section.

4.1 COMPRESSIVE STRENGTH

UHPC have a very high compressive strength of 150MPa or much higher as compared to the ordinary concrete. Fibers do not necessarily improve compressive strength, but provides a ductile nature to the concrete because of their restraining and confining effect [30]. Later in 2006, Graybeal [31] investigated the curing condition's effect and concluded that under steam curing, compressive strength is increased significantly. Autoclave and steam curing seems very effective ways to increase the compressive strength of UHPC due to improvement of hydration process under these curing regimes [9]. The application of thermal treatment advances pozzolanic reactions, leading to formation of additional calcium silicate hydrates (C–S–H). These C–S–H phases fill small pores, leading to denser microstructure and consequently higher mechanical properties [32, 33]. Some results have shown that air dry curing is less effective as compared to wet and steam curing as it provides a compressive strength of 160MPa at 20˚C in 90 days whereas steam curing (90˚C in 90 days) gives approximately a higher strength of 200MPa [34]. Compressive strength of RPC containing high volume mineral admixtures (silica fume, GGBS, fly ash) exceeded 200 MPa after standard water curing [9]. It was observed that increasing the cement content increased the UHPC compressive strength; however, beyond an optimum cement content, compressive strength tends to decline likely due to limited participation of aggregates [35]. Because of the very low water/binder ratio (w/b) of UHPC, only part of the total cement hydrates and the unhydrated cement can be replaced with crushed quartz, fly ash or blast furnace slag. For instance, up to 30, 36 and 40 % by volume of cement in UHPC mixtures can be replaced with crushed quartz, blast furnace slag or fly ash, respectively, without compromising the compressive strength [36]. There will be a decrease of about 15–25% in compressive strength if crushed sand (CS) completely replaces the standard sand in UHPC, due to high amount of free water present in case of CS mix [37]. 5% SF, if used as a binder material can produce a compressive strength of 155MPa at 90 days. However, silica fume (>10%) does not shows any significant changes in the compressive strength, providing strength similar to 5% SF addition [38]. Alsalman et al. [38] further concluded that the compressive strength increases by 4–8% depending upon the specimen size due to addition of 3% steel fibers. Other industrial by-products giving good results in strength development are fly ash (FA) and coal bottom ash (CBA). Additional compressive strength can be provided by CBA at 28 days due to its pozzolanic reaction and its highly amorphous structure [39]. Soliman and Hamou [40] used glass powder for making an eco-friendly UHPC and found out 20 and 50% glass powder as the optimum replacement of cement with respect to compressive strength and flowability, respectively. By complete 100% replacement of quartz powder with glass powder, a compressive strength of 234MPa can be attained under hot curing. Infact, complete replacement provides better compressive strength along with cost reduction [40].

4.2 TENSILE STRENGTH

UHPC matrix with the addition of fibers, generally have a tensile strength in the range of 15–20MPa depending upon the matrix property. It is almost twice as that of UHPC without fibers. Ultimate cracking strength (post), energy absorption capacity and the strain capacity are very important tensile parameters that has to be properly investigated to observe the tensile behavior. Nguyen et al. [41] inspected the effect of geometry and size on the tensile properties of UHPC. The results confirm that the ultimate cracking strength, energy absorption capacity and the strain capacity get reduced on increasing the volume, gauge length and the section area of specimen. It is noticeable that the tensile properties of UHPC get significantly improved depending on the types of fiber used in the matrix. Park et al. [42] compared the effect of different percentage of long smooth (LS), hooked fibers: type A, B (HA and HB) and twisted macro steel (TMS) fibers used with a particular content of micro fibers. Twisted fibers have shown the best results for post cracking strength as well as the strain capacity, followed by the hybrid and smooth fibers. Meng and Khayat [43] has used graphite nano platelets (GNP) and carbon nano fibers (CNF) to produce UHPC. Results showed that the tensile strength effectively increases (by 56 and 45%) on addition of these nano-materials. Moreover, hybridization of fibers can also be introduced in the production of UHPC to attain better strength and performance. Results demonstrates that Steel (S) and polyethylene (PE) hybrid fiber UHPC provide better first cracking and ultimate tensile strength as compared to single steel fiber UHPC [44]. Thus, it can be concluded that a combination of high strength synthetic fibers and steel fibers provide better tensile property.

4.3 SHEAR STRENGTH

Shear strength of a material is the capacity to resist the structural failure or yield in shear. The shear strength lay in the range 7.5-10MPa. UHPC provides better shear resistance as compared to normal strength or high strength concrete (NSC/HSC). Hussein and Amleh [45] concluded in their study of UHPC's structural behavior that the ultimate shear strength of UHPC was higher than NSC/ HSC. Generally, UHPC show a very complex behavior under shear loading. The main factors behind the shear failure of a structure are shearing forces along with bending moments. The resistance to these shear failures is directly proportional to the volume of fibers incorporated in the mix, whereas inversely proportional to the ratio of shear span to depth. The experimental results also showed that the shear strength of UHPC was always greater than its tensile strength. The shear strength of 1.5% fiber mixed UHPC was found approximtely 1.6 times greater than its tensile strength [46]

4.4 FLEXURAL STRENGTH

Flexural strength is sometimes a more important feature than the compressive strength of UHPC. Types of aggregates, fibers, and the casting methods are some of the important factors which significantly affects the flexural strength of UHPC. Fine aggregates like barite sand, quartz, and nano-materials (e.g. nano-silica) have stronger bond with hardened paste and thus provides better flexural strength [47]. Researchers [48, 49] reported flexural strength values of up to 48 MPa (7.0 ksi) for UHPC depending on its mixture design and curing regime. In comparison to regular beams without fibres, an improvement of 2.5% in the mixtures of additional steel fibres resulted in a 144% increase in flexural strength [50]. Some results [51] have shown that the twisted fibers increase the flexural strength as compared to straight fibers. Whereas, some other results [52] shows that the best toughness and flexural strength was obtained for the beams with straight fibers as compared to twisted one. Yoo et al. [51] also stated that better flexural strength, fracture energy and toughness is obtained by using longer fibers due to their improved pull out performance. Better flexural performance is obtained by using single twisted fibers (2%) as compared to hybrid twisted and straight fibers [52]. An improved performance of UHPC under flexure will be obtained by increasing the speed of casting in layer casting method for uniaxial beams [52].

4.5 IMPACT RESISTANCE

UHPC has higher strength and improved durability as compared to ordinary concrete. It provides much better earthquake and impact resistance. Under impact loading, it is characterized with higher dissipation of energy and much better post loading performance. The important factors affecting the resistance capability of UHPC against impact loadings are specimen size, fibers (type, dosage, length, orientation) and mineral admixtures [53]. According to Wu et al. [54], the impact resistance capacity of UHPC get improved on incorporation of SCMs and fibers due to enhancement in its microstructure, ductility and toughness properties.

V. DURABILITY PROPERTIES

Under this section, attempts have been made to provide a summary of investigations made on some of the durability properties of UHPC by the eminent authors.

5.1 WATER ABSORPTION

Concrete with high water permeability can become a barrier that allows chemicals, such as chloride ions, to diffuse into it and eventually result in corrosion of steel rebars and fibers. UHPC has lower porosity and a much denser microstructure than both conventional concrete (CC) and high-performance concrete (HPC). The low porosity makes UHPC a superior permeability-resistant material. The water absorption capability of concrete provide information on factors such as the porosity and quantity of permeable pores and the interconnectedness of those pores [55]. The durability of concrete increases with a decrease in the water absorption capacity of the concrete. Compared to HPC, UHPC's potential absorption of water is about ten times lower, and it is 60 times lower than NSC's potential absorption of water [56]. It has been found that the water absorption coefficient of UHPC after 90 days is approximately five times lower than that of control concrete [57]. The UHPC-NSC made with nanoparticles showed a 36% lower water absorption rate than the reference mixture. The gas permeability coefficient of UHPC is less than 1×10^{-19}, which is three orders of magnitude lower than the gas permeability coefficient of conventional concrete. When the porosity of the pores is low, the pore connectivity is restricted and water absorption is greatly reduced. On addition of mineral admixtures to UHPC, the microstructure of UHPC becomes more homogeneous, and the thickness of the ITZ is reduced. This reduces the UHPC's water absorption capacity because it partially blocks its water transport pathway [58].

5.2 CHLORIDE PENETRATION

Chloride ion penetration resistance is one of the most critical factor in the strength of concrete. Higher ductility is attained from concrete with higher chloride tolerance. The w/b ratio, exposure condition, curing regime and the exposure duration are the main determinants of chloride penetration [59]. The incorporation of cemented components and thermal treatment considerably improves the resistance of concrete against chloride penetration. UHPC had about three orders of mgnitude lower chloride diffusion coefficient than NSC, after 95 days of exposure to a 3.5% by weight NaCl solution. This means to achieve the same chloride threshold at the steel-concrete interface by diffusion, a 1,000 times longer time period will be required; hence, time-to-corrosion initiation will be prolonged [60]. Vernet 2004 [61] suggested that the diffusion coefficient of UHPC is two orders of magnitude lower than that of HPC and three orders of magnitude lower than that of NSC. Thermally treated UHPC has a much lower coefficient of chloride diffusion (2×10^{-14}m2/s) than high-performance concrete (6×10^{-13}m2/s) and ordinary concrete (1×10^{-12}m2/s), according to Roux et al. [62]. Chloride penetration of the specimen is also defined by the electrical charge passed in coulombs as per ASTM C1202-10.

5.3 FREEZING AND THAWING

UHPC is highly resistant to freezing-thawing actions. The main factors which provide such a great resistance are highly enhanced homogenous microstructure, lower permeability, and the reduced porosity [30]. Normally, it can sustain a freezing-thawing cycles of 400–500 and wetting-drying cycles of 4500 without any degradation [61]. Acker and Behloul [63] showed that freeze-thaw cycle of 300 have no degradation effect on the microstructure of UHPC. Concrete deterioration due to freeze-thaw is expressed in terms of relative dynamic modulus (RDM) given in ASTM C 666. After a significant number of freezethaw cycles, internal micro-cracks get generated and the concrete deterioration starts along with their further propagation. Freeze-thaw resistance of UHPC can be enhanced by incorporation of mineral admixtures. Only 10% of class C fly ash and silica fume significantly increases the resistance capability of UHPC [64]. All these results show that UHPC has a very good performance under freezing and thawing.

5.4 CARBONATION

Carbonation in concrete is a measure of its long term durability. Carbonation lowers the alkalinity of concrete via the consumption of $Ca(OH)_2$. The passive protective oxide film around steel is destroyed by the decrease in alkalinity, leading to corrosion. Carbonation test was conducted after conditioning the samples in the carbonation chamber for 3 months and 6 months. After three months in a 50% CO_2 environment, the carbonation front reached 5.6 mm in the NSC cylinders while it reached up to 12 mm after 6 months. On the other hand, there were no signs of carbonation in HPC and UHPC after 6 months in a similar environment [60]. Similar observations are reported by Roux et al. [62] after placing RPC in 100% CO_2 environment for 42 days. The carbonation rate depends on the quantity of $Ca(OH)_2$ in the matrix, the concentration of CO_2, and the availability of H_2O. In the case of NSC, the $Ca(OH)_2$ constitutes up to 20% of the total hydration products, which increases the carbonation rate of concrete. In the case of HPC and UHPC, the composition of the hydrated matrix is different than that of NSC. The pozzolanic reaction in which the SCM react with $Ca(OH)_2$ to form C–S–H gel consumes the Ca $(OH)_2$ needed for the carbonation reactions [60].

5.5 FIRE RESISTANCE

UHPC have highly dense microstructure and very low water–binder ratio. Thus, it is more vulnerable to fire attacks. The concrete gets exposed to high temperature during fire, due to which it produces some physical and chemical metamorphosis in the concrete matrix. This metamorphosis cause the disintegration of concrete structures. There occurs development of internal pore pressure due to evaporation of free water and the loss of CSH bounded water. When this internal pressure exceeds the bearing capacity of concretes, spalling i.e., the explosion of concrete take place. Ye et al. [65] found that the maximum cracks in UHPC were generated at 300 degree celsius and the complete explosion take place at 400 degree celsius. Fiber addition will enhance the fire resistance capability of UHPC as after their burning and melting, capillary pores get developed along with the interlinking of cement matrix and aggregate's transition zone [66]. This will increase the permeability and decrease the steam pressure. Polypropylene (PP) fibers are found to be the best reinforcement for increasing resistance of UHPC against fire as compared to others like steel. Introduction of PP fiber with density of 2 kg/m3 showed negligible changes in UHPC for temperature up to 300 degree celsius and little deformation at 400 degree celsius [65].

VI. CONCLUSIONS

Based on the comprehensive review and discussions made in this paper, following conclusions are emphasized in the end:

- Fine mineral admixtures like silica fume, fly ash, groung granulated blast furnace slag, metakaolin, nanomaterials, etc. are very efficient in enhancing the overall performance of UHPC. The best aggregates which should be used for UHPC production are characterized by high mechanical strength (hard, durable, etc.), well-graded size distribution and free from any harmful contaminants (clay, silt, chemicals, etc.), so that it may not affect the strength, density, and porousness of the concrete matrix. The low water-binder ratio of UHPC mixes in general only could be attained with high-range water-reducing (HRWR) admixture or superplasticizer. Addition of fibers provide a ductile behavior and a better resistance against the crack generation and propagation.
- Microstructure improvement, homogeneity enhancement, porosity reduction, excellent hydration, and toughness betterrment are the basic requirements for producing UHPC. For this, the basic requirements of UHPC mix are very high binder content, low water–binder ratio, high quantity of superplasticizers, good quality of fibers, and excellent mix design along with proper curing.
- Compressive strength can be enhanced with the addition of mineral admixtures in the concrete mix. Fiber's addition has a very negligible effect on compressive strength as it is mainly responsible for enhancing the tensile and flexural strength of UHPC. Autoclave and steam curing seems very effective ways to increase the compressive strength of UHPC due to improvement of hydration process under these curing regimes. Tensile properties of UHPC get significantly improved depending on the types of fiber used in the matrix. A combination of high strength synthetic fibers and steel fibers provide better tensile property. Ultimate shear strength of UHPC is higher than normal strength concrete and high strength concrete. Impact resistance capacity of UHPC get improved on incorporation of SCMs and fibers due to enhancement in its microstructure, ductility and toughness properties.
- The durability of UHPC increases with the decrease in the water absorption capacity, chloride penetration, and increase in the freezing-thawing resistance. Incorporation of mineral admixtures, proper heat treatment, and lower water-binder ratio help in achieving highly enhanced homogenous microstructure, reduced porosity, and lesser permeability.

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