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A REVIEW ON ULTRA-HIGH PERFORMANCE CONCRETE

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Abstract - *Ultra-high performance concrete (UHPC) is an advanced cementitious material showing compressive strength greater than 150MPa. It has excellent properties like high strength, high ductility, and excellent durability. It can become a practicable solution to improve the sustainability of buildings and other infrastructure components. This paper assesses the theoretical principles, raw materials, mixture design methods, and preparation techniques for UHPC. Four theoretical principles for the development of UHPC include a reduction in porosity, enhancement in microstructure, improvement in homogeneity, and increase in toughness are reviewed. The influence of different raw materials on the performance of UHPC is summarized. The impact of using various percentages of the constituent materials and their available variation on compressive strength is presented. The maximum packing density is determined by puntke test. It was showed that the curing of UHPC is regarded as a very important aspect of its development as it considerably affects the reactivity of its constituent. The curing methods such as room temperature curing, steam curing, and autoclave curing are reviewed.*

Key Words: Ultra-high performance concrete, Reactive powder concrete, packing density, autoclaving.

1.INTRODUCTION

Ultra-high performance concrete (UHPC) is reasonably a new generation of cementitious material with excellent rheological properties that include workability, self-placing, and self-densifying properties. It has improved mechanical and durability performance with very high compressive strength, and non-brittleness behavior. UHPC added with fiber can be considered as a combination of three concrete technologies of self-compacting concrete (SCC), fiber reinforced concrete (FRC), and high-performance concrete (HPC). Superior qualities of concrete such as strength and its durability, the capability for it to be placed in many forms, and its low price have made concrete to be considered the most prominent material in the construction industry. In 1993; (Richard & Cheyrezy, 1995) used components with more fineness and reactivity to develop Reactive powder concrete through thermal treatment. Reactive powder concrete is a major innovation in the development of UHPC. Its concept was the arrangement of different particles in a very dense packing. It is depicted by high binder content, very high cement content, very low W/C, use of silica fume (SF), fine quartz powder, quartz sand, SP, and steel fibers. In 1994, De Larrard proposed the term ‘‘Ultra-high performance concrete” (UHPC). The development of UHPC often uses thermal curing at 90°C or higher, vacuum mixing, and pressure before and during the setting. Although these technical processes are favorable to the mechanical properties of UHPC, they can result in low production efficiency and high energy consumption. From the year 2000 onwards, significant progress has been made on the development of UHPC. Supplementary cementitious materials, such as fly ash (FA), ground granulated blast furnace slag (GGBS), rice husk ash (RHA), and SF, are used for replacing cement. It was used in the attempt of producing sustainable UHPC and decreasing its current cement utilization. Because of the development of environmentally friendly UHPC with comparatively low cost, the applications of UHPC are widening. Since the 2000s, several countries have been involved in various applications of UHPC. However, there are various challenges before the widespread application due to the lack of normally accepted standards for testing methods, design guides for engineers, and quality control methods in manufacturing facilities.

2. THEORETICAL PRINCIPLES FOR PRODUCTION OF UHPC

Four theoretical principles [1]for the production of UHPC are reduction in porosity, improvement in microstructure, enhancement in homogeneity, and increase in toughness. Pore structure plays a significant role in governing the strength of hardened cement-based materials. The pore size distribution, shape, and position of pores are also critical, but it is both difficult and impractical to include all these parameters. Many experimental research has confirmed that an acceptable improvement of strength can be obtained by decreasing porosity. The porosity and pore size distribution can be effectively improved by the utilization of superplasticizer, incorporation of very fine reactive mineral admixtures, and close packing of raw materials. Many close packing models have been suggested by researchers. Its performance is improved by the addition of fine powders in the mix. These fine materials generate a free large surface area that needs a high amount of C-S-H gel. ITZ developed in conventional cement mortars and UHPC from SEM observations are shown in Figure 1.

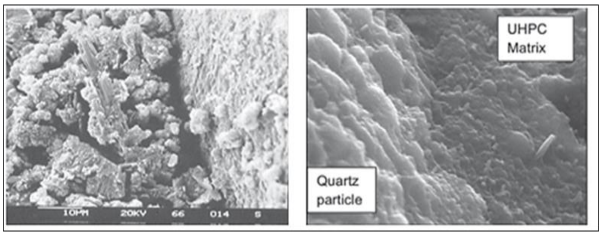

Fig -1: ITZ in conventional mortar and UHPC

3.RAW MATERIALS

The raw materials for the development of UHPC include cementitious components, quartz powder, quartz sand, superplasticizer and, fibers. Cement content in UHPC is usually 800-1000 kg/m3. The cement which has low alkali content, low to medium fineness, and a low C3A content can decrease water demand and heat of hydration. Silica fume is used as the chemical admixture and the secondary binder. It was because silica fume is a pozzolanic material with micro-sized particles which eliminate the micro-particulate voids in the binder paste. It improves the packing density and enhances durability and strength by producing secondary hydrates by the pozzolanic reaction. It is found that optimum silica fume content is 25% of the cementitious component. Silica fume content is 150-300 kg/m3[2]. Quartz powder has an excellent paste aggregate filler that decreases the initial porosity of the mixture. [3]

Supplementary cementitious materials such as fly ash, ground granulated blast furnace slag (GGBFS) are used to replace cement. UHPC replaced with 20%, 40% and 60% GGBFS. The maximum compressive strength is obtained when 20% of cement is replaced with GGBFS[4]. Fly ash is added at varying percentages. The optimum fly ash replacement to produce long-term strength is 30%. The combination of GGBFS and fly ash can enhance compressive strength and considerably increase the toughness of concrete. Maximum compressive strength is obtained by the combination of GGBFS and fly ash by 10% replacement of cement[5]. The addition of steel fiber improved flexural strength, toughness, tensile strength and, ductility. The tensile strength was improved with increasing fiber volume ratio from 0 to 5%. The optimum percentage of steel fiber is fixed as 2-2.5%[6]. The increased amount of fiber improved the interaction of fibers during mixing, caused balling and, decreased the workability of the mixture. Typical water/cement ratio for UHPC is in the range 0.14 - 0.2. A lower water/cement ratio reduces voids between particles and thus packing density can be increased. Maximum compressive strength is obtained when the water/cement ratio is 0.16. Polycarboxylate ether (PCs) was the most efficient superplasticizer. It was studied that optimum PC dosages for UHPC are in the range of 0.5-2%.[7]. Nanoparticles, including nano-silica (nano-SiO2), nano-CaCO3, nano-titanium oxide (Nano-TiO2), and nano-iron (Nano-Fe2O3), nano-Zirconia, etc., have been added to UHPC. They have a large surface area to volume ratio compared with other materials of concrete. Meantime, they can act as nuclei for cement phases, further progressing cement hydration due to their high reactivity. It acts as nano-reinforcement and/or as filler, densifying the microstructure and the ITZ, thereby, leading to a decreased porosity. The optimum nano-silica for obtaining maximum compressive strength is 3%.[8].

4. OPTIMIZING PACKING DENSITY BY PUNTKE TEST

The concept of particle packing is the main element in the mixture proportioning of concrete. Particle packing involves the determination of appropriate sizes and proportions of particulate materials to get the proper combination of optimal packing. The basic principle of Puntke test is that the water added to the dry materials fills the voids in between the particles and acts as a lubricant to make the materials compact effectively. The water, which is in excess after filling the voids, appears at the surface of the mixture, representing the saturation limits. Puntke test comprises the selection of binder proportion by volume.

The mass equivalent to 20 cm^3 of the cementitious materials was placed in a beaker. The materials were mixed thoroughly for homogenization before water was added. De-ionized water was added gradually, mixing the mixture with a stirrer until it attained a closed structure after repeated tapping of the beaker. In the next step, water is added drop by drop to the mix using a pipette. This process is continued until the saturation point is reached. At this point, the surface smoothens itself after repeated tapping of the beaker and appears glossy[9].

From the volume of water used, the packing density Θ_p was found out by using:

$$\Theta_p = 1- (V_w/(V_s+ V_w))$$

where V_w = volume of water (cm3); V_s = volume of solid particles

5.SAMPLE PREPARATION

The four-stage mixing method in Figure 2 has shown superior flow and strength properties. It is because of the improved interface bonding between cement with the aggregate and the healthy development of hydrated products. UHPC prepared with 15 minutes mixing duration has shown improved flow and strength characteristics. This may be due to the development of dense microstructure and the formation of strong ITZ between cement paste and fine aggregate. It has improved interface bonding and the healthy development of hydrated products.

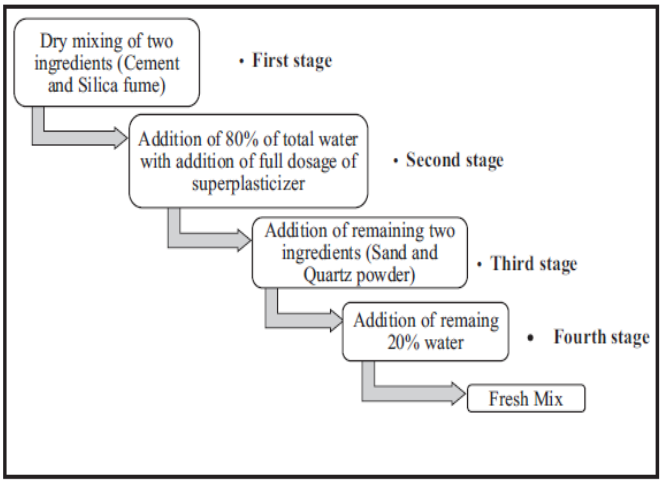

Fig -2: Four-stage mixing method

6. CURING REGIME

Standard room temperature curing, heat curing under atmospheric pressure, and autoclave curing regimes are the different methods used for the production of UHPC. The major principle of UHPC production is the enhancement of microstructure to be dense by applying pressure with different heat treatments during concrete curing. So the benefits from the incorporation of silica fume to UHPC will be obtained only after applying curing regimes to the mixture. Moreover, it was seen that standard curing is not satisfactory for concrete generally and UHPC specially as the rate of strength gain and hardening process will be very slow. The most convenient temperature for RPC curing by hot dry air may reach up to 250 °C, while exposure to temperature more than 250 °C may cause a reduction in the compressive strength. This may also create serious microstructure deterioration due to the existence of both large numbers of pores and cracks in the surface of the specimen. The advantages of thermal curing are, It provides a dense microstructure and a high mechanical performance to UHPC by rising the ability of fresh RPC at early ages to complete the reaction between SF and portlantide that quickens the pozzolanic reaction and therefore a new crystallized hydrates C-S-H is formed. This will enhance the micro aggregate reactivity causing an increase in the inclusion matrix adhesion. This process is very vital due to the existence of a high dosage of cementitious materials which will remain un-hydrated. Due to the low w/c ratio and hence the pozzolanic reaction between the SF and the portlantide will also remain not completed. As for Quartz powder, heat treatment facilitates to produce secondary hydrates by the pozzolanic reaction. So crushed quartz powder acts as pozzolanic material only at a high temperature of more than 90 °C. Heat treatment alters the chemical composition of hydrated grains. This can reduce the ratio of calcium oxide to silicon dioxide. Also, it decreases the ratio of water to calcium oxide. All these reactions lead to the development of the C-S-H family which are (1) Tobermorite (2) Secondary Xonotlite (3) Xonotlite. Autoclave curing improves density and decreases porosity. However, there is an exact time for both pressure and temperature, beyond these critical times a negative effect on both mechanical performance and microstructure of RPC is observed. Applying pre-setting pressure for 6–12 h will reduce the pores resulted from autogenous shrinkage but will increase the capillary pore volume due to the movement of grains. These spaces will permit the formation of additional C-S-H in the hydration process and hence the pozzolanic reaction.[10]

7. CONCLUSIONS

- The main principles for the production of UHPC design are reduction in porosity, enhancement in microstructure, improvement in homogeneity, and increase in toughness. Raw materials, preparation techniques, and curing regimes have a significant influence on the properties of UHPC.
- The use of commonly available supplementary cementitious materials, such as fly ash and slag for partial replacement of cement and silica fume, could significantly decrease the materials cost of UHPC. At the same time, UHPC with the proper amount of those supplementary cementitious materials could achieve a compressive strength of 150– 200 MPa after a normal curing regime.
- Addition dosages and procedures of polycarboxylates (PCEs) have an important influence on the performance of fresh and harden UHPC.
- Optimized packing density is determined by puntke test.
- Four stage mixing method has shown better strength and flow properties.
- High-temperature curing is adavantageous to the pozzolanic reactions between CH from the hydration of cement and supplementary cementitious materials such as silica fume, which improves the microstructure and hence results in higher strength. It also increases the chain length of C–S–H.

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