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Review

A review on ultra high performance concrete: Part II. Hydration, microstructure and properties

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HIGHLIGHTS

- The hydration process of binders in UHPC is similar to that in ordinary concrete.
- UHPC has a very low porosity.
- The mechanical properties of UHPC are much better than that of ordinary concrete.
- UHPC has a character of superior durability.

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ABSTRACT

Ultra high performance (UHPC) is a new cement based material, and it has aroused interest around the world since it was introduced in the early 1990s. Part I reviewed the theoretical principles, raw materials selection, mixture design and preparation techniques for UHPC. This part II reviewed the hydration, microstructure, mechanical properties, dimensional stability and durability of UHPC. Finally, some needs for future studies of UHPC are suggested. The portlandite of UHPC is much lower than that in the normal concrete. Heat curing could promote secondary hydration between mineral admixtures and $Ca(OH)_2$, and xonolite was formed when the temperature was over 250 °C. UHPC has a very low porosity, especially under heat curing. UHPC has a character of high strength, stiffness and superior durability, etc.

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1. Introduction

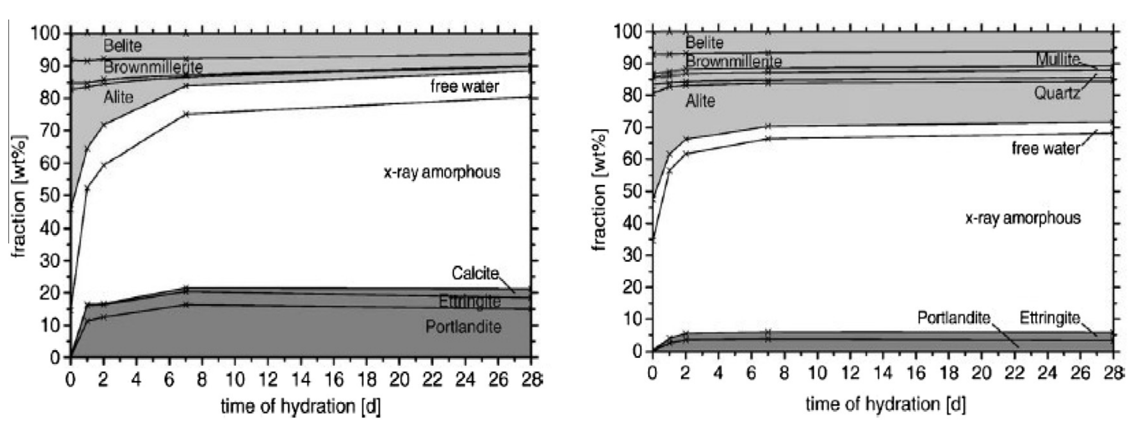
Ultra high performance concrete (UHPC) could show compressive strength from 150 to 810 MPa [1], approximately 3–16 times as that of conventional concrete. With incorporation of steel fiber, the ductility and energy absorption of UHPC is typical 300 times greater than that of high performance concrete (HPC). UHPC is nearly impermeable to carbon dioxide, chlorides and sulfates. Its superior durability leads to long service life with reduced maintenance. The enhanced abrasion resistance provides extended life for bridge decks and industrial floors, while the enhanced corrosion resistance provides protection to areas with bad or harsh climate conditions [2]. A significant amount of unhydrated cement in the finished product provides a self-healing potential under cracking conditions. Due to ultra high compressive strength, UHPC structures weigh only one-third or one-half of the corresponding conventional concrete structures under the same load. This weight reduction has benefit in producing more slender structures, increasing usable floor space in high-rise buildings and reducing overall costs. Elimination of steel reinforcement bars reduces labor costs and provides greater architectural freedom, allowing nearly limitless structural member shapes and forms for architects and designers [2]. Though UHPC possesses many outstanding properties, they have certain weaknesses. High binder content of about 800–1000 kg/m^3 affects not only the production costs, but also high heat of hydration, causing shrinkage problems [3]. UHPC is generally costly and cannot replace the conventional concrete in most applications where the conventional mixtures can economically meet the performance criteria.

Many researchers have conducted studies on UHPC, but information on materials and structural property of UHPC is still limited. Heat curing makes UHPC mainly suitable for precast elements other than ready-mix concrete. Moreover, the high cost of UHPC restricts its applications. This review includes two parts; the first part reviewed the theoretical principles, raw materials selection, mixture design and preparation techniques for UHPC. This second part reviews the hydration process, microstructure and properties of UHPC. The purpose of this review is to summarize previous progress and to suggest some needs for future researches.

2. Hydration

The hydration of cementitious materials in UHPC is similar to that in ordinary concrete (OC). First, Portland cement hydrates to form calcium silicate hydrate and calcium hydroxide, then mineral admixtures (such as silica fume) react with calcium hydroxide to form calcium silicate hydrate (C–S–H). Fig. 1 shows the time dependent phase development in OC and UHPC at room temperature [4]. It can be seen that the content of crystalline phases was considerably higher in OC, whereas less amorphous phases in the UHPC were measured. The difference arises from the pozzolanic reactions associated with the relatively high amounts of silica fume and fly ash. The consumption of portlandite becomes remarkable after the second hydration day, and is much lower than that in normal concrete after 28 days, which indicates pozzolanic reactions are still incomplete. The fact that no calcite was detected by X-rays in UHPC even after 28 days may be interpreted as indication of no considerable phase carbonation in this specimen. The variations of ettringite content development between the first and second hydration day indicate that some conversion of ettringite to monosulfate phase is possible, and that significant amount of aluminate may enter the X-ray amorphous C–S–H phases [4].

The increase of curing temperature accelerates the hydration of cement and promotes secondary hydration between mineral admixtures and $Ca(OH)_2$ [5]. Hydration products at 90 °C remain amorphous. Under the autoclave curing, the hydration of C_3S and C_2S leads to the formation of crystalline α-dicalcium silicate hydrate in the absence of an external SiO_2 source. Tricalcium aluminate (C_3A) and tetracalcium alumino-ferrite (C_4AF) yield a hydrogarnet phase. The bonding characteristics of these two phases are rather unfavorable. In the presence of finely ground quartz and/or other SiO_2 sources, a pozzolanic reaction takes place, yielding crystalline 1.1 nm tobermorite ($C_5S_5H_5$) as the main



(a) OC (b) UHPC

Fig. 1. Time dependent phase development in OC and UHPC [4].