

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 General

The development of Ultra High Performance Concrete modified with nanoparticles relies on similar principles as Reactive Powder Concretes (RPC). It aims at modification of the nanostructure with the employment of nanoparticles (nanopowders). The production of RPC in general is based on the formulation of high density systems with compatible and well graded components. The various pozzolanic components employed in these formulations play an essential role. The finest pozzolanic component which is available and is being used as the principal constituent in various RPC/UHPC systems in combination with superplasticizers is microsilica (silica fume, SF), with grain sizes that have their lower size limit at around  $0.1\mu\text{m}$  -  $100\mu\text{m}$ . Hence, the need for extending granulometry to nanoscale through targeted use of nanoparticles becomes obvious. A better packing could be realized by extending the size range below this limit using nanoparticles (nanopowders) which have specified particle sizes covering the nanometer range from 1-100nm<sup>[16]</sup>.

These characteristics make pyrogene oxides ideal pozzolans for developing multiscale Ultra High Performance Concrete. Multiscale means here that the granulometry of the components is chosen to span over the whole scales from millimeters down to nanometer. The magnitude and average particle size of each component is chosen to decrease progressively and to serve the principle of filling the voids (gaps) left by the packing of larger size powders down to the nanometer scale<sup>[17]</sup>. The filling effect realized by the well dispersed nanoparticles has a double physico-chemical nature; the nanoparticles do not only fill in

the voids left by the larger size particles, but by being highly reactive they react with the calcium hydroxide and additionally act as nucleation sites for the production of very fine calcium-silicate-hydrate (C-S-H) phase and nucleate their further growth <sup>[18]</sup>.

## 2.2 Mechanism of Nanosilica

The amorphous or glassy Silica, which is the major component of a pozzolan, react with calcium hydroxide formed from calcium silicate hydration. The rate of the pozzolanic reaction is proportional to the amount of surface area available for reaction. Therefore, it is possible to add nano-Silica particles (NS) to make high performance concrete.

In concrete, the micro-silica (silica fume Sf and silica fume SF) works on two levels. The first one is the chemical effect: the pozzolanic reaction of silica with calcium hydroxide forms more CSH-gel at final stages. The second function is a physical one, because micro-silica is about 100 times smaller than cement <sup>[19]</sup>. Micro-silica can fill the remaining voids in the young and partially hydrated cement paste, increasing its final density <sup>[20]</sup>.

Nanosilica addition in cement paste and concrete can result in different effects. The main mechanism of this working principle is related to the high surface area of NS, because it works as nucleation site for the precipitation of CSH gel. However, according to Bjornstrom et al. <sup>[21]</sup>, it has not yet been determined whether the more rapid hydration of cement in the presence of NS is due to its chemical reactivity upon dissolution (pozzolanic activity) or to their considerable surface activity.

## 2.3 Effect of Nanosilica (NS) on the Properties of Concrete

Collepari et al.(2004) <sup>[22]</sup> investigated the Ultra-fine amorphous colloidal silica which was found to be much more efficient than micron

sized silica for improving the performance of concrete such as permeability, and subsequently, durability. In addition, reduced amount of about 15 to 20 kg/m<sup>3</sup> of nano-silica was found to provide the same strength as 60 kg/m<sup>3</sup> of regular or micro silica.

Li, et al.,(2004)<sup>[23]</sup> studied the compressive strengths of mortars with nanosilica (NS) were all higher than those of mortars containing silica fume at 7 and 28 days. An addition of 10% nano-SiO<sub>2</sub> with dispersing agents resulted in a 26% increase of 28- day compressive strength, whereas the increase was 10% with 15% silica fume without dispersing agents.

Ji, (2005)<sup>[24]</sup> studied the effect of NS addition on concrete water permeability and microstructure. Different concrete mixes were evaluated incorporating NS particles of 10 to 20 nm (surface area 160 m<sup>2</sup>/g), fly ash, gravel and plasticizer to obtain the same slump time as for normal concrete and NS concrete. The test results showed that NS can improve the microstructure and reduce the water permeability of hardened concrete.

Green (2006)<sup>[25]</sup> investigated the development of a high-strength, high-density cementitious grout mixture. This portland cement-based grout incorporated nano-silica in the form of an ultra-fine amorphous colloidal silica admixture along with hematite fine aggregate, silica fine aggregate, silica fume, water, and other chemical admixtures to match as closely as possible the given in-situ high-strength rock properties. The grout was then placed in the field with over 200 individual batches to fill the annular space surrounding instrumentation packages previously placed in drilled boreholes. The resultant mechanical properties of the field-placed rock-matching grout (RMG) included unconfined compressive

strengths of 91.2 MPa, hardened densities of 2680 kg/m<sup>3</sup>, and ultrasonic pulse velocities of 4.40 km/sec.

Sobolev et al. (2006) <sup>[26]</sup> carried out an investigation on nano materials and nanotechnology for high-performance cement composites they found that the major problem of nano-SiO<sub>2</sub> application is strength loss at later ages due to the agglomeration of nano particles (30-100 nm) at the final drying stage of sol-gel. A problem which was solved using acrylic polymer based super plasticizer called Gaia at a dosage of 1.3% by weight of cementitious materials. They also found that high-temperature treatment at (400°C or more) of nano-SiO<sub>2</sub> concrete affects the performance of these additives and must be avoided.

Flores et al. (2006) <sup>[27]</sup> examined the workability and mechanical properties of high-performance superplasticized mortars with nano-SiO<sub>2</sub>. Experimental results demonstrated an increase in compressive strength of mortars containing nano-particles. It was found that at constant W/C, the application of nano-SiO<sub>2</sub> admixture resulted in an increase of 15-20% in the compressive strength. Mortars with compressive strength of up to 144.8MPa were obtained by using this approach.

An investigation was carried out by Jo et al. (2007)<sup>[28]</sup> to study the characteristics of cement mortar with nano-SiO<sub>2</sub> particles. Five different water/cementitious ratios were used, namely 0.23, 0.25, 0.32, 0.35, and 0.48 with four contents of NS (3, 6, 9, and 12%) by weight of cement. The compressive strengths of cement mortar with the addition of silica fume were also evaluated at w/c of 0.35 and compared with mortars containing nano-silica particles and three contents of silica fume which were 5, 10, and 15% by weight of cement. The results showed that the values of compressive strength of mortars with NS were all higher than those of mortars containing silica fume at 7 and 28 days.

Qing et al (2007)<sup>[29]</sup> investigated the influence of nanosilica (NS) on properties of hardened cement paste (hcp) as compared with silica fume (SF). The study comprised measurement of compressive and bond strengths of hcp, and by X-Ray diffraction (XRD) and Scanning Electron Microscopy (SEM) analysis. Different results were obtained showing the influence of NS and SF on consistency and setting time of fresh cement paste. NS made cement paste thicker and accelerated the cement hydration process. Compressive strengths of hcp and bond strengths of paste-aggregate interface incorporating NS were obviously higher than those incorporating SF, especially at early ages. And with increase the NS content, the rate of bond strength increase was more than that of compressive strength increase. With 3% NS added, NS digested calcium hydroxide (CH) crystals, decreased the orientation of CH crystals, reduced the crystal size of CH gathered at the interface and improved the interface more effectively than SF. The results suggested that with a small amount of added NS, the CH crystals at the interface between hcp and aggregate at early ages may be effectively absorbed in high performance concrete (HPC).

Remzi and Meral O. (2008)<sup>[30]</sup> studied the effect of nano powders on cement paste, mortar and concrete and found that the use of nano powders in concrete technology affects the cement kinetics and accelerates hydration significantly due to larger surface area, stronger electrostatic forces of nano powders, and the improvement in the microstructures of concrete having nano powders.

Lin et al. (2008)<sup>[31]</sup> demonstrated the effect of NS addition on permeability of eco-concrete. It was shown with a mercury porosity test that the relative permeability and pores sizes decreased with the addition of 1 and 2% NS by weight of cement.

Roddy et al. (2008) <sup>[32]</sup> applied particulate NS in oil well cementing slurries in two specific ranges of particles sizes, one between 5 to 50 nm, and a second between 5 to 30 nm. Also they used NS dry powders in encapsulated form and concentrations of 5 to 15% by weight of cement. The respective test results for the slurries demonstrated that the inclusion of NS reduced the setting time and increased the compressive and tensile strengths, Young's modulus and Poisson's ratio.

In study carried out by Sobolev et al., (2009)<sup>[33]</sup> it was shown that the addition of small amounts of NS (i.e., 0.25%) caused 10% increase in compressive strength and 25% increase in flexural strength at 28 days. Nanofume, a new ultrafine, powder admixture of amorphous SiO<sub>2</sub> produced from fly ash, was used to prepare high-strength concrete based on ordinary portland cement. Compressive strength of the concrete increased with increasing specific surface area of nanofume (20 m<sup>2</sup>/g to 130 m<sup>2</sup>/g). Nanofume with a specific surface area between 30 m<sup>2</sup>/g and 50 m<sup>2</sup>/g was recommended for the preparation of a concrete with compressive strength of 120 MPa.

Abbas (2009) <sup>[34]</sup> carried out an investigation on the influence of Nano-Silica addition on properties of conventional and ultra-high performance concretes. He found that nano-Silica (NS) concretes requires additional amount of water, since each kilogram of NS added required 0.4 kg of water to maintain the same workability. Also nano-silica addition resulted in significant early increase in compressive, splitting and flexural strengths of concrete in case of high cement content.

Khanzadi et al. (2010) <sup>[35]</sup> studied the influence of nano silica particles on the mechanical properties and durability of concrete, by measurement of compressive and tensile strength, water absorption, and the depth of chloride penetration. Cubic tests of 100 millimeters for

compressive strength tests 100×200 millimeters cylinders for tensile splitting strength tests were used, at 7, 28 and 91 days. The results showed that, when small amounts of nano particles were added, both the compressive and splitting strengths of concrete were enhanced. This enhancement occurred as a result of increasing the bond strength of cement paste-aggregate interface by means of the filling effect of nano silica particles.

The nano-silica used in this research was of water soluble type with 15% suspension produced by Sweden with the following specifications; diameter of particles =5nm, density =1.1g/cm<sup>3</sup>, purity percentage=99.9. The experimental results showed that the mechanical properties and durability of the concrete mixed with the nano particles were better than that of a plain concrete. Also the scanning electron microscopy ( SEM) study of the microstructures showed that the nano particles filled the cement paste pores and, by reacting with calcium hydroxide crystals from calcium silicate hydration, decreased the size and amount of these crystals. Therefore the results indicate that nano scale silica behaves not only as a filler to improve microstructure, but also as an activator to promote pozzolanic reaction.

Boshehrian and Hosseini(2011)<sup>[36]</sup> studied the mechanical properties ( by compressive and flexural strength tests), durability (by water absorption test), and microstructural properties of interfacial transition zone (ITZ) (by Scanning Electron Microscopy and Atomic Force Microscopy tests) of mortars applicable for the casting of ferrocement elements reinforced with nano-SiO<sub>2</sub> particles. The colloidal nano-SiO<sub>2</sub> (with solid content of 30%) was used in addition to water reducer superplasticizer (naphthalene-type with a solid content of 40%). Two series of mixtures with different sand to cementitious materials

(S/CM) ratio of 2 and 2.5 were considered. Each series had three water to cementitious materials (W/CM) ratios (0.35, 0.4 and 0.5). The compressive strengths of all mixtures increased with addition in nano-particles content. This trend continued with increase in silica nano-particles content up to 3% replacement.

Querciam et al (2012) <sup>[37]</sup> studied two different types of nanosilica applied in self compacting concrete (SCC), both having similar particle size distribution but produced in two different processes (fumed powder silica and precipitated silica in colloidal suspension). The influence of the nano-silica on the SCC was investigated with respect to the properties of concrete in the fresh state (workability) and in the hardened state (mechanical properties and durability). The results showed that the compressive and tensile splitting strengths of SCC were improved by the addition of both types of nano-silica. The highest compressive strength was found for the colloidal nano-silica SCC, while the highest splitting tensile strength was found for the powder type nano-silica SCC.

Jalal et al (2012) <sup>[38]</sup> studied the effects of silica nanopowder and silica fume on rheology and strength of high strength self compacting concrete, they tested 12 concrete mixtures designed with a constant water/binder (w/b) ratio of 0.38 and total binder content of 400, 450 and 500 kg/m<sup>3</sup>. Concrete samples were prepared with 10% and 2% (by weight) replacement of Portland cement by Silica Fume and Nano Silica respectively. The result revealed that replacement by 2% NS in binary mixtures increased the compressive strength for binder content of 400, 450 and 500 by 22%, 38% and 43%, 21%, 55% and 61%, 22%, 56% and 62% at 7, 28 and 90 days respectively. Generally in binary mixtures, the compressive strength improvement was higher in the mixtures containing 2% NS and the highest in ternary mixtures. Regarding splitting tensile

strength, replacement by 10% SF and 2% NS in ternary mixtures increased the splitting tensile strength for binder content of 400, 450 and 500 by 17%, 33% and 25%, 40%, 8% and 11%, 27%, 2% and 11% at 7, 28 and 90 days respectively. In the same mixtures, binder content increase was found to lead to average increase of splitting tensile strength by about 4%. In general flexural strength results compared to control specimens, replacement by 10% SF + 2% NS mixtures increased the flexural strength for binder content of 400, 450 and 500 by 23.5%, 18.4% and 20%, 58.9%, 54% and 52%, 47%, 50% and 52% at 7, 28 and 90 days respectively.

Park & Lee (2012)<sup>[39]</sup> studied the effects of nanosilica and silica fume content on the bond properties of macro-synthetic fiber in cement – based composites. The pullout behavior of macro-synthetic fiber was evaluated by performing dog-bone tests according to Japan Concrete Institute (JCI) at nanosilica and silica fume replacement ratios of 0% ,2%, 4%, 6% and 8% based on cement weight . The addition of nanosilica and silica fume had a significant effect on the bond properties of macro-synthetic fiber. Specifically, the addition of 0-2% nanosilica enhanced pullout behavior, bond strength and interface toughness , whereas 4% or more nanosilica reduced pullout behavior ,bond strength and interface toughness. For silica fume , pullout load-to-displacement behavior ,bond strength and interface toughness increased in the range of 0 to 8%. These results demonstrate that the presence of nanosilica and silica fume strengthen the fiber –matrix interface of macro-synthetic fiber in cement – based composites by filling voids in the interface region . The relative bond strength and interface toughness were also analysed, except for compressive strength , to evaluate the bond properties of macro-synthetic fiber in cement –based composites at various nanosilica and silica fume replacement ratios. The ratios of nanosilica and silica fume had a significant effect on bond properties, regardless of the compressive

---

strength of the cement –based composites .Microstructural analysis of macro-synthetic fiber after pullout tests showed scratches due to friction.

Beigi et al.,(2013)<sup>[40]</sup> studied the combined effects of fibers and nanosilica on the mechanical properties (compressive, splitting tensile, flexural strength, toughness , modulus of elasticity), rheological properties (L-Box, slump flow, T50) and durability (resist once to chloride ion penetration (RCPT) and water absorption) of self compacting concrete. In addition, microstructural properties of concrete were assessed using Atomic Force Microscopy (AFM) and X-Ray Diffraction (XRD) techniques. Totally, 40 concrete mixes , labeled as A, B, C and D, with nanosilica contents of 0, 2, 4 and 6 weight percent (wt.%) of cement, respectively and three types of reinforcing fibers (steel: 0.2, 0.3 and 0.5 volume percent (v%) and polypropylene: 0.1, 0.15 and 0.2 v% and glass: 0.15, 0.2 and 0.3 v%) were evaluated. The results of the study showed that the presence of both nanosilica and reinforcing fibers in optimal percentages, can improve the mechanical properties and durability of self-compacting concrete significantly. Mechanical properties such as compressive, flexural and tensile strengths initially increased by the increase of nanosilica content up to 4 wt.% and then decreased, In this experimental research, concretes with different fibers showed different mechanical properties. In case of metal fiber-reinforced concrete, increasing the fiber up to 3 v%, initially increased compressive strength to reach a peak value and then decreased, while flexural and tensile splitting strengths followed a relatively linear increase throughout the ascending load behavior .

Hashemi and Mirzaei (2014)<sup>[41]</sup> studied the parameters affecting the compressive strength, such as water to cement ratio, cement grade, nanosilica to cement percentage, and the various ratios of lightweight expanded clay aggregate( LECA) to total aggregate. Taguchi method was

used to examine optimization of the obtained 9 mix designs. Since lightweight concrete is brittle like normal concrete, to resolve this problem polypropylene fibers by 0.56% and 1% ratios of concrete volume was used. Moreover, to improve the mechanical properties and to study the effect of nano-silica in lightweight concrete and its effect on the adhesion between concrete and reinforcement in the mixes containing fibers, 1.5% and 3% nano-silica was added. Finally, the test result of specimens at ages 28 and 90 days resulted in the best mix to get highest bond strength between lightweight concrete and reinforcement, and it was found that adding fibers and nano-silica have great effect to improve the bond strength between lightweight concrete and reinforcement. Adding polypropylene fibers by 1% of concrete volumes increased 70% bond strength of concrete and the reinforcement. While adding nano-silica and polypropylene fibers simultaneously can make an increase up to 90% in bond strength of light weight concrete and reinforcement. For getting the maximum bond strength between reinforcement and lightweight concrete containing Leca aggregate, the best ratio is 1.5% cement replacement by weight with nano-silica and adding polypropylene fibers up to the 1% of concrete volume.

## **2.4 Shear Strength in RPC Beams**

Voo et al. (2002)<sup>[42]</sup> studied the behavior of RPC deep beams. Three specimens were tested to investigate the influence of steel fiber reinforcement on the strength of RPC deep beams. Comparison of the crack patterns for the specimens showed that the quantity of fibers in concrete mixture did not significantly affect the cracking load but did have an influence on the rate of crack growth and on crack widths.

Graybeal and Hartman (2002)<sup>[43]</sup> tested four prestressed RPC beams, one flexural test and three shear tests. They considered the

structural behavior of AASHTO Type II prestressed girder fabricated with RPC and without positive reinforcement. One flexural test was a 0.91 m deep girder with a span of 23.9 m. The girder carried a peak applied moment of 4400 kN-m that sustained a deflection of over 0.46 m prior to failure. While the shear tests girders did not contain any mild reinforcing steel, all shear forces were carried by the concrete and fiber matrix. The testing showed that an AASHTO Type II composed of RPC can carry between 1690 and 2200 kN of shear force.

Voo et al. ,( 2006)<sup>[44]</sup> investigated the shear strength of fiber reinforced RPC prestressed girders without stirrups. Seven 650 mm deep large –scale RPC I-section girders failing in shear have been tested. The girders were cast using (150-170) MPa strong steel fiber RPC that were designed to assess the capacity to carry shear stresses in thin webbed prestressed beams without shear reinforcement. The tests showed that the quantity and type of fibers in the concrete mix did not significantly affect the initial shear cracking load. However, the increase in the volume of fibers leads to an increase in the failure load.

Kirillos (2012)<sup>[45]</sup> investigated the mechanical and structural properties of UHPFRC. The mechanical properties focused on examining the tensile behavior by testing the fracture energy, tension stiffening and shear friction properties of UHPFRC. The structural properties focused on investigating behaviors such as; flexure and shear. The tensile behavior proved to be significantly improved by the use of fibers. A total of five beams (cross section 178x305mm<sup>2</sup>, span 1830mm) were cast to investigate the flexure and shear behaviour of UHPFRC. All beams were tested under a four-point loading symmetrical system. Five Strain gauges were affixed to the reinforcing bars, at L/6 spacing, to monitor the strain due to the applied load at various locations. In the case of the control beam with no reinforcement bars, SB1, a fiber optic strain gauge was used to monitor

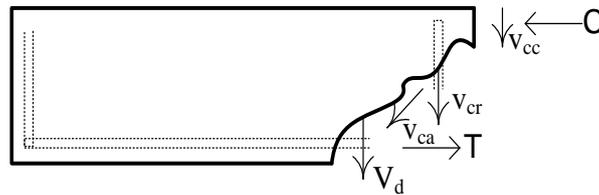
the strain variation. In addition, three LPDTs gauge were mounted to measure the deflection of the beam at a spacing of  $L/4$ . The beams were designed to investigate the influence of reinforcement ratio,  $\rho_w$ , (0, 1.25%, 2.5%) and the shear span ratio ( $a/d$ ) (2.3, 4.6) on the structural response of the reinforced UHPFRC beams. The results showed significantly improved shear and flexure behavior of reinforced beams. The influence of the fiber reinforcement was very significant; promoting flexural failure in reinforced beams rather than the shear failure when compared to normal and high strength concrete.

Omar,(2013)<sup>[46]</sup> studied using three types of concrete, namely; Normal Strength Concrete (NSC) of ( $f'_c = 42$  MPa), High Strength Concrete (HSC) of ( $f'_c = 63.75$  MPa) and Ultra High Performance Concrete (UHPC) of ( $f'_c = 134.5$  MPa).The experimental program included casting and testing fifteen reinforced concrete deep beams without web reinforcement (stirrups), nine specimens of (UHPC), three specimens of (HSC) and three specimens of (NSC). (the shear strength and behavior of deep beams under two point loading). The variables considered were; the compressive strength of concrete (42, 63.75 and 134.5 MPa), the shear span to depth ratio ( $a/d$ ) (1, 1.5 and 2) and over all depth of the beam ( $h$ ) (180, 240 and 300 mm), while the width of all beams was (120 mm). The experimental results showed that both the compressive strength of concrete and the shear span to depth ratio ( $a/d$ ) have significant effects on the failure load, while the increase in overall depth of the beam from (180 to 240) mm reduces the nominal shear stress significantly, but beyond which no obvious size effect was noticed.

## 2.5 Shear Failure Mechanisms in RC Beams

Shear failure of RC beams is mainly caused by the formation of diagonal tension cracks within the web of the beam, which can become

unstable and fail <sup>[47]</sup>. In order to resist the shear stresses produced by the applied loads, the beam web develops several shear transfer mechanisms as shown in Fig. 2.1: (a) shear resistance developed by the uncracked concrete in the compression zone ( $V_{cc}$ ); (b) interface shear transfer by aggregate interlocking in the cracked concrete ( $V_{ca}$ ); (c) dowel action of the longitudinal reinforcement ( $V_d$ ); and (d) residual tensile stresses across the cracks ( $V_{cr}$ ). The shear resistance provided by the uncracked concrete depends on the depth of the intact- concrete. The interfacial shear transfer by the aggregates decreases with decrease in the aggregate size and increase in crack width. The resistance provided by the dowel action is dependent on the ratio of the longitudinal reinforcement ( $\rho$ ) and the concrete cover ( $c$ ).

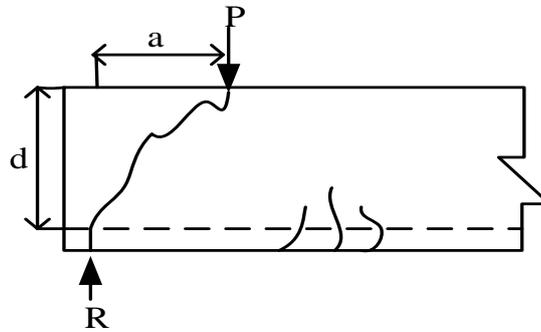


**Fig. 2.1: Shear Force Transfer Mechanism** <sup>[47]</sup>

Thus the shear failure mechanism of a RC beam depends mainly on the compressive strength of the concrete ( $f'_c$ ), effective depth of the beam ( $d$ ), maximum aggregate size ( $d_a$ ), and shear span to depth ratio ( $a/d$ ). The behavior of beams failing in shear can be studied with respect to the different shear span to depth ratio. Three different cases can be considered <sup>[47]</sup>:

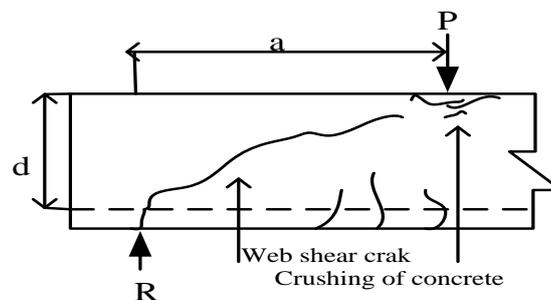
(a) Short shear span beams, which have  $a/d$  smaller than or equal to 2.5. Beams having very short shear spans, i.e.,  $a/d$  less than one, are generally referred to as deep beams. Such beams develop inclined cracks joining the load and support as shown in Fig. 2.2. Thus, the beam develops an arch

action, thereby destroying the horizontal shear flow from the longitudinal steel to the compression zone. The reinforcement behaves as a tension tie in a tied arch. Such beams fail by anchorage failure at the ends of the tension tie.



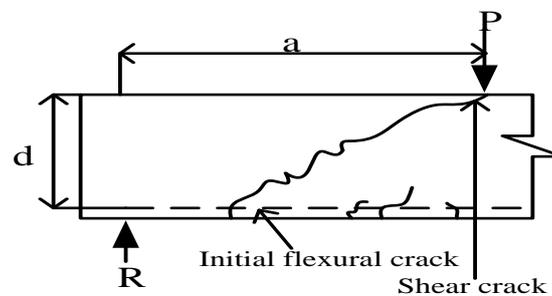
**Fig. 2.2: Concrete Compression Diagonal Crushing**

Short shear span beams with  $a/d$  between 1 and 2.5 initially develop small flexural cracks on the tension face of the beam. However, these cracks are intersected by the longitudinal reinforcement and do not progress further. The beams also develop an inclined crack referred to as web shear crack, which propagates towards the neutral axis. Simultaneously, crushing of concrete occurs in the top compression fibers along with redistribution of loads. This causes a reduction in the progression rate of the shear crack. However, sudden failure occurs when the principal inclined shear crack reaches the crushed concrete zone as shown in Fig. 2.3. This type of failure is referred to as shear compression failure.



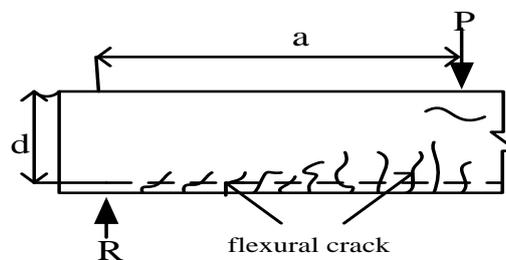
**Fig. 2.3: Shear Compression Failure in Beams with  $1 < a/d < 2.5$**

(b) Slender beams, which have shear spans with  $a/d$  contained between 2.5 and 6. These beams initially develop flexural cracks, which are more or less vertical into the beam. These cracks cause stress concentration near the head of the cracks owing to the altered state of stress in the beam. Upon increase of load, the flexural cracks extend to become shear cracks. This diagonal shear crack encounters resistance as it propagates up into the compression zone. With further increase in load the crack extends gradually at a flatter slope until sudden failure occurs. This type of failure is known as diagonal tension failure as shown in Fig. 2.4.



**Figure 2.4: Diagonal Tension Failure in Beams with  $2.5 \leq a/d \leq 6$**

(c) Beams with very slender shear spans (i.e.,  $a/d$  greater than 6), which fail in flexure before the formation of the diagonal tension cracks as shown in Fig. 2.5. The failure is initiated by the yielding of the tension reinforcement, eventually resulting in concrete crushing at the section with maximum bending moment or rupture of the longitudinal steel reinforcement in tension.



**Fig. 2.5: Flexural Failure in Beams with  $a/d > 6$**

## 2.6 Effect of Principal Parameters on Shear Strength of Fibrous Beams

Elzanaty et al. (1986)<sup>[48]</sup> conducted numerous researches on the shear capacity of reinforced concrete beams using high strength concrete. The research was focused on parameters affecting shear strength such as; concrete compressive strength  $f'_c$ ,  $a/d$  ratio and longitudinal steel ratio  $\rho_w$ . He concluded that the shear strength of beams without stirrups increased with the increase of concrete strength. However, the ratio of the test to the predicted shear strength decreased with the increase of concrete strength.

Narayanan and Darwish (1987)<sup>[49]</sup> studied the behavior of steel fiber reinforced concrete beams subjected to predominant shear. The results of some 49 shear tests carried out on simply supported rectangular beams under symmetrically placed concentrated loads were presented and analyzed; of these, 10 beams contained conventional stirrups and 33 were reinforced with crimped steel fibers as web reinforcement. The parameters varied were the volume fraction  $V_f$  of the fibers, fiber aspect ratio  $L/D$ , concrete strength  $f_{cu}$ , amount of longitudinal reinforcement  $\{\rho_w\}$ , and the shear span/effective depth ratio  $a/d$ . The test results showed that the first crack shear strength increased significantly due to the crack-arresting mechanism of the fibers; the improvements in ultimate shear strength were of the same order as that obtained from conventional stirrups even for a fiber volume fraction of 1 percent. Any further increase in fiber contents did not result in corresponding improvements in the shear strengths. Based on these tests and on tests by previous investigators, predictive equations were suggested for evaluating the cracking shear strength and ultimate shear strength of fiber reinforced concrete beams. The comparisons between computed values and the experimentally observed values were shown to validate the proposed theoretical treatment.

Ashour, et al.,(1992)<sup>[50]</sup> studied 18 rectangular high-strength fiber reinforced concrete beams subjected to combined flexure and shear. All beams were singly reinforced and without shear reinforcement. The main variables were the steel fiber content, the longitudinal steel ratio, and the shear-span/depth ratio. The concrete matrix compressive strength was about 93 MPa containing only one type of fiber. Two empirical equations are proposed to predict the shear strength of high-strength fiber reinforced concrete beams without shear reinforcement. The proposed equations gave good predictions for the shear strength of the tested beams. Addition of fibers increased the beam stiffness and ductility, depending upon the shear-span/depth ratio and transformed the mode of failure into a more ductile one.

Bunni (1998)<sup>[51]</sup> found that there is a decrease in shear strength of HSFRC beams  $V_f=1.0\%$  when larger (a/d) ratios were used (for example, when a/d ratio was increased from (2.6 to 3.5), the diagonal cracking strength decreases from (120 to 110) kN, i.e. a decrease of 8.33%, and the ultimate shear strength decreases from (156.97 to 138.38) kN, i.e. a decrease of 11.84%.

Al-Sakiny(2002)<sup>[52]</sup> made an investigation to study the engineering properties of ultra high strength fiber reinforced concrete and the effect of steel fibers content on the flexural toughness. The results demonstrated that the concrete reinforced with 2%, 2.5%, and 3% steel fibers by volume showed a significant increase in flexural toughness compared with nonfibrous concrete specimens.

Jatale and Kalrkar (2013)<sup>[53]</sup> tested twenty five high strength fiber reinforced concrete beams with steel fiber-volume fractions (0.5 to 4%), three shear span-depth ratios (2, 3, and 4) .The results demonstrated that flexural strength increased with increasing fiber volume. As the fiber content increased, the failure mode changed from shear to flexure.

### Summary of literature review

- ✓ A lot of research works were carried out for the production of RPC which is an UHPC, but very few studies precisely compared in detail their mechanical properties with RPC. RPC without fibre is very brittle and to make it ductile it is necessary to add fibre. The volume and aspect ratio of fibre to be added should be optimized.
- ✓ Many investigators have established that inclusion of high strength, high elastic modulus steel fibres of short length and small diameter improves the tensile strength and ductility of concrete significantly
- ✓ Being a pozzolanic material, nano silica participates in the pozzolanic reaction consuming CH crystals and producing more high stiffness CSH. This results in stronger concrete with higher chemical resistance
- ✓ Nano particles act as a filler for the voids therefore resulting in reduced concrete porosity .
- ✓ Nano particles act as nucleation sites allowing to form small sized uniform clusters of CSH while favoring the formation of small sized crystals. They promote further hydration, resulting in increased strength
- ✓ With their smaller particle size and greater surface energy, nano silica has higher amount of free and unsaturated bonds resulting in an unstable state of thermodynamics. Coupled up with the increase in the area for chemical reaction, nanosilica shows higher performance in concrete/cement paste when compared with the performance of silica fume
- ✓ Nano particles if well dispersed can increase the viscosity of the fresh cement paste, thus will lead to improved segregation resistance. Nano silica makes the cement paste thicker as well.
- ✓ Compressive and tensile strengths of concrete increase with the addition of nano-silica, especially at early ages. However, the early strength of the concrete decreases slightly with the addition of silica fume, but increases at later ages. These results indicate that the pozzolanic activity of nano-

silica is greater than that of silica fume. So far, no research work has been reported on the effects of nano-silica on the shear strength of RPC beams incorporating steel fibers.

In this study such effects of nanosilica on the structural behavior of RPC beams are considered and the research is focused on the shear strength of such beams. Important parameters are taken into account in preparing the required specimens for carrying out the experimental tests which are believed to play a vital role on the structural performance of these new created type of RPC beams.