CHAPTER ONE

INTRODUCTION

1.1 General

In the last three decades of the previous century great development has been achieved in producing many types of concrete. Steel fiber concrete (SFC) and high strength concrete (HSC) are some of these types. Moreover, high performance concrete (HPC) became not the last one of developing process when the strength is not the only required goal, followed by the ultra high performance concrete (UHPC) or reactive powder concrete (RPC). In the race for strength, two distinct lines of research have emerged. The first is compact granular matrix concretes or what is called densified with small particles (DSP). DSPs contain high superplasticizer and silica fume contents and may also incorporate ultra-hard aggregates, such as steel aggregates. The principle behind DSPs is that the denser the matrix, the greater the resulting compressive strength. The second line of research concerns macro-defect free (MDF) pastes which exhibit very high tensile strength. The combination of these two approaches has led to the production of UHPC which was developed in France in the early 1990s with the possibility to obtain compressive strength up to 800 MPa and tensile strength of up to 100MPa[1].

UHPC contains no coarse aggregate, and the maximum aggregate particle size is 0.3mm. To improve ductility, steel fibers are added. Other components are silica fume, ground quartz, superplasticizer and high amount of Portland cement (up to 1000kg/m^3). The performance of today's UHPC can be further improved by nanotechnological approaches [2]. As an example, a further increase in both resistance to corrosive media, and a strength up to 500 MPa can be expected by adapted production processes[3] combined with incorporating synthetic nanosilica particles with a carefully controlled particle size distribution and – dissolved 1:1 in water, extending the packing optimization to the nanoscale and significantly improving the hydration potential by the fast and complete reaction of the nanoscaled SiO_2 with the $CaCO_3$ of the cement forming additional C-S-H-phases. Furthermore, so called “alternative binders” which are largely free of Portland cement clinker – based e.g. on puzzolanic fly ashes from combustion of hard coal, ground granulated slag, activated by sulfuric or alkaline accelerators [4] – yield a structure that proves stable against most acidic attacks.

Structural designers continually seek new approaches and ideas that will make their structures more aesthetically pleasing, functionally effective, and cost efficient. Historically, the improvement of structures depended strongly upon the characteristics of engineering materials. A new kind of material with excellent properties usually results in a revolution in structures; this is true for steel structures and concrete structures as well. However, design of structures with new materials, such as nano-silica, cannot be carried out with normal design recommendations that do not cope well with nontraditional materials. In many countries, concrete with a compressive strength of more than 80MPa, cannot be used because application of current codes is restricted by certain strengths. Therefore, much work on setting up new design of standards and codes for nano-silica structures must be carried out to make use of the materials potential. So, it is necessary to study the mechanical properties of nano-silica beams, slabs, columns, …., etc.

1.2 Nanosilica

Nanotechnology was first introduced by Nobel-winning physicist Richard Feynman in his well known lecture at the California Institute of Technology in 1959[5] when he said ‘‘There’s Plenty of Room at the Bottom,” and he also suggested "What would happen if we could arrange the atoms one by one the way we want them?" Since then many fields of science began adopting nanotechnology in many inventions and in improvements to already existing ones.

Nanotechnology has great effects on different areas of science and industry. The main reason behind the spread of nanotechnology is that it provides improvement for system reliability, extends functionality beyond traditional applications and decreases cost, size and energy consumption. Incorporating nanotechnology in the field of materials, facilitates increasing materials durability and provides materials with ultra-high performance. It also enables better usage of natural resources and getting the required materials properties with minimal usage[5].

Mainly nanotechnology can be defined as handling the materials at the nano-scale (10^{-9} m) in order to produce novel materials. There are two main approaches that are followed in the area of nanotechnology: The first one is ‘‘top-down” approach, which means deconstruct large structures into their nano-scale components without any molecules level control, which is common to be used today in the area of nanotechnology. The second approach is ‘‘bottom-up” approach or ‘‘molecular nanotechnology” [6] and in this approach, the materials are built from their atom components. It is a promising approach that is not commonly used today, but nevertheless in the future it could provide many breakthroughs in nanotechnology science. Both approaches are clarified in Fig. 1.1.

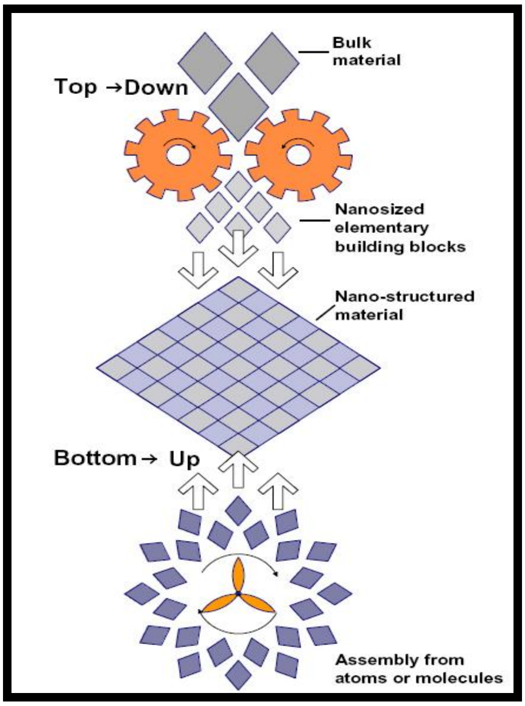

Fig. 1-1 Illustration of the ‘‘top-down” and ‘‘bottom-up” approaches in nanotechnology. [7]

Attracting civil engineers to adopt nanotechnology could enable them to provide pioneering solutions to the complex problems of construction today. It is well known that materials are the core elements of construction industry and these materials could be developed by using nanotechnology. Although the high prices of nano-materials today could obstruct their broadened application in the current period, it is expected that these prices will fall in the near future[8].

Nano-science in concrete means studying the characterization of nano-structure of concrete to better recognize the effect of it on the macro-scale properties and performance via using new techniques and molecular level modeling. Nano-engineering means benefitting from the structure at the nano-scale to provide new materials with novel properties[9].

The extra tiny particle size of the nano-materials explains its supreme properties in comparison to the ordinary materials. That is why it attracted attention to be used in producing new materials with special desired properties. Nano-materials could be described as materials that have at least one dimension between (1-100) nanometer, (ASTM E2456).

One of the most famous drawbacks of incorporating nano-materials in concrete is the self aggregation of nano-particles which decreases the small particle size benefits of nano-materials and produce un-reacted pockets that lead to concentration of stresses in the case of loading[9].

The rank of application of nanotechnology in construction is ranging from eight to ten for the applications that most likely have impact in the developing world [10] . Nanotechnology can be defined as "the use of very small particles of materials to create new large scale materials" [11]. Nano-sized particles have a high surface area to volume ratio as shown in Fig. 1.2.

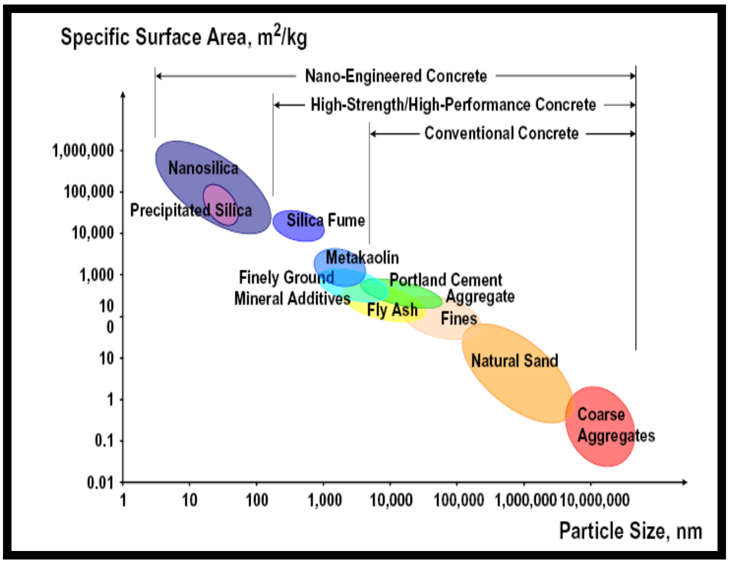

Fig. 1.2 Particle size and specific surface area related to concrete materials [7].

Some of the main or most important construction fields that benefited from using nanotechnology, are[11,12]:

1-Construction materials with ultra high performance (high durability, high ductility and high strength) such as steel, concrete, polymers and self healing structural composites.

2-Embedded structural sensors that could be used for health and moisture content monitoring such as Micro-Electro-Mechanical Systems(MEMS) and intelligent aggregates.

3-New coatings such as self cleaning and corrosion protection coatings.

4-New structural design for infra structures incorporating strong materials with ultrahigh ductility.

5-New tools that can be used to recognize nano-structure of construction composites behaviour.

There are many composites and forms for nano-materials, the most abstracting of which are the carbon nano-tubes which could be added to concrete to enhance its properties [13] . The SiC nano-particles into Si_3N_4 surrounding substance enhance its mechanical properties [14] . The most commonly used nano-particles in concrete are nano-TiO_2, nano-SiO_2 and nano-Fe_2O_3 [13] . These types of nano particles should be incorporated in future research work in order to reveal their benefits in enhancing construction materials.

Nano-silica has a great impact on the mechanical properties of concrete and mortars. The addition of this material increases density, reduces porosity and bleeding, and improves the bond between cement matrix and aggregates [7&15] . Thus, a concrete with high compressive and flexural strengths can be produced when using nano-silica. However, the use of nano-silica is even more restricted than the micro-silica due to the high price of the commercial products.

1.3 Problem Statement

Concrete is considered as the most commonly and widely used construction material in the world. However, cementitious materials in general are very brittle and characterized by a very low tensile strength and a very low strain to failure. Steel reinforcing bars have been added to concrete since the late 1850s to provide tensile strength and ductility. Within the last few decades, researchers began testing discrete fibers as means to control crack growth in cementitious materials (e.g., cement paste, cement grout, concrete). The idea behind this transition to fiber-reinforced cement (FRC) is that the tensile strength is developed from many individual fibers rather than a few pieces of steel. Therefore, the use of discrete fibers results in a more uniform distribution of stress within cementitious materials. The use of FR became more important in ultra-high-performance concrete (UHPC) than conventional concrete.

The terminology of UHPC is not new anymore for many today’s concrete researchers. These mentioned UHPC, also widely known as reactive powder concrete (RPC) is a revolutionary material developed by the French in the mid 1990’s. One of the most distinctive properties of RPC is that the fracture energy is more than two orders of magnitude higher than conventional concrete. In short, with its superior mechanical properties and high tension failure mechanism, fiber reinforced RPC can be used to resist all but direct primary tensile stresses or localised shear. Thus, this may eliminate the need for supplemental shear and other auxiliary reinforcing steel. In the recent years the application of nanotechnology in building materials has increased exponentially. One of the most referred and used nano-materials is amorphous silica with particles size in the nano-range, even though its application and effect in concrete has not been fully understood yet. Nano-silica (NS) have raised the interest of some concrete researchers due to their remarkable mechanical, chemical, and excellent performance in concrete materials. Micro-silica in(RPC) may activate the bond strength between matrix and FR at the micro-scale; however, nano-silica (NS) can further activate the bond strength between matrix and FR at the nano-scale. These nano materials NS may prove to be superior alternatives or compliments to traditional silica fume, and promising candidates for the next generation of high-performance and multi-functional cement based materials and structures.

To successfully utilize NS within FR cement matrix, two key requirements must be met. These include good dispersion, and good bond strength. The first requirement is achieved by uniform transfer of stresses due to the filling of NS most of the concrete voids. The second requirement becomes right if the NS particles fill the voids of the CSH-gel structure and act as nucleus to tightly bond with CSH-gel particles.

The use of large quantities of cement produces increasing CO_2 emissions, and as a consequence the green house effect. A method to reduce the cement content in concrete mixes is the use of silica fines. One of the silica fines with high potential as cement replacement and as concrete additive is nano-silica (NS).

1.4 Objectives

The nano scale of particles can result in dramatically improved or same properties of micro scale local materials different in their chemical composition percentages. Accordingly, the use of nano-SiO_2 in particles forms 99.8% of it in nano scale with average particle size 12 nm will lead to improvement of RPC properties. This NS will be used in this research. Many studies have been conducted to determine the behaviour of steel fiber reinforced normal strength and high strength concretes in slender beams and other structural elements. In contrast, no studies have been reported in the public literature on the shear behaviour of Nano-Silica Concrete Composite slender beams.

The main aim of the present study is to investigate the shear behaviour and shear strength of nano-silica reactive powder concrete (NSRPC) beams. The scope of the work can be divided into three categories :

1. Experimental program, consisting of testing 16 beams which have been designed to fail in shear to investigate the effect of several parameters on the shear behaviour of NSRPC beams. These parameters are; shear span to effective depth ratio (a/d), main reinforcement ratio (ρ_w), volume fraction of steel fibers (Vf), silica fume content (SF) and nanosilica content (NS).
2. Theoretical estimates of the shear behaviour and shear capacity of NSRPC beams using nonlinear finite element method through applying ANSYS software package program(version 11)
3. Formulation of expressions based on experimental data are established to predict the shear resistance capacity of NSRPC beams.

The thesis comprises seven chapters as follows:

- In ***Chapter One*** an introduction to the research problem is presented.
- In ***Chapter Two*** literature review of related research work which deals with the study and analysis of nano-silica characteristics and physical properties is summarized. In addition, the chapter also gives a review of shear behaviour and mechanisms of shear transfer in beams.
- ***Chapter Three*** presents the experimental program of the research work in which full details of the material used, equipment and procedure of tests are clearly presented and described.
- The experimental results are presented and discussed in ***Chapter Four.***

- ***Chapter Five*** comprises theoretical investigation of the shear capacity of NSRPC beams using ANSYS program and comparison with the experimental results .
- In ***Chapter Six*** investigation of the the mechanical properties of NSRPC and establishing new expressions for the shear resistance capacity of such beams, are presented.
- ***Chapter Seven*** gives summary of the main conclusions to be drawn from the present research work and suggested recommendations for future researches