July 2017 Ph.D. in Civil Engineering AsraaYounis ALGOODY

UNIVERSITY OF GAZİANTEP
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EXPERIMENTALBEHAVIOR OF SCCWITH NANO-SILICA AND NUMERICAL ANALYSIS OF CFST COMPOSITECOLUMNS USING SCC AS AN INFILL

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IN
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BY
ASRAA YOUNIS ALGOODY

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ExperimentalBehaviorof SCC With Nano - Silica and Numerical Analysis of CFST Composite Columns Using SCC as an Infill

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Supervisor
Assoc. Prof. Dr. Esra METE GÜNEYİSİ

by
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This is to certify that we have read this thesis and that in our opinion it is fully adequate, inscope and quality, as a thesis for the degree of Doctor of Philosophy.

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AsraaYounis ALGODDY

ABSTRACT

EXPERIMENTALBEHAVIOROFSCC WITH NANO - SILICAAND NUMERICAL ANALYSISOF CFST COMPOSITE COLUMNs USING SCC AS ANINFILL

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Composite sections are being increasingly popular in construction industry. Among them, concrete filled steel tube (CSFT) members are primarily suited for different structural applications. This composite system uses the compressive strength of the concrete core as well as the strength, stiffness and confinement effect of the surrounding steel tube. In this thesis, firstly, an experimental study on the behavior of self- compacting concrete (SCC) containing high volume of nano- silica (up to 6%) and fly ash (up to 75%) was conducted. Secondly, a numerical investigation on short CFST columns made with SCC produced in the first part of study was carried out. The structural response of the composite columns were evaluated under the effect of compression up to failure. Two design codes such as American Concrete Institute (ACI) and Eurocode 4 (EC4) were used for calculating the ultimate axial strength of CFST columns filled with SCC.The 16 SCC mixtures were studied and their concrete compressive strength results at two different testing ages were used to get the code predicted ultimate axial strength of the composite columns. The experimental and numerical results were given and discussed comparatively.

Keywords: Composite column, Concrete filled steel tube column, Nano-silica, Performance assessment, Self-compacting concrete.

ÖZET

NANO SİLİKALI KYB' UN DENEYSEL DAVRANIŞI VE BUNUN DOLGU OLARAK KULLANILDIĞI BETON DOLGULU ÇELİK TÜP KOMPOZİT KOLONLARIN NÜMERİK ANALİZİ

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Kompozit kesitler inşaat sektöründe giderek artan bir kullanım alanına sahip olmaktadırlar. Bunların arasında, beton dolgulu çelik tüp elemanlar farklı yapısal uygulamalar için oldukça uygundur. Bu kompozit sistem beton çekirdeğin basınç dayanımını ayrıca bunu çevreleyen çelik tüpün dayanımını, rijitliğini ve sargı etkisini kullanmaktadır. Bu tezde öncelikle yüksek miktarda nano-silika ve uçucu kül içeren kendiliğinden yerleşen betonun (KYB) davranışı deneysel olarak incelenmiştir. İkinci olarak, üretilen bu betonların dolgu olarak kullanıldığı beton dolgulu çelik tüpler nümerik olarak incelenmiştir. Basınç etkisi altındaki kompozit kolonların yapısal tepkisi değerlendirilmiştir. Amerikan Beton Enstitüsü ve Eurocode 4 adlı iki tasarım kodundan KYB dolgulu çelik tüplerin maksimum eksenel dayanımlarının hesaplanmasında yararlanılmıştır. 16 KYB karışımı ve bunların 2 farklı yaştaki basınç dayanımları, kompozit kolonların maksimum eksenel dayanımlarının kodlar tarafından tahmininde kullanılmıştır. Deneysel ve nümerik sonuçlar sırasıyla bu çalışmada verilmiş ve karşılaştırmalı olarak tartışılmıştır.

Anahtar kelimeler: Kompozit kolon, Beton dolgulu çelik tüp kolon, Nano-silika, Performans değerlendirmesi, Kendiliğinden yerleşen beton.

To My Homeland Iraq …….
To My Family, For their
Love, Support and Understanding……..

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LIST OF SYMBOLS

A	Cross sectional area of the sample
Ac	Cross-sectional area of concrete
ACI	American Concrete Institute
AIJ	Architectural Institute of Japan
AISC	American Institute of Steel Construction
As	Cross-sectional area of steel tube
Asc	Area of composite section
B, C	Constant factors used in DL/T code
CCs	Conventional concretes
CFST	Concrete filled Steel Tube
CH	Hydrated lime; Ettringite
CSH	Calcium silicate hydrate
D	Outer diameter of the column
Dc	Diameter of the concrete core
DL/T	Chinese Design Code for Steel-concrete Composite Structures
E	The static modulus of elasticity
Ec	Modulus of elasticity of concrete
Ec1	Modulus of elasticity of concrete (normal weight concrete)
EC4	Eurocode 4
Es	Modulus of elasticity of steel
FA	Fly ash
fc, fcu	Mean cube compressive strength
fc'	Compressive strength of standard concrete cylinders (Φ150×300mm)
fck	characteristic strengths of the concrete
fscy	Nominal yielding strength of the composite section
fy	Yield stress of steel
g	Gravitational acceleration
h	Height of the cylinder
HPC	High performance concrete
HRWRA	High range water reducer agents
HSC	High strength concrete

ITZ	Interfacial transition zone
Ke	Correction factor=0.6
L	Length of the column
Ic	Moment of inertia of concrete core
Is	Moment of inertia of steel tube
m	Mass of the beam
n	Number of data samples
N	Rotational speed
NA	Natural aggregate
NCAs	Natural coarse aggregates
Nu, Pu	Ultimate axial load carrying capacity
Pmax	Ultimate load
SCC	Self-compacting concrete
SD	Standard deviation
SF	Silica fume
SIF	Stress intensity factor
SSD	Saturated surface dry condition
SP	Superplasticizers
t	Thickness of steel tube
T500	Time required to reach 500 mm slump flow
τ	Shear stress
τo	Yield stress
μ	Plastic viscosity
γ'	Shear rate
δs	The specified deflection of the beam
ξ, η	Confinement factor
ηa, ηao	Factors related to the confinement of steel tube
ηc, ηco	Factors related to theconfinement of concrete

CHAPTER 1

INTRODUCTION

1.1 Background

New types of structures and new technologies in building (i.e. multi-story structures, towers, marine structures) created more difficult requirements for the construction material. Therefore, the needs for new generation structural concretes have been increased. The concept of self-compacting concrete (SCC) was recommended in 1986 by Okamura (1997), but the prototype was first advanced, at the University of Tokyo in 1988 in Japan, by Ozawa (1989). SCC was advanced at that time to develop the durability of concrete structures. Meanwhile, different investigations have been approved to use SCC in practical structures by large construction companies, in Japan. Most certainly, SCC flow has been simulated at the first time outside Japan by Hakami et al. (2001) and Petersson (2003). This part of work is a continuation of his developer work. SCC flow had been conducted in Japan to study dynamic segregation, blocking mechanisms and rheological parameters. A SCC rational mix-design method, and ability testing methods have been established in investigations from the standpoint of making it a standard concrete. SCC is cast with a view to no additional inner or outer vibration is necessary for the compaction. Mix blocking has been studied when designing an SCC, so slump flow, J-ring and L-box were computed to study blockingand rheological parameters. As larger volumes are pretended, a continuous lines has been presented as a commendation. It permits a superior image to model correctly for filling or blocking discrepancies, which can be additional investigation with a discrete model for details (Petersson, 2003).

1.2 What is SCC

SCC can be defined as a fresh concrete owns superior flowability with stability preservation without segregation, so material consolidation without addition of energy. Permitting self-compacting that (The Concrete Society and BRE, 2005) is called SCC "the discreet revolution in concrete construction". It flows like "honey" with a very smooth surface level after placing. SCC consists of the same components as conventional vibrated concrete, by regard to its composition, which are cement, aggregates, and water, with the addition of chemical and mineral admixtures in diverse proportions. Usually, high-range water reducers are used as the chemical admixtures and viscosity-modifying agents, which alteration the rheological properties of concrete. Besides ordinary cement, mineral admixtures are used such as an extra fine material, or replaced cement in some cases. Admixtures have a main role in improving the flowing and strengthening characteristics of the structural SCC (Bartos, 2000).

1.3 Nanotechnology

Nanotechnology is a very energetic research field has application in a number of areas. Presently, the most active consideration are as the use of nano- size ingredients like alumina and silica particles and any other pozzolanic material, in research dealing with cement and concrete. Nowadays increasing amounts of research investment are being converted into the nano level, because the micro-level does not provide enough visions into building materials. Therefore, all around the world, which is claimed to have enormous sustainable for the future (Scrivener and Kirkpatrick, 2008). The essential processes that govern the properties of structural concrete are impressed by the performance of the material on a nano scale. The mainly properties depend on the microstructure of the hardened cement paste and the gradually improving of the paste-aggregate interface zone which in turns the enhanced mechanical properties and the durability of concrete for the structural applications (Shabani et al., 2010).

1.4 Concrete Filled Steel Tubular Columns

Concrete filled steel tubes (CFST) is a structural member, and a type of the composite steel-concrete structures used presently in civil engineering and consists of steel tube and concrete with high strength core inside it. This composite member combines the advantages of both hollow structural steel and concrete. Composite columns are structural members, which are subjected mainly to axial compressive forces and end moments. The general term ’composite column’ refers to any compression member in which the steel element acts compositely with the concrete(Darshika et al., 2014). Composite columns have widely accepted in the engineering applications because they have superior strength and ductility act. On the other hand, the filled tubular columns require more attention, there are significant differences in structural properties like ductility and energy absorption capacity of concrete filled steel tubular systems when compared to conventional reinforced concrete members. Due to their outstanding static and dynamic (earthquake-resistant) characteristics, CFSTs have been commonly utilized in the various types of structures such as bridges, high rise buildings, subway platforms, etc. (Gardner and Jacobson, 1967; Chen and Chen, 1973; Lin, 1988; Zeghiche,1988; Tsuda et al., 1995; Zeghiche and Chaoui,2005; Lu and Zhao, 2010).

CFST has become popular as structural members in buildings due to their excellent structural performance characteristics, which exclude high strength, stiffness, and high ductility. The advantages of the CFST over other composite members are that the steel tube delivers formwork for the concrete, the filled-in concrete from extends local buckling of the steel tube wall, the tube prevents extreme concrete falling, and composite columns enhance significant stiffness to a frame compared to more traditional steel frame construction. According to the compressive behavior of CFSs performed in the past study indicate that the ultimate axial strength of CFTCs is greatly affected by the thickness of the steel tube, and the shape of its cross section. The confining effect could be also expected in circular columns and square columns which show only a small increase in axial strength due to triaxial effects, although those with large wall thicknesses. Conversely, the axial load-deformation performance of columns is unusually affected by the cross-sectional shape, diameter/width-to-thickness ratio of the steel tube, and strength of the filled concrete (Giakoumelis and Lam, 2004).

CFST column is formed by filling a steel tube with concrete. According to the form of the cross-section, CFST columns can be divided into different groups, such as circular, square and octagon CFST columns, etc. The cross sections of these columns can be either solid or hollow. A solid concrete-filled steel tube (S-CFST) column is formed by pouring fresh concrete into the entire space enclosed by the steel tube, and a hollow concrete-filled steel tube (H-CFST) one is formed by pouring concrete into a steel tube using the centrifugal method. Figure 1.1 shows some of the commonly used cross sections of the concrete-filled steel tube columns (Ye JQ et al., 2010).

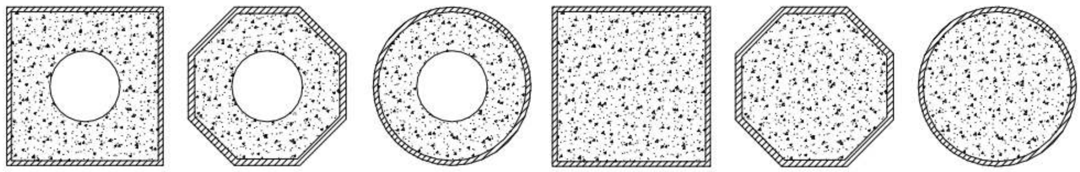
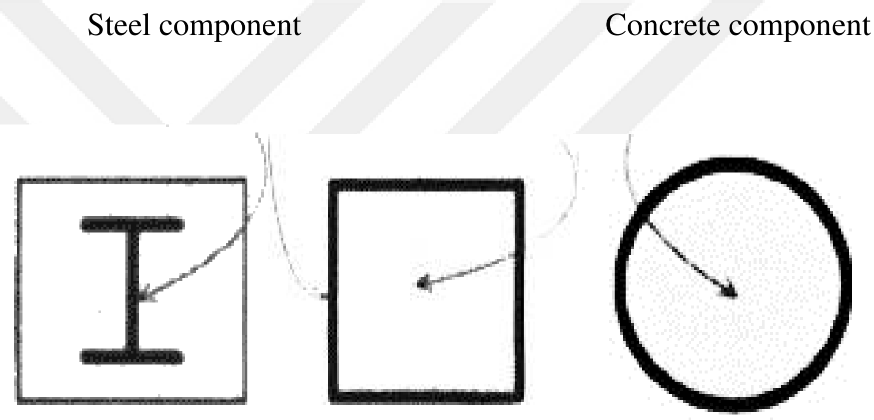


Figure 1.1 Common section types of CFSTs (Ye JQ et al., 2010)

Composite steel-column are used widely in modern structures, buildings and bridges construction, a steel unit, for instance steel tube is filled with concrete constituent as shown in Figure 1.2 or I-section (steel) incased with concrete (Oehlers and Bradford, 1999). CFST columns have been widely used in many constructions attributable to their excellent performance, such as toughness against seismic loads, improved fire resistance over bare steel columns, integral usage of materials, advanced strength, great stiffness and ductility, big asset in construction time and especially higher fire resistance compared to common steel, in addition CFST columns require additional protection against fire (Tian et al., 2010). The use of CFST columns, in recent years has increased and becoming very commondue to the combined action of the steel tube confines the concrete core improving its compressive strength, the concrete core prevents the steel tube from suffering local buckling CFST columns combine the action of steel and concrete when carrying compressive loads and moments showing an ideal structural performance. The steel tube goes about as both longitudinal and transverse reinforcement, and furthermore gives a confining pressure to the concrete, which puts the concrete under a triaxial condition of stress. Then again, the steel tube is hardened by the concrete core. It is outstanding that the ultimate strength of CFST columns is affected by their essential material properties, such as the compressive strength of concrete, the yield strength of steel, and the steel proportion.In spite of the fact that there have been a substantial number of studies on CFST sections with concrete normal and high-quality concrete, there has been moderately little research on CFT sections with SCC. In this manner, there is a good potential for utilizing CFST sections with SCC in structures. (Han and Yao, 2004) in a previous research indicated that the load carrying capacity and failure modes of CFST columns filled with SCC and with normal concrete were actually the same as if the concrete strength is close.The axial compressive stiffness and ultimate capacity are the fundamental properties of CFST columns. In the literature there are diverse assessments and decisions about the axial compressive stiffness of the columns, and one of the principle reasons may be that researchers used different deformation measurement strategies for the composite columns under axial compressive loading.



a) b)

Figure 1.2 Composite steel-concrete columns (Oehlers and Bradford, 1999)

1.5 Research Objectives

This thesis consists of two main parts. In the first, an experimental study was performed so as to investigate the material aspects of SCC having nano-silica (NS) and fly ash (FA). The high volume of FA and NS were used together to develop environment friendly and cost effective structural SCC. In the second part of the study, a numerical analysis was conducted in order to evaluate the structural aspects of the composite columns infilled with SCC under axial compression. To take the benefit of compressive strength results of SCC on the behavior of the composite columns, a special procedure was adopted in this part of study. American Concrete Institute design code (ACI 318) and Eurocode (EC4) were used to analyze the axial load carrying capacity of the CFST columns. More specifically the following objectives can be listed:

- Performing a comprehensive study firstly on the SCC with combined use of highvolume FA and NS and then the structural behavior of steel tubular column infilled with such concrete.
- Testing the fresh and hardened properties of SCC having NS up to 6% and FA up to 75%.
- Utilization of two design codes such as American Concrete Institute (ACI318) and Eurocode (EC4) for evaluating the ultimate axial strength of the composite column with SCC served as concrete core in the steel tube. For this, circular steel tube with different D/t ratio of 30 to 90 and yield strength of 185 to 450 MPa were considered. The wall thickness and length to diameter (L/D) ratio of the steel tubes were kept constant.

1.6 Structure of the thesis

This thesis consists of five chapters: - A general introduction is presented in
Chapter 1, along with the objectives and scope of the research.
Chapter 2, this chapter summarizes the most important published information on SCC, applications of nano materials in constructions, and researchworks and use of concrete filled steel tube columns as structural members.
Chapter 3 includes the experimental program and numerical analysis conducted throughout this study. The first deals with the properties of the materials used in preparing the test specimens, details of the tests of fresh and hardened properties of SCCs. The second focuses on the details of numerical study. It merits specifying that the plan and outline explained from two distinctive outline design codes (ACI, Eurocode 4) are utilized and presented to anticipate the ultimate axial capacity of CFST compositecolumns.

Chapter 4 provides the results of the testing program. The properties of SCC are discussed. The list of results, figures, and evaluation are presented. The results of numerical comparisons and code evaluation for the predicted axial load carrying capacity (Pu) of the concrete filled steel tubular short columns and in addition appropriate relations and proposed formulas extricated from the study are displayed.

Chapter 5 is a key to the main conclusions drawn from the results of the present study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In reinforced concrete buildings, bridges, and tunnels, self - compact concrete (SCC) has been used and find high potentials for wider structural applications. A significant amount of available literature on SCC published in Japanese which first appeared in 1989, and has been increasing significantly since that time, reflecting the amount of research and practical applications taking place. In recent years, the use of nano-particles have received particular attention in many fields of applications to produce high performance structural concrete with new functionalities (Neville, 2000; Li et al., 2004; Lea, 1998).The performance of the nano- particle included concrete is strongly dependent on nano-size solid particles, or nano-size porosity. Strength, durability, shrinkage and steel-bond are the typical properties affected by nano-size particles or voids (Collepardi, 2005). Nano-particles of SiO_2 (NS) can fill the spaces between particles of gel, acting as a nano-filler. Furthermore, the amount of product increases, by the pozzolanic reaction with calcium hydroxide, resulting a greater densification of the matrix, which develops the strength and durability of the materials. Previous researches by Lea (1998), Li (2004), and Björnström et al. (2004)indicates that the inclusion of nano-particles modify fresh and hardened state properties, even when compared with conventional additives. In the recent years, there are considerable interests on the behavior of steel tubular members infilled with concrete. Thedevelopment of the composite members with high performance is expected to increase its utilization in the construction industry. Based on the scope and aim of this study, this chapter is deals with SCC nano materialsand concrete filled steel tubular columns.

2.2 SCC in Construction Industry

2.2.1 Definition

SCC, a recent innovation in concrete technology, hasnumerous advantages above conventional concrete. SCC, is a type of concrete, as the nameindicates, that does not require external or internal compaction, because itbecomesleveled and compacted under its self-weight. SCC,purely by means of its self-weight, it can spread and fill every corner ofthe formwork thus disregarding the need of vibration or anytype of compacting effort (Meyer, 2009).The conception behind developing SCC was the concerns regarding, the homogeneity andcompaction of conventional cast-in-place concrete within intricate (i.e., heavily-reinforced)structures and to improve the overall strength, durability, and quality of concrete. The SCCis highly flow able and cohesive enough to be handled without segregation. It is alsodenoted to as self-consolidating concrete, self-leveling concrete, and super- workable concrete, highlyflow able concrete, non-vibrating concrete, and other similar names(Mehta, 2001).

Therefore, Okamura et al. (1995) has changed the term for the proposed concrete to "Self-Compacting High Performance Concrete". European Guidelines (2005) define SCC as "an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement ". Ashok (2004) defines SCC as a "highly flow able yet stable, concrete that can spread readily into place and fill the formwork without any consolidation and without undergoing any significant separation".EFNARC (2005) describes SCC as "the most radical innovation in concrete construction for several decades" originally developed to substitute a growing absence in skilled laborers.This focuses on the resistance to defects at early ages, such as thermal and shrinkage cracking, and long term durability in service in addition to the self-compacting properties during construction. ACI Committee 237 (2007) defines SCC as "highly flow-able, non-segregating concrete that can spread into place, fill the formwork, and enfold the reinforcement without any mechanical consolidation." provider are currently scout about the use of SCC becauseit may produce members with homogeneous quality even in highly packed, narrow members such as pre-stressed concrete members.Batrtos (1999); Okamura and Ouchi (2003) considered SCC is as a concrete, which can be placed and compacted under its own weight with little or no vibration without segregation or bleeding. It is used to facilitate and ensure proper filling and good structural performance of restricted areas and heavily reinforced structural members. It has gained significant importance in recent years because of the advantages it offers. Ghezal and Khayat (2002) considered SCC is a concrete that can settle into the heavily reinforced, narrow and deep sections by its own weight to completely fill the formwork without any internal or external mechanical vibration.

SCC is also called a “healthy” and “silent” concrete as it does not require external or internal vibration during and after pouring to achieve proper consolidation. Mechanical vibration is a noisy and demanding task for the members of the casting team. The reduction or total elimination of this assignment diminishes the environmental impact for both those who are involved in the construction process and the surrounding neighbors (Walraven, 2002). From many other researches and the experimental work of this study, the following definition can be adopted for SCC, concrete that is able to flow under its own weight up to leveling, completely fill the formwork even in the presence of densereinforcement, airs out, compacts and consolidates without the need of any vibration,whilst maintaining homogeneity due to high resistance to segregation.

2.2.2 History and Basic Principles for SCC

The history and development of SCC can be divided into two key stages: its initial development in Japan in the late 1980s. It was first proposed for construction by Okamura in Japan to offset a growing shortage of construction labor (www.acmcentre.com/testing-scc/index.php.), and its subsequent introduction into Europe through Sweden in the mid- to late-1990s. The first research publications that looked into the principles required for SCC were from Japan around 1989 to 1991. These studies concentrated upon high performance and super-workable concretes and their fresh properties such as filling capacity, flow ability and resistance to segregation (Tanigawa et al., 1989/1990; Tangtrmsirikul et al., 1991).

The first significant publication in which ‘modern’ SCC wasidentified is thought to be a paper from the University of Tokyo by Ozawa et al. (1992). The term SCC is not used within the paper, although a high performance concrete was produced which possessed all the essential properties of a SCC mix. In the following few years, many research papers were published on concretes such as super-workable, self-consolidating, highly workable, self-place able and highly- fluidized concretes, all of which had similar properties to what we now know as SCC. In 1993, research papers were beginning to be published of case studies on the use of these early forms of 'SCC' in actual applications (Sakamoto, 1993; Kuroiwa, 1993). One of the first published references utilizing the term at studying SCC for housing (Billberg, 1999). As part of this project, large numbers of half-scale house walls were cast using SCCs, which were made with different filler materials. The work from this project contributed to the first European project on SCC, which began in January 1997 and was completed in 2000. The main goal of this Brite-EuRam project (BRPR-CT96-0366) was to develop a new vibration-free production system to lower the overall cost of in-situ-cast concrete construction.

The first part concerned the development of SCC with or without steel fibers and the second part dealt with full-scale experiments in civil engineering and housing. This project included partners from several European countries, including the UK. During this time, the CBI also developed a mix design model for the design and production of SCC (Billberg, 1999). In the last decade, SCC has become very popular in structural applications in Japan and Europe, and just recently in the United States. Housing and tunneling as well as bridge construction of the Swedish National Road Administration

were the main areas of use for SCC. In the Netherlands and Germany, the precast industry is mainly driven the development of SCC. In the United States, the precast industry is also leading SCC technology implementation. Double tee girders, piles and reduced size slabs constitute (Marsh, 2002). Furthermore, several state departments of transportation in the United States arealready involved in the study of SCC (Vachon and Daczko, 2002).

The concrete industry in countries such as France and the Netherlands has also recently developed and using the material, with countries such as Germany and the UKprogressing closely behind. All of these countries have now used SCC in both in situ and precast applications. Countries such as Greece and the Eastern European countries are still mainly conducting research and development or are at the initial site trial stage. Two European-wide research projects are currently under way in the field of SCC.Since then several investigations have been carried out to achieve a rational mix design for a standard concrete, which is comparable to normal concrete. SCC is defined so that no additional inner or outer vibration is necessary for the compaction. SCC compacts itself alone due to its self-weight and it stays homogeneous while flowing in the formwork. In structural members with high percentage of reinforcement, it fills also completely all voids and gaps. SCC flows like "honey" and has nearly a horizontal concrete level after placing. With regard to its SCC consists of the same components as conventionally vibrated normal concrete, which are cement, aggregate, water and admixtures. However, the high amount of superplasticizer for the reduction of the liquid limit and for better workability, the high powder content as "lubricant" for the coarse aggregates, as well as the use of viscosity-agents to increase the viscosity of the concrete have to be taken into account. In principle, the properties of the fresh and hardened SCC, which depend on the mix design, should not be different from NC (Normal Concrete). One exception is only the consistency. SCC should have a slump flow SF of approx. SF> 65 cm after pulling the flow cone. Figure 2.1 shows the basic principles for the production of SCC (Frank et al., 2000).

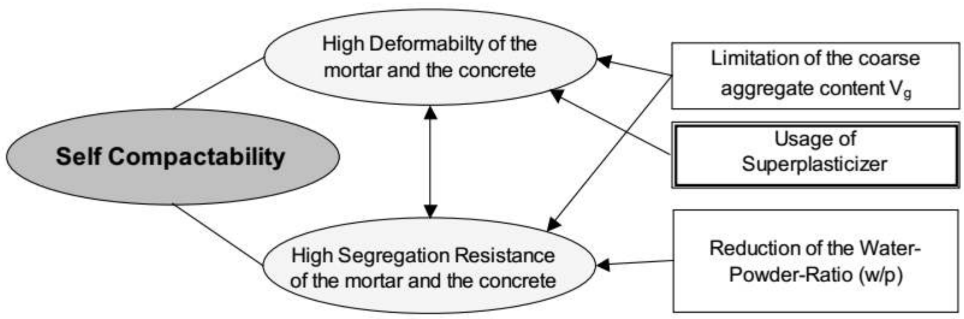


Figure 2.1 Basic principle of the production of structural SCC (Frank et al., 2000)

Current studies in SCC, which are being conducted in many countries, can be divided into the following categories: - use of rheometers to obtain data about the flow behavior of physical properties required to generate SCC. However, the water–

powder ratio and superplasticizer dosage still have to be adjusted when conducting the trial mixing and testing of SCC. Recently, many studies realized the importance of the fundamental principles involved in physical phenomena. These studies investigated SCC from a rheological point of view and noted that the quality control of rheological properties is critical for the success of SCC (Saak et al., 2001; Bui, 2002; Roussel, 2006; Chidiac et al., 2009; Wallevik, 2011; Tregger et al., 2012).

2.2.3 Future of SCC

From its origins in Japan in the late 1980s, research, development and use of SCC has spread steadily throughout the world. Approximately 7–10% of the Swedish ready-mix market is now SCC and research is being conducted in virtually every country in Europe. National working groups on the material now exist in some form in most countries in Europe, with the majority of them working towards producing some form of guidance on the use of SCC. Large amounts of research and development are now also being conducted in Canada and the USA at places such as the University of Sherbrooke and the university Laval. American concrete organizations such as the American Concrete Institute (ACI), American Society for Testing and Materials (ASTM) and PCI (Precast/Pre-stressed Concrete Institute) have all recently formed committees to produce guidelines, standards and specifications for SCC (Vacon and Daczko, 2002). Countries such as Argentina, Australia and New Zealand are also all now beginning to conduct research and development work into SCC, with more countries sure to follow.

A third International Symposium on SCC is being held in Iceland in August 2003, where much of the research and development work presently under way will be presented. The main barrier to the increased use of SCC in the UK and Europe seems to be the lack of experience in the process, and the lack of published guidance, codes and specifications.

This situation will improve, however, as experience and knowledge increases and each country begin to produce its own guidance and specifications. Pre casters are currently the sweeping users of SCC in the UK, in Europe and in the USA. This is partly due to them owning and operating the on-site batching plant, and so they are able to take full advantage of all the potential benefits of SCC. They can also minimize or control the potential disadvantages of the material (such as inconsistency of supply and site acceptance). Although SCC is not expected to ever completely replace conventional vibrated concrete, the use of the material in both the precast and ready-mix markets in the UK, Europe and the rest of the world is expected to continue to increase. It is considered that the main obstacles for making SCC, widely used have been solved. The next task in Japan is to distribute the technique for manufacturing and construction of SCC rapidly. In addition, new structural design and construction systems, making full performance of SCC should be introduced (Ouchi, 2014).

2.2.4 Mechanism for Achieving Self-Compactibility

To achieve self- compactibility, the fresher mixes should have the high deform ability, good cohesiveness between material ingredients, and excellent consistency of the fluidity over time, and should have sufficient segregation resistance. This objective may be imposed on the rheological characteristics of fresh mix, which are affected by inter-particle microstructure, fiber properties, and interfacial properties between the matrix and fibers. Specific requirements include: - The fresh matrix should have an optimal viscosity and low yield stress to provide good deform ability, while preventing phase separation. During the casting process, the suspension should maintain its initial flow ability by effective stabilization of the system. The flow properties of fiber-free mix should be minimally disturbed upon fiber addition, to prevent poor fiber dispersion due to high fiber aspect ratio and/or high fiber volume fraction. The fiber surface should have the optimal weight ability with the fresh cementations mix so that the fresh mix can flow homogeneously through reinforcements or complex formwork figures without any phase separation or clogging (Okamura and Ozawa, 1995; Ozawa and Sakata et al., 1995). Okamura and Ouchi (2003) suggested that in order to achieve self -compact ability of fresh concrete, deform ability of paste (mortar) and resistance to segregation between aggregate particles and mortar when the concrete flows through the restricted zone of reinforcing bars, and have to be considered. Okamura and Ozawa (1995) have utilized the following methods to achieve self-compactibility of fresh concrete. Firstly, they limited the amount of aggregate content (coarse aggregate Â 50% of the concrete volume and sand, 40% of the mortar volume). Secondly, they used low water/powder ratio, with higher dosage of superplasticizer admixture. According to

Shetty (2005), using superplasticizer, which is used with concrete components as an essential chemical admixture, leads to increase the workability of fresh concrete without regard to reducing the water content in the concrete mixture (Okamura and Ouchi, 2003). When concrete is placed into the formwork, the relative distance between the concrete particles will decrease. As a result, the frequency of collision and contact can increase and consequently, internal frictions between concrete particles also increase, especially near hindrances. Research has found that the energy, which is required for flowing the concrete during the casting is consumed by the increased internal friction between particles, and resulting in blockage of aggregate particles to flow through, confined places. For this reason, limiting the amount of coarse aggregate, whose consume more energy, to a level lower than normal will increase the efficiency of concrete flowability and avoid concrete particles from this kind of blockage. It is stated the following methods for achieving self- compatibility by limited aggregate content, low water- powder ratio, and use of superplasticizer.

On the other hand, highly viscous paste is also required to avoid the blockage of coarse aggregate when concrete flows through obstacles. When concrete is deformed, paste with a high viscosity also prevents localized increases in internal stress due to the approach of coarse aggregate particles. High fluidity can be achieved only by the employment of a superplasticizer, keeping the water-powder ratio to a very low value (Okamura and Ozawa, 1995).

Before designing a mix for SCC, an understanding is needed of the properties required for self-compacting and how this can be optimized by utilizing materials currently available. The two main requirements are a specified material with limitation and high resistance to segregation. To achieve a highly mobile concrete, a low yield stress is required and for a high resistance to segregation, a highly viscous material is important. Water can be added to decrease the yield stress, but this addition also lowers the viscosity. The addition of superplasticizer will also lower the yield stress, but will lower the viscosity, slightly (Wallevik and Nielsson, 1998). Each material, cement, sand, coarse aggregate, concrete, admixture, filler, and pozzolanic must be evaluated according to the type, strength characteristics, gradation, fineness, and interaction in combination with each other (Ralf and Sika, 2000).

2.2.5 Design of Mixture

The mix design of coarse and fine aggregates in the concrete is important both for the fresh and hardened concrete properties. Correct proportioning results in better workability of the fresh concrete as well as increased durability of the hardened concrete. Meininger (1982) developed relationships between the quantities of cement, air and water voids. Generally, a better packing system of aggregates is believed to result in a concrete product of higher quality. Conventional concrete has a higher amount coarse aggregate than SCC. Included aggregates can be packed more densely, since stiffness may be easily loosened up with a poker vibrator. If vibrating too much, segregation of particles and water will occur. SCC is particularly sensitive in that sense, since it is highly flowable. The paste and mortar content needs to be higher for SCC, in order to keep aggregate particles apart to reduce friction between them. Adequate packing and paste content will maximize workability as well as durability. SCC can be largely affected by the characteristics of materials and the mix proportions.

The first model for proportioning SCC mixes was developed in 1988 using constituent material readily used in conventional concrete (Okamura and Ouchi, 2003). The model was performed satisfactorily with regard to fresh properties and also long-term hardened properties such as shrinkage and density. The cementations component of the model is much larger than conventional concrete with a subsequent reduction in the volume fraction of coarse aggregate (Okamura and Ouchi, 2003). To achieve the required combination of properties in fresh SCC mixes, the following points must be considered (Banfill, 2003): the fluidity and viscosity of the paste are adjusted and balanced by careful selection and proportioning of the cement and additions, by limiting the water/powder ratio and then by adding a superplasticizer, and (optionally) a viscosity modifying admixture. Correctly controlling these components of SCC, their compatibility and interaction are the key to achieve good filling ability, passing ability and resistance to segregation, in order to control temperature rise and thermal shrinkage cracking as well as strength, the fine powder content may contain a significant proportion of Type I or II additions to keep the cement content at an acceptable level, the paste is the vehicle for the transport of the aggregate; therefore, the volume of the paste must be greater than the void volume between the coarse aggregate, so that all individual coarse aggregate particles are fully coated and lubricated by a layer of paste. This increases fluidity and reduces coarse aggregate friction, and the coarse to fine aggregate ratio in the mix is reduced so those individual coarse aggregate particles are fully surrounded by a layer of mortar. This reduces aggregate interlock and bridging when the concrete passes through narrow openings or gaps between reinforcement and increases the passing ability of the SCC. These mix design principles result in concrete as compared to traditional vibrated concrete, normally contains, lower coarse aggregate content, increased paste content, lower water/powder ratio, increased superplasticizer content, and sometimes a viscosity modifying admixture (Banfill, 2003). The basic components of the mix composition of SCC are the same as those used in conventional concrete. However, to obtain the requested properties of fresh concrete in SCC, a higher proportion of ultrafine materials and chemical admixtures must be used. Because of this, self-compactibility can be largely affected by the characteristics of materials and mix proportion.

Mix designs often use volume as a key parameter because of the need to overfill the voids between the aggregate particles. There are many different mix design theories. Some methods try to fit available constituents to an optimized-grading envelope. Other methods are to evaluate and optimize the flow and stability of first the paste and then the mortar fraction before the coarse aggregate is added and the whole SCC mix tested (Khayat and Guizani, 1997; EFNARC, 2005).

2.2.5.1 Rational Design Method

A relatively simple mix design method was developed in Japan in 1995. The method was based on the fact that self-compatibility of concrete can be affected by the mix proportions (Okamura, 2003). The principle of the mix design method is that the coarse and fine aggregate content is fixed so that the self-compactibility of the fresh concrete can be achieved. The fundamental steps in the procedure are, as follows. The coarse aggregate content is fixed at 50% of the solid volume of the concrete. The fine aggregate content is fixed at 40% of the mortar volume. The water / powder ratio is assumed to be (0.9-1.0) % by volume depending on the properties of the powders. The superplasticizer dosage and final water /powder ratio are determined so as to ensure self-compact ability (Okamura and Ouchi, 2003).

2.2.5.2 Domone Design Method

The optimum mix design method is based on the rational mix design method (Okamura, 2003), but this is modified by using a water/powder ratio which are generally less than 0.5 (by weight) and mixes have a lower coarse aggregate content and higher paste content than conventional concrete. Admixtures and additives contribute to increase both workability and segregation resistance (Okamura and Ouchi, 2003). Experience in Japan and Europe showed that there are a wide variation of materials and proportions that can be used to produce satisfactory SCC, with certain key factors, which fall within certain limits (König and Holschemacher et al, 2001; Okamura and Ouchi et al., 1998).

2.2.5.3 Japanese Design Method

This mix design method, like rational mix design method, is based on experience from Japan (Okamura and Ouchi et al., 1998). For the production of SCC, the mix design should be performed so that the predefined properties of the fresh and hardened concrete are reached for sure. The components should be coordinated one by one, that segregation, bleeding and sedimentation are prevented (EFNARC, 2005) Figure 2.2 shows the rules for the mix design of SCC.

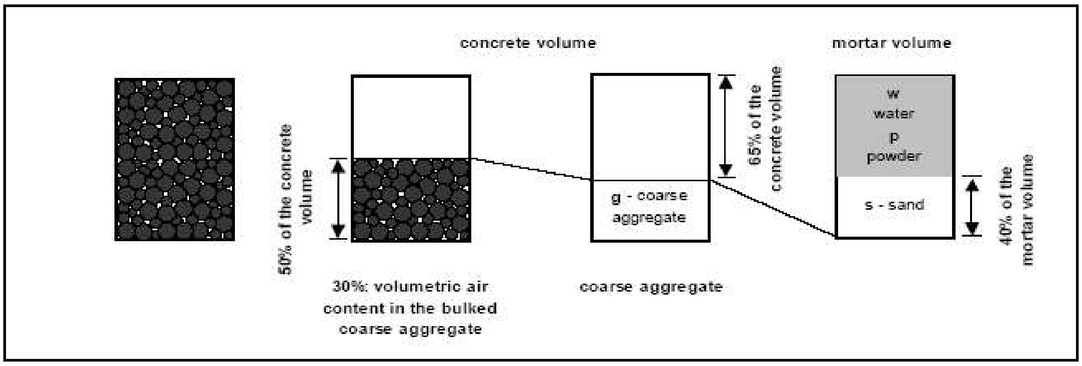


Figure 2.2 Determination of the Japanese Mix Components for SCC (EFNARC, 2005)

In order to take the characteristics of deviating materials into account, empirical tests have to be carried out on three levels. First, the level of cement paste is considered. At this stage, the water demand of the powders is to be determined by flow tests at different water contents. Second, cement paste lubricates small aggregates in mortar.

At this stage, superplasticizer is added to decrease the water demand and to determine its effect in combination with powders. Finally, the content and the maximum size of coarse aggregates are chosen to pass the reinforcement at a specified bar spacing (Takada et al, 1997).

2.2.5.4 CBI Design Method

Petersson (1998), Tviksta (2000) and Partner (2002) summarized CBI method (Concrete of Building Investigation). This method is used for housing building concrete when the compressive strength is between 25-30 MPa and it is based on the requirement for the element to be cast, e.g. strength, durability and free space between reinforcement, one can calculate the minimum amount of paste. Using the aggregate's grading curve and nature of aggregate (natural or crushed), the calculation is performed by using a "risk curve" (for the type of aggregate used). The risk curve is related to the grading curve and void space between aggregates. This calculation gives the minimum paste content for sufficient passing ability. For a house building concrete with better passing ability, the void content is determined in the aggregate to give the minimum paste content. The paste content (addition amount) can sometimes be higher because of segregation resistance reason. A certain excess amount must be used for workability reasons. Superplasticizer is then used and adjusted to give the right filling ability (normally slump flow).

2.2.5.5 LCPC Design Method

Petersson (1998); Tviksta (2000); and Partner (2002) also described LCPC method (Laboratory, Civil Performance Concrete). This method is used for a civil engineering concrete when the compressive strength is greater than 30 MPa. It consists of determining certain properties of the selected components (packing density, real density, absorption, grading curve). These data are introduced into specially designed software with built-in models to predict the flow behavior, the passing ability and the risk of segregation. The software is then used to estimate the actual content of each component as to meet the set of requirements. The theoretical optimum mix is later adjusted by lab tests.

2.2.6 Engineering Properties of SCC

The main characteristics of SCC are the properties in the fresh state. The SCC mix design is focused on the ability to flow under its own weight without vibration, the ability to flow through heavily congested reinforcement under its own weight, and the ability to obtain homogeneity without segregation of aggregates. Workability measures the easiness of fresh concrete to be placed and to flow around reinforcement without blockage. Workability combines all features of fresh concrete to assess the self-compactibility of a concrete (EFNARC, 2005). The workability requirements for successful placement of SCC necessitate that the concrete exhibits excellent deform ability and proper stability to flow under its own weight through closely spaced reinforcement without segregation and blockage. Ensuring high stability is important to limit bleeding, segregation, and surface settlement of concrete after placement and secure uniform properties of the hardened concrete, including bond to embedded reinforcement. The American Concrete Institute (ACI) and the American Society for Testing Materials (ASTM) Committee C09.47 on Concrete and Concrete Aggregates are involved in the development of quality control standards. Three functional requirements are internationally recognized as the main characteristics of SCC in the fresh state (Petersson et al., 2003): -

Filling ability: SCC must flow into forms and around obstacles such as reinforcing steel under only the force of gravity. This does not mean that all SCC is self-leveling, however. Filling ability is the ability of fresh concrete to change its shape under its own weight, and it is a balance between deformation capacity and deformation velocity. For example, a concrete with high deformation capacity and very low deformation velocity tended to be very viscous and would take long time to fill the formwork. Deform ability includes two aspects:-The deformation capacity is the maximum ability to deform, that is, how far concrete can flow, and deformation velocity refers to the time taken from the concrete to finish flowing, that is, how fast concrete can flow.

Passing ability (resistance to blocking): SCC must pass through various obstacles and fill the open spaces in the formwork without blockage due to aggregates being restricted from passing through narrow openings. Typical aggregate size for opening size relationships are at least 1:2, such that, for example, a 6.4 mm maximum nominal size aggregate would require a 12.5 mm or larger opening.

Stability (segregation resistance):-SCC must have dynamic stability of remaining homogenous throughout mixing, transporting, placing, and have static stability during finishing and curing.Segregation includes that between water and solid or between paste and aggregate or between mortar and coarse aggregate in both stationary and flowing states. Several methods have been created to assess each of these characteristics of SCC. However, the close interdependence of the SCC properties in the fresh state makes it impossible for any method to test and evaluate these properties individually. Some methods give a more limited evaluation than others; therefore, they must all be conducted and defined separately (Ferraris et al., 2000).

To achieve a high workability and avoid obstruction by closely spaced reinforcing bars, SCC is designed with limits on the nominal maximum size (NMS) of the aggregate, the mount of aggregate, and aggregate grading. However, when the workability is high, the potential for segregation and loss of entrained air voids increases. Designing a concrete with can alleviate these problems: A high fine-to-coarse-aggregate ratio, a low water– cementations material ratio (w/cm),good aggregate grading, and a high-range water-reducing admixture (HRWRA). However, care should be exercised when a higher fine-to-coarse aggregate ratio is used for shrinkage would increase. Viscosity modifying admixtures (VMA) is also used to reduce the tendency for segregation and enhance the stability of the air-void system. (Khayat, 1998; Khayat and Assaad, 2002).

The slump-flow value describes the flow ability of a fresh mix in unconfined condition. It is a sensitive test that will normally be specified for all SCC, as the primary check that the fresh concrete consistence meets the specification. The basic equipment is the same as for the conventional slump test. However, the sample placed into the mold is not rodded. When the slump cone has been lifted and the sample has collapsed, the diameter of the spread is measured rather than the vertical distance of the collapse. Table 2.1 shows the slump flow classes and the corresponding structural application of SCC (EFNARC, 2005).

Table 2.1 Slump-flow classes and structural application (EFNARC, 2005)

Classes	**Characteristic and Application**
SF1 (550-650) mm	*Unreinforced or slightly reinforced concrete structures that are cast from the top with free displacement from the delivery point (e.g. Housing slabs).*Casting by a pump injection system (e.g. Tunnel linings).*A section that is small enough to prevent long horizontal flow (e.g. Piles and some deep foundations).
SF2 (660-750) mm	Suitable for many normal applications (e.g. Walls and columns).
SF3 (760-850) mm	Typically produced with a small maximum size of aggregate (less than 16mm) and is used for vertical applications.

Passing ability (PA) describes the capacity of the fresh mix to flow through confined spaces and narrow openings such as areas of congested reinforcement without segregation, loss of uniformity or causing blocking. The defining dimension is the smallest gap through which SCC has to continuously flow to fill formwork. This gap is usually, but not always related to the reinforcement spacing. Unless the reinforcement is very congested, the space between reinforcement and formwork cover is not normally taken into account as SCC can surround the bars and does not need to continuously flow through these spaces. Examples of passing ability specifications are given in Table 2.2 (EFNARC, 2005).

Table 2.2 Passing ability classes and structural application (EFNARC, 2005)

	Characteristic and Application
PA1	Structures with a gap of 80 mm to 100 mm, (e.g. Housing, vertical structures).
PA2	Structures with a gap of 60 mm to 80 mm, (e.g. Civil engineering structures).

Segregation resistance (SR) is fundamental for SCC in-situ homogeneity and quality. SCC can suffer from segregation during placing, and also after placing but before stiffening. Segregation, which occurs after placing will be most detrimental in tall elements and even in thin slabs, it can lead to surface defects such as cracking or a weak surface. Segregation resistance becomes an important parameter with higher slump- flow classes and /or the lower viscosity classes, or if placing conditions promote segregation. Segregation resistance (SR) is classified, as shown in Table 2.3 (EFNARC, 2005).

Table 2.3 Segregation resistance classes and structural application (EFNARC, 2005)

Classes	Characteristic and Application
SR 1	Generally applicable for thin slabs and for vertical applications with a flow distance of less than 5 meters and a confinement gap greater than 80 mm.
SR 2	Preferred in vertical applications if the flow distance is more than 5 meters with a confinement gap greater than 80 mm in order to take care of segregation during flow.

Filling ability, passing ability and stability of mixtures can be considered as the distinguishing properties of fresh SCC (Okamura and Ouchi, 1999). These requirements are not common to conventional concrete and, therefore, are handled through special tests. These tests should be done carefully to ensure that the ability of SCC to be placed remains acceptable. The flow properties of SCC have been characterized (Sonebi and Bartos, 2002; Geiker and Brandl et al., 2002; Banfill, 2003).Walraven (2003) indicated that the type of application should determine the properties of SCC necessary for the job. Based on experience, it was found that various consistency classes could be defined using a combination of V-funnel time and slump flow distances. The application – walls, floors, ramps – would then indicate the requirements of these two tests Figure 2.3. In the case of ramps, for example, a V-funnel time of 9 – 25s and a slump flow of 470 – 570 mm is suggested. With experience gained from further studies, it may be possible to even set limits on the water content, powder content (or water-to-powder ratio), mortar and coarse aggregate content for a particular type of application. In other words, based on the application, one would be able to choose the required consistency class, which can be built into the mixture design procedure of SCC for appropriate selection of ingredients. This can only be possible if mixture design guideline tables for SCC, on the lines of the conventional concrete design procedures, are created using an available database. Figure 2.3 shows the structural application of SCC.

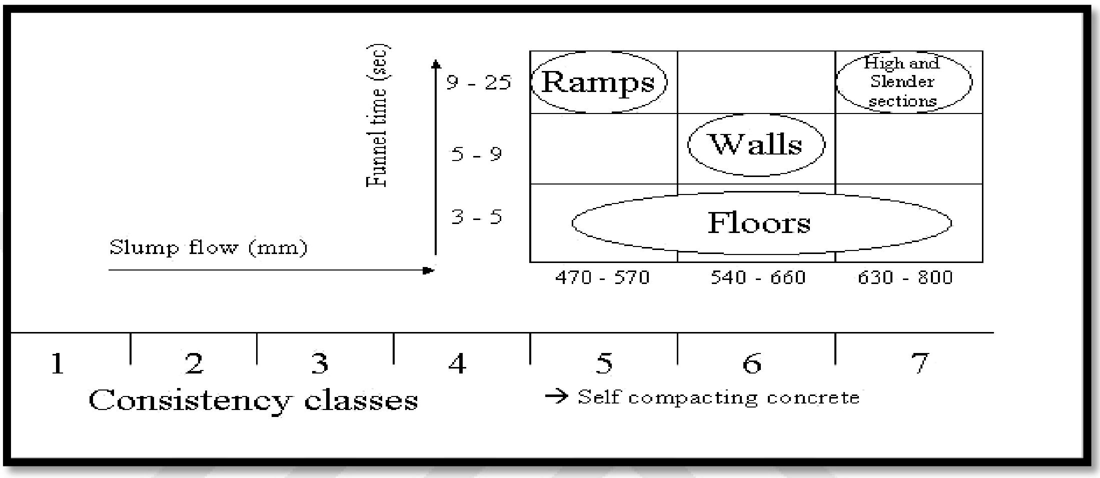


Figure 2. 3 Structural applications of SCC (Walraven, 2003)

To obtain homogeneity in the hardened properties, the segregation of coarse aggregate and bleeding must be avoided. The proneness to segregation of coarse aggregate can be evaluated on the fresh concrete with the stability sieving test. Alternatively, it can be assessed by measuring the mean distance from the surface of the two aggregate particles closest to surface (Tviksta, 2000).SCC should have slightly different criteria depending on what kind of construction is used for and if the part of the construction is horizontal or vertical. Different criteria for test methods used are given in Table 2.4 (EFNARC, 2005).

Table 2.4 Acceptance criteria for SCC (EFNARC, 2005)

Application	**L-Box h2/h1**	**Slump Flow (mm)**	**T500 (mm) (S)**	**V-Funnel (S)**
Civil-engineering vertical	≥0.80	650-725	3-7	5-15
Civil-engineering horizontal	≥0.80	600-650	3-7	5-15
Housing-building vertical	≥0.80	600-700	2-5	5-15
Housing-building horizontal	≥0.80	600-700	2-5	5-15

* Structural SCC: strength ≥ 30 MPa

Rheology is the study of material flow, or deformation, under stress. The ideal rheological model is show in Figure 2.4. The fresh state characteristics of cementations materials can be described using rheological parameters. For cementations materials, rheological parameters help in describing the ease with which it can be used in the fresh state, including workability, place ability, compactibility, finish ability, flowability, pumpibility, and extrude ability. Different applications require different rheological characteristics. By understanding the theology of basic cementations materials, mix designs can be tailored to the desired applications (Kuder et al., 2007). Banfill (2003) defined rheology as the science of the deformation and flow of matter, and the emphasis on flow means that it is concerned with the relationships between stress, strain, rate of strain, and time. Concrete and mortar are composite materials, with aggregates, cement and water as the main components, described concrete as really a concentrated suspension of solid particles in a viscous liquid fluid and is itself composed of particles in a liquid.

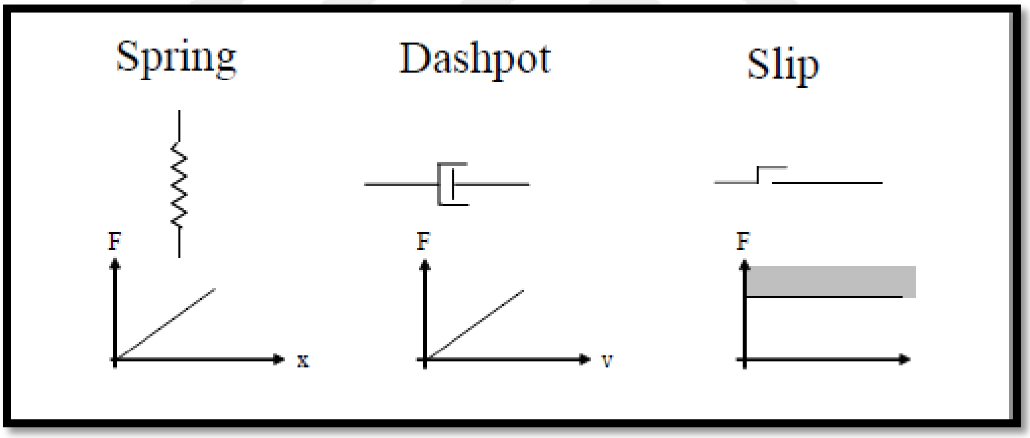


Figure2.4 Ideal models, describing elastic and plastic behavior (Kuder et al., 2007)

2.3 Applications of Nanotechnology and Nano Materials in Construction

Nanotechnology is an evolving field of science associated to the understanding and control of matter at the nano scale, at dimensions between approximately 1 and 100 nm. At the nano scale, exclusive phenomena qualify version applications. Nanotechnology implicates nano scale science, engineering, and technology that involve imaging, measuring, modeling, and employing matter at this length scale (www.nano.gov, 2007). Nanotechnology, introduced almost a half century ago, is one of the most active research areas with both novel science and useful uses that has gradually well-known itself in the past two decades (Sanchez and Sobolev, 2010). Nanotechnology is not simply working on ever-smaller dimensions; rather, working at the Nano scale qualifies scientists to consume the exclusive physical, chemical, mechanical, and optical properties of materials that naturally occur at that scale.Not surprisingly, it is observed that expenditure on nanotechnology research is significant. Actually, nanotechnology is not a new science or technology. It was believed first introduced by Richard P. Feynman in his lecture at the California Institute of Technology in 1959. However, the research on this topic has been very active only in recent two decades. This is because the development and application of nanotechnology are relying on the development of other related science and technology such as physics and chemistry that are commonly newer to break through at that time(Roco et al., 1999). Nanotechnology is the creation of materials and devices by controlling matter at the levels of atoms, molecules, and supra molecular (nano scale) structures (Mann, 2006).In other words, it is the use of very small particles of materials to create new large-scale materials. Although some researchers used more thorough definitions as well, the key is the size of particles because the properties of materials are dramatically affected under a scale of the nanometer (nm) and 9 meter (m)(Balaguru, 2005).

Most promising developments of nanotechnology are fullerene (a new form of carbon, C60) and carbon nanotubes.The new features of construction materials and elements accordingly change the material usage and force and resistance calculations of project design and its related fields construction operation and management. Nanotechnology considers two main lines:-

(a) the ‘‘top down” approach in which larger structures are reduced in size to the nano scale while conserving their original properties without nuclear-level control (e.g., miniaturization in the domain of electronics) or deconstructed from larger structures into their smaller composite parts and (b) the ‘‘bottom-up” approach, also called ‘‘molecular nanotechnology” or ‘‘molecular manufacturing” in which materials are engineered from atoms or molecular components through a process of assembly or self-assembly (Sanchez and Sobolev, 2010).Nanotechnology can be used for design and construction processes in many areas since nanotechnology generated products have many unique characteristics. These characteristics can, again, significantly fix current construction problems, and may change the requirement and the organization of the construction process. These include products that are for: Lighter and stronger structural composites, low maintenance coating, improving pipe joining materials and techniques, better properties of cementations materials, reducing the thermal transfer rate of fire retardant and insulation, increasing the sound absorption of acoustic absorber, and increasing the reflectivity of the glass. The abbreviated list is not an exhaustive list of applications of nanotechnology in construction (Sobolev and Gutierrez, 2005).

2.3.1 Structural Composites

Steel is a major construction material. Its properties, such as strength, corrosion resistance, and weld ability, are very important for the design and construction(Schmidt and Amrhein et al., 2013).The new steel was developed with higher corrosion-resistance and weld ability by combining copper nanoparticles from at the steel grain confines. Sandvik Nano flex materials technology is the new stainless steel with *ultra-high strength, *good formability, and a *good surface finish, *its good corrosion and wear resistance can keep life cycle *costs low, and it's suitable for application which requires lightweight and rigid designs. MMFX2 is nano structure modified steel, produced by MMFX steel corp. compared with the conventional steel, it has* a fundamentally different microstructure- a laminated lath structure resembling "plywood". This unique structure provides MMFX2 steel with *amazing strength (three times stronger), *ductility, *toughness, and corrosion resistance. Due to the high cost, the stainless steel reinforcement in concrete structure is limited in high-risk environments. The MMFX2 steel could be an alternative because it has the similar corrosion resistance to that of stainless steel, but at a much lower cost (MMFX Steel) the coatings uniting convinced nanoparticles or nano layers have been industrialized for certain purposes. It is one of the chief applications of nanotechnology in construction. For instance, TiO_2 is used to coat glazing because of its sterilizing and anti-fouling properties, and it will analysis and disintegrate organic dirt through influential catalytic reaction (Arafa and DeFazio et al., 2005).

Additionally, it is hydrophilic, which allow the water to blow out lightly over the surface and wash away dirt previously broken down. Other special coatings also have been developed, such as antireflection coating, thermal control, energy sawing, anti-graffiti(Zhang et al., 2007).In 2009, the use of nano products in the European construction industry was at a relatively low level. Within the as yet small money-market in the construction industry, primarily coatings. The most important nano products in these applications seem to be nano-TiO2 and silica. A major barrier is the nano products high price of used in majority amounts. The coatings incorporating certain nano particles or nano layers have been developed for certain purpose. Nanoparticles are used in industrial and local applications to control modified product properties. For the occasion, in the area of surface coatings, nanoparticle-based additives improve scratch resistance, ultraviolet light resistance or clearness of visible light (Sepeur et al., 1999; Glasel al., 2000; Bauer el al., 2002). But there are several worries concerning possible risk to, health, safety (Lam et al., 2004; Singh et al., 2009) and environment (Karn et al., 2009).

Nano and micro electrical mechanical systems (MEMS) sensors have been developed and used in construction to monitor and/or control the environment condition and the materials/structure performance. These sensors could be embedded into the structure during the construction process.Smart aggregate, a low cost piezo ceramic-based multi-functional device, has been applied to monitorearly age concrete properties such as moisture, temperature, relative humidity and early age strengthdevelopment. The sensors can also be used to monitorconcrete corrosion and cracking.The smart aggregate can also be used for essential health monitoring. The unveiled system can monitorinternal stresses, cracks and other physical forces in the structures during the structures' life. It is capableof providing an early indication of the structural condition before a failure of the structure can occur (Saafi and Romine, 2005; Song and Mo, 2008).

2.3.2 Use of Nanotechnology for Structural Concrete

Concrete is one of the most common and widely used construction materials. Its properties have been well studied at macro or structural level without fully understanding the properties of the cementations materials at the micro level. The rapid development of new experimental techniques makes it possible to study the properties of cementations materials at micro/nano-scale. Research has been conducted to study the hydration process, FA reactivity, and alkali-silicate reaction

(ASR) using nanotechnology (Balaguru, 2005). The superior, attentive of the structure and behavior of concrete at micro/nano-scale could help to improve concrete properties, such as an addition of nano scale materials into cement could improve its performance. For example, Li (2004) found that nano-SiO2 could improve the compressive strength for concrete, containing large volume FA, at early age and improve pore size distribution by filling the pores between large FA and cement particles at nano scale. The dispersion/slurry of amorphous nano silica is used to improve segregation resistance for SCC (Bigley and Greenwood, 2003). It has also been reported that adding a small amount of carbon nanotube (1%) by weight could increase both compressive and flexural strength (Mann, 2006).

Cracking is a major concern for many structures. University of Illinois, Urbana-Champaign is working on healing polymers, which include a microencapsulated healing agent and a catalytic chemical trigger (Bigley and Greenwood, 2003). When the microcapsules are broken by a crack, the healing agent is released into the crack and contact with the catalyst. The polymerization happens and tie the crack faces. The self-healing polymer could be especially applicable to fix the micro cracking in bridge piers and columns. But it requires costly epoxy injection. The mechanical performance of concrete materials depends to a great extent on structural elements and spectacles that are effective on a micro- and nano scale. The size of the calcium silicate hydrate (C-S-H) phase, the primary factor responsible for strength and other properties in cementations structures, lies in the few nanometers range (Taylor, 1997). The structure of C-S-H is much like clay, with thin layers of solids separated by gel pores filled with interlayer and adsorbed water (Mehta, 1986). This has significant impact on the performance of concrete because the structure is sensitive to moisture movement, at times resulting in shrinkage and consequent cracking if accommodations in element sizes are not made (Jennings et al., 2007). Hence, nanotechnology may have the potential to engineer concrete with superior properties through the optimization of material behavior and performance needed to significantly improve mechanical performance, durability, and sustainability. The development of nanotechnology-based concrete materials requires a multidisciplinary approach, consisting of teams of concrete materials experts: civil engineers, chemists, physicists, and materials scientists (Birgisson et al., 2010).

Balaguru (2005) reports that the better understanding of the structure and behavior of concrete at micro/nano-scale could help to improve concrete properties and prevent the illness, such as alkali-silicate reaction and FA, addition of nano scale materials into cement could improve its performance. Li (2004) found that nano-SiO_2 could significantly increase the compressive for concrete, and improve pore size distribution by filling the pores between cement particles at nano scale (Bigley and Greenwood, 2003). The dispersion/slurry of amorphous nano silica is used to improve segregation resistance for self-compacting concrete (Maheswaran et al., 2012) nano materials have been developed that can be applied to concrete mix designs to study the physical, chemical and enhanced mechanical properties of concrete. Among the various developed or manufactured nano materials such as nano silica, nano alumina, nano titanium, nano zirconia, nano Fe_2O_3 etc., carbon nanotubes (CNT) or wires etc.

A cement paste is composed of small grains of hydrated calcium silicate gels, nano-sized individual pores, capillary pores, and large crystals of hydrated products. Thus, there should be room for nano-phase materials to fill the pores of the cement paste. Amorphous or glassy nano-scale silica, which is the main component of pozzolan, reacts with calcium hydroxides formed by the hydration of calcium silicates. The rate of the pozzolanic reaction is commensurate with the value of the Blaine fineness. Nowadays, using nano silica causes a noticeable increase in the cost of the construction. Moreover, this increase of cost is different from country to country and also in terms of the quality of materials. However, in the light of the commercial production of nano silica it is expected to be able to use this material in the construction industry in the future. Nowadays, there are different methods to produce NS products (Sakka and Kosuko, 2000):-

1 - One production method is based on a sol-gel process (organic or water route) at room temperature. In this process, the starting materials (mainly Na_2SiO_4 and oregano metallic like TMOS/TEOS) are added in a solvent, and then the pH of the solution is changed, reaching the precipitation of silica gel. The produced gel is aged and filtered to become a xero gel (Sakka and Kosuko, 2000). This xero gel is dried and burned or dispersed again with a stabilized agent (Na, K, NH_3, etc.) to produce a concentrateddispersion (20 to 40% solid content) suitable for use in the concrete industry (Sobolev and Gutierrez, 2005; Hermosillo et al., 2006).

2- An alternative production method is based on vaporization on silica between 1500 to 2000°C by reducing quartz (SiO_2) in an electric arc furnace.

3- Furthermore, NS is produced as a byproduct of the manufacture of silicon metals and ferro-silicon alloys, where it is collectedby subsequent condensation to fine particles in a cyclone (Jonckbloedt, 1997; Dunster, 2009). Nano-silica produced bythis method is a very fine powder consisting of spherical particles or microspheres with amean diameter of 150 nm with high specific surface area (15 to 25 m^2/g).

4- Estevez et al. (2009) developed a biological method to produce a narrow and bimodaldistribution of NS from the digested humus of California red worms (between 55nm to 245nmdepending of calcination temperature). By means of this method, nano particles having aspherical shape with 88% process efficiency can be obtained. These particles were producedby feeding worms with rice husk, biological waste material that contain 22% of SiO2.

5- NS can also be produced by precipitation method. In this method, NS isprecipitated from a solution at temperatures between 50 to 100 °C (precipitated silica)(Lieftink, 1997, Sobolev, Flores and Hermosillo, 2006). It was first developed by Iller in 1954. This method uses different precursors likesodium silicates (Na2SiO3), burned rice husk ash (RHA), semi-burned rice straw ash(SBRSA), magnesium silicate and others (Lieftink, 1997;Sakka and Kosuko, 2000;Thuadaij and Nuntiya, 2008).

In addition, nano-silica (NS) is being developed by way of an alternative production route.Basically, olivine, and sulphuric acid is combined, whereby precipitated silica with extremefineness but agglomerate form is synthesized (nano-size with particles between 6 to 30 nm),and even cheaper than contemporary micro-silica (Lieftink, 1997). On the other hand, colloidal nano-silica, which is manufacturedas a suspension stabilized by a dispersive agent, is aready-to-use form of nano-silica (Said and Zeidan et al, 2012). Colloidal silica (CS) denotes small particles consisting of an amorphous SiO2 core with ahydroxylated surface, which are insoluble in water. The size of the particles can be varied between 1 and 500 nm, hence they are small enough to remain suspended in a fluid medium without settling. Parameters such as specific surface area, size and size distribution can be controlled by the synthesis technique. Dueto the high specific surface area for the nano-meter sized CS particles they constitute a highly reactive siliceous material. The presence of nano-silica is due to its chemical reactivity upon dissolution (pozzolanic activity) or to a considerable surface activity (Achraf et al., 2011). The microstructural studies of mortar specimens with and without nano particles have revealed the mechanisms for improved performance with nano-SiO2 (Sanchez and Sobolev, 2010). In concrete, the micro-silica (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 physically one, because micro-silica is about 100 times smaller than cement (Dunster, 2009). Nano-silicaadditionincementpasteandconcretecanresultindifferenteffects.Theacceleratingeffectincementpasteiswellreportedintheliterature(Qing and Zenan et al., 2007; Lin, and Chang et al., 2008).Themainmechanismofthisworkingprincipleisrelatedtothehighsurfaceareaof NS,becauseitworksasnucleationsitesforthat causes significant enhancement in the performance of end product (Sobolev, 2005; Jo and Kim et al., 2007).

2.4 Composite Columns

The steel tube in a concrete filled steel column goes about as longitudinal and lateral reinforcement subjected to longitudinal compression and hoop tension, while the concrete is focused on tri-pivotally. The benefits of the concrete filled steel tube (CFST) columns over other composite frameworks are that the steel tube gives support, formwork for concrete, averts concrete spalling, natural harm and from hostile offices while concrete in the steel tube bolsters thin dividers and delays/avoids nearby clasping of the steel tubing. The composite columnsadd significant stiffness to the structure when contrasted with additional customary steel outline.(Giakoumelis and Lam, 2004).

The CFST members, including a hollow steel tube filled with concrete, have been utilized in several structural applications, particularly for columns in high rise buildings and bridge piers. The other uses comprise the structural purposes in civil infrastructural work, industrial construction, offshore oil and gas installation and protective structures. A number of design codes on CFST members have been found by American, Chinese, Europe and Japanese codes as well as CIDECT guide (International Committee for the Development and Study of Tubular Structures). They describe several cross-sections for CFST as illustrated in Figure 2.5. Different types of double symmetric CFST members with uniform cross- section over the member length are given in figure. The members can be formed without reinforcement and with reinforcement or with an encased steel section inside (BC4, 2015).

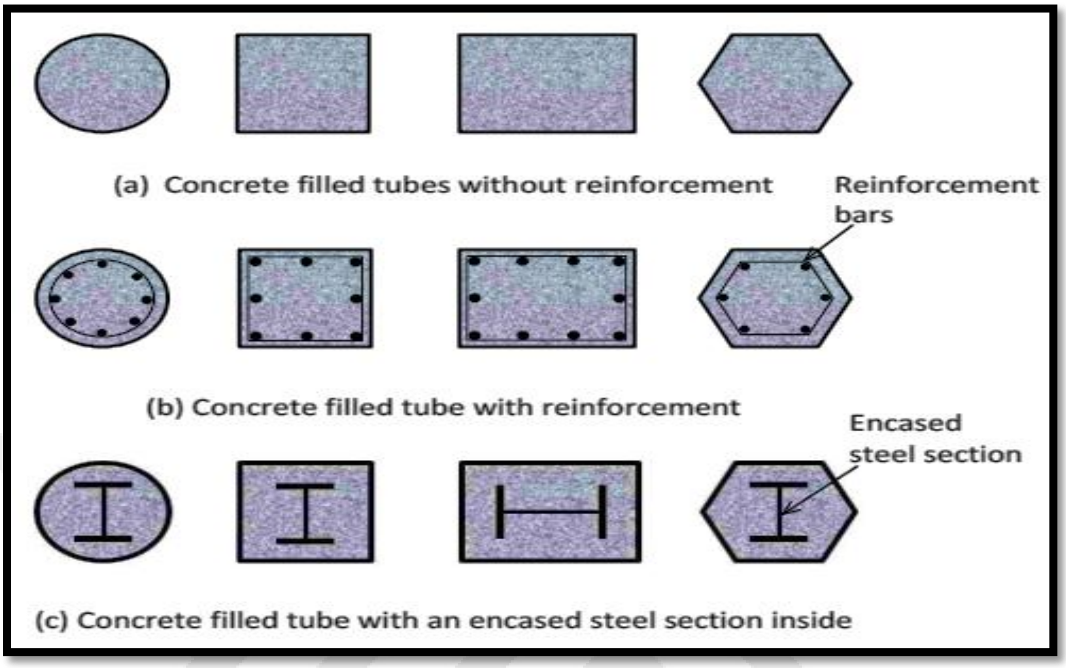


Figure 2.5 Types of double symmetric concrete filled steel tubular members (BC4, 2015)

2.4.1 Historical background

The ideas in development construction have changed from one of securing strength to that of stressing the materials to the optimum values. This has brought about light structures contrasted with the pre-nineteenth century developments. This has been made conceivable by eliminating in the more up to date materials, the short comings of poor tensile strength of the conventional materials, that's with the advent of steel and reinforced concrete. The advanced inquire about on CFST column has been fundamentally looked into and gathered under different classes. In 1940's, the historical backdrop of the main utilization of composite columns in development industry has been seen and the details of the advances are given blow:-

In 1966, concrete filled steel tubular columns are used as bridge piers, the four level motor way bridge at Almonds bury in U.K. was constructed using tubes with (1070 mm) diameter, steel thickness of 50 mm, and core concrete grade was M30. U.K. and U.S.A interested this type of construction. Because of improvement of outline strategies and codes. The development is significantly encouraged because of improvement of high strength, high performance concrete (up to 100 MPa), admixtures and self-compacting concrete. 1970, the development of cement filled steel tubes in Japan and this practice was taken after by numerous nations around the globe. After, on the evidence of the investigation comes about, numerous nations have built up their design codes for use by their engineers. The current design principles and determinations have created either from the steel or concrete design approach of that time. Basu and Sommerville proposed a design method which adopted by European codes, then modified by Virdi and Dowling later. In 1981 published by European Committee of Constructional Steel Research (ECCS).A significant amount of effort over thepast 40 years has been aimed for better understanding of circular concrete filled tubes. Be that as, it has been demonstrated that the enhanced strength of the circular thin-walled tubes filled with concrete is because of the impact of bond between the steel tube and concrete as opposed to side longer striation (Kibriya and Iqbal, 2007).

2.4.2 Studies on Geometrical Effects

The behaviors of concrete filled steel tubular columns, are studied by (Dutta and Bhattacharyya, 1995), they concentrate the load conveying limit of concrete filled steel tubular columns and found that, this load is more than at of hollow steel tubular columns. It is accounted for that this expansion in strength is not simply because of the addition of individual capacity, but due to confinement of concrete. (Sakino et al., 2004) investigate the confining effect of steel tubes on concrete strength and there stressing impact of the concrete fill on local buckling of the steel tube wall, experimental investigations on centrally loaded hollow and CFST short columns. The purposes of these tests were to and furthermore to develop procedures to assess ultimate load and load - deformation relationships. As indicated by the estimations of the diameter to thickness (D/t) or width to thickness (B/t) proportion, the examples were arranged into three gatherings. The estimation of D/t proportion or B/t proportion was controlled by changing the outside diameters of circular tubes, or the widths of square tubes.Outline equation to assess the ultimate axial compressive load limits were proposed for CFST columns with both circular and square sections in view of tests results was gotten. The contrast between the ultimate strength and the nominalsquash load of circular CFST columns, which is given by confining theconcrete, can be evaluated as a linear function of the tube yield strength. The capacity reduction factor because of the local buckling of the square steel tube wall was observationally inferred in view of the test consequences of columns. Kuranovasand Kvedaras (2007) investigate the yield and ultimate strength of circular hollow sections. It was measured by standard steel plate coupons and rings tests. The oretical and test examinations demonstrated that conduct of hollow steel tube components was more complicated than that of solid ones. Due to complex hollow stress states, none of stresses in hollow concrete core were equitably disseminated through the thickness of its cross-segments. They additionally talked about the Poisson's proportion of the CFST and solid sections.

In the study of Yadar and Chen (2017), the load carrying CFST column under the effect of compression was investigated for different D/t ratios. They fixed the diameter of the steel tube as 150 mm but changed the thickness from 1.2 to 10 mm. Thus, the D/t ratios varied from 15 to 125. They reported that when the D/t ratio was raised, the capacity of the column was observed as dropping up to 67.9 %. Figure 2.6 shows the force- displacement curves of the columns having various D/t ratios. Yu et al. (2007) concluded that by using higher strength concrete, the specimens with the whole segment stacked encountered a noteworthy increment in the ultimate capacity, yet their remaining limit after disappointment was practically constant. These conclusions set through concentrated the conduct of circular concrete-filled steel tube stub columns with self-compacting concrete and normal concrete concentrically stacked in compression to failure was. However, the ultimate capacity and residual capacity were hardly influenced. The conduct of these stub columns in restriction was examined. In the event that:-

- The steel tube was notched, the axial compressive stiffness of specimens was reduced; in some cases, and the ultimate capacity was also reduced.
- The steel tube acted more as a transverse confinement than an axial compression component.

The steel tube was notched with small holes in the mid height region, the confinement effect was presented earlier and enhanced. But the axial compressive stiffness got reduced. Han et al. (2008) utilized a finite element analysis modeling for analyzing concrete filled steel tubular columns that were subjected to axial local compression, as well as experimentally investigation the behavior of the CFST subjected to axial compression. And the comparison of results was showed generally good agreement with the test results. For a accessibility of analysis, strength index (SI) and ductility index (DI) for CFST were calculated so, the higher the SI and the DI be, when the end plate thickness are bigger.

2.4.3 Effect of Concrete Zone and Confinement

The concrete behavior under confined and unconfined condition is completely changed. Figure 2.6 illustrates the influence of the confinement. As seen from the figure, the initial stiffness, strength level as well as the ductility are significantly affected by the presence of the confinement (Yadar and Chen, 2017).

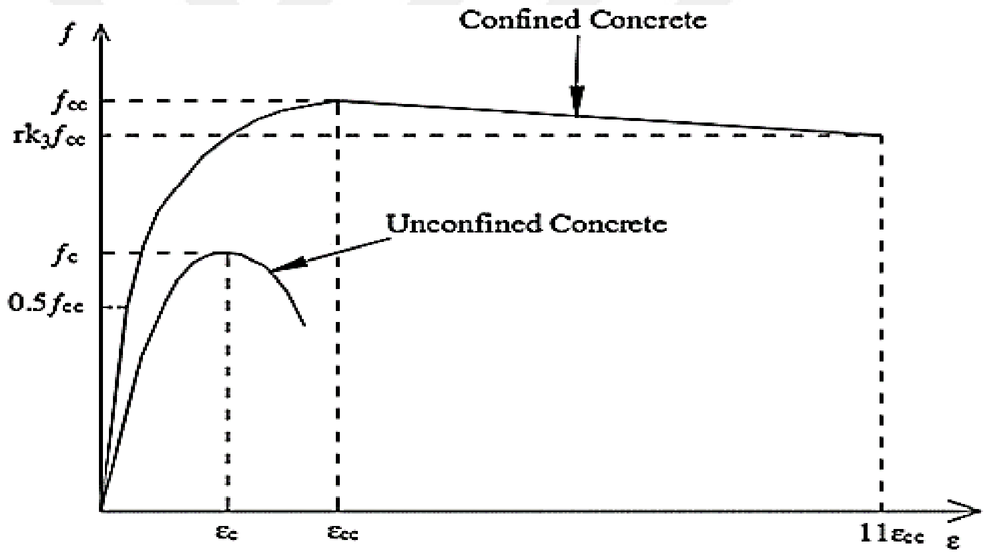


Figure 2.6 Equivalent stress- strain curves of unconfined and confined concrete (Yadarand Chen, 2017)

Knowls, and Park,(1969); Giakoumetic and Lam, (2014) and Kibriya, (2005); saw that the imprisonment effect of concrete increments the concrete strength for concrete filled circular sections, because of concrete imprisonment the stress bearing limit of concrete expanded 3.5 to 4.5 circumstances in circular columns. They suggests that when diameter is kept consistent and steel thickness is increased, the confinement factor increments subsequently expanding the compressive strength of concrete. They have too been observed that for circular sections, increment in concrete zone increased the strength of the column.

In another study for forwarded by Yadar and Chen (2017), the effect of concrete zone grade on the axial behavior of concrete zone grade on the axial behavior of CFST columns was examined. Figure 2.7 indicates the load- displacement curves of the composite columns having different concrete core strength. It was thought that the strength of concrete decided the stiffness of the columns. The ultimate strength of the CFST columns increased with rising the concrete compressive strength. The increasing concrete strength from 30 to 70 Mpa resulted in up to about 54% capacity increment.

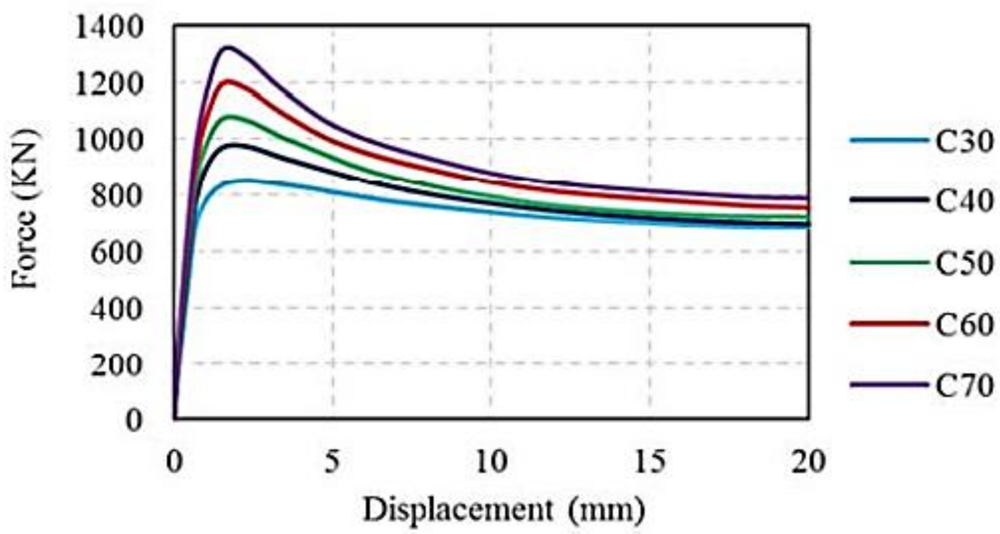


Figure 2.7 Load- displacement curves for different Grade of concrete (Yadar and Chen, 2017)

2.4.4 Column Failure Modes

Almost all columns failed due to local buckling of steel followed by crushing of concrete. The failure was a ductile one. The failure mode of all columns was because of steel plate clasping alongside run of the mill squashing failure of concrete where the steel divider was pushed out by the concrete core, which was bound by the steel as appeared in Figure 2.8. At the point when the steel was expelled from the specimen after failure, the concrete was found to have taken the state of the deformed steel tube, which delineates the composite activity of the segment (Kibriya, 2006). In the study of Lam and Testo (2008), the typical failure mode of the composite elliptical hollow section (EHS) specimen is shown in Figure 2.9. For the unfill specimen, both inward and outward local buckling was observed in the deformed specimen while for the fill specimen, even though inward buckling was prevented by the concrete core, outward local buckling was clearly evident in the deformed specimen.

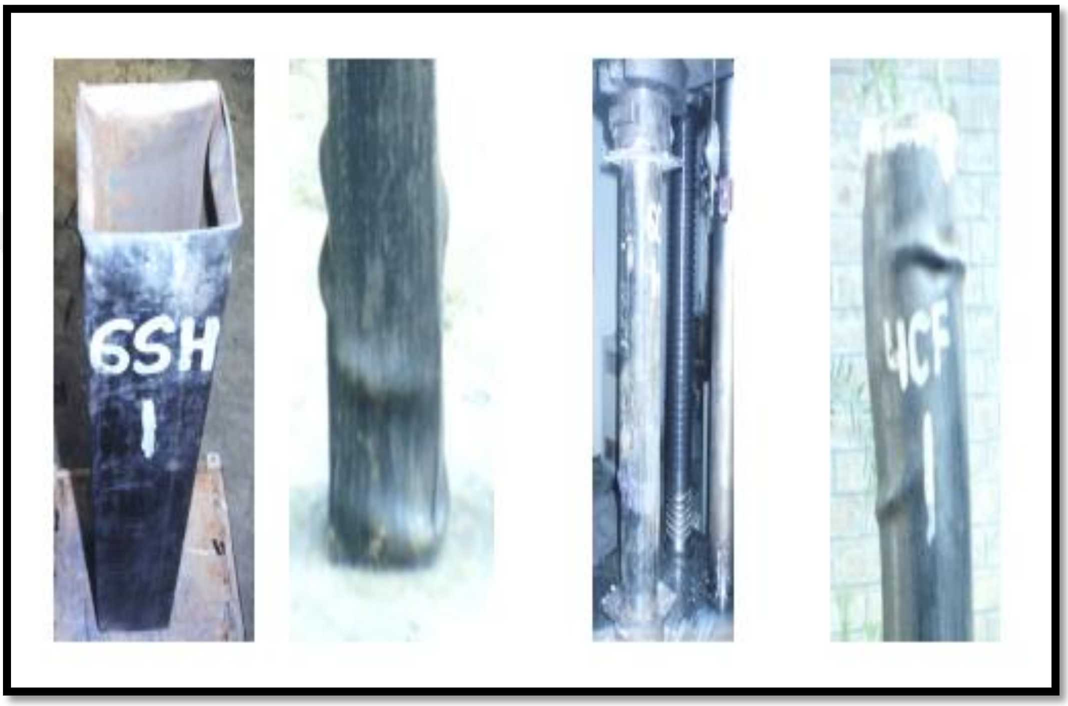


Figure 2.8 Photographs showing failure modes of columns (Kibriya, 2006)

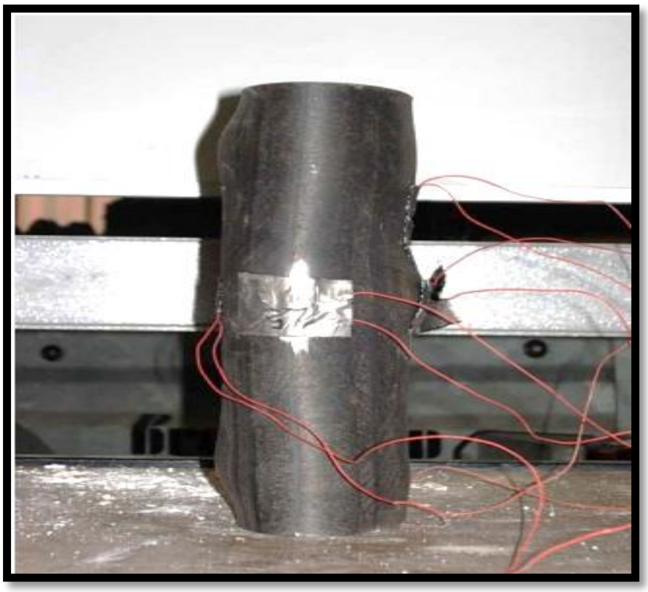


Figure 2.9 Typical failure mode of composite EHS (Lam and Testo, 2008)

2.4.5 Use of SCC in CFST Columns

Self-compacting concrete (SCC) consolidates under its own weight with no vibration and without exhibiting segregation or bleeding assures the structural integrity and uniformity of the cross-sectional area of such deep sections.Compacted concrete might segregate whilst under compacted concrete can have voids and cavities. Consequently, the integrity and uniformity of the concrete cross-section is not assured, adversely affecting the strength.The compressive strength of concrete and the integrity of the concrete cross section within the confined steel tube depend on the effective consolidation of fresh concrete during placement achieved through vibration. In shallow and smaller concrete sections with limited openness, consolidation of concrete is mostly difficult (Kibriya, 2006). Kibriya and Iqbal (2007) stated that the research on the structural behavior of confined SCC tubes as columns is scare and there is little data available. They studied experimentally the performance of the short column made with SCC, with blended cement containing 75% cement and 25% rice husk ash. They reported that SCC with blended cement increased the load carrying capacity of hollow steel columns by 350 to 460 % for square and circular columns, respectively. The failure strains observed for SCC with blended cement filled column were similar to those for tubes with normal concrete.

In the study of Thanuja et al. (2013), they made a comparison with predicted formula on the behavior of circular concentrically loaded SCC fibre reinforced filled steel tube columns and studied the experimental behavior. Concrete of design strength of 70 MPa was produced using crimped steel fibres was made from low carbon drawn flat wires, employed with volume percentage equal to 0.5% to 2.0% by volume of concrete corresponding to 76 kg/m^3. And included steel tube with, D/t ratio, L/D ratio of steel tube and addition of % of steel fibre. The influence of these parameters on the confinement of the concrete core the compression shared by the steel tube and ultimately load carrying capacity of the CFST was investigated, thenconcluded that fiber reinforced SCC filled steel tubular columns has relatively high stiffness compared with plain concrete filled columns, while the ductility is found to be almost equal and the energy absorption capacity of the composite columns was enhanced when use fiber reinforced SCC in the steel tube results The use of fiber reinforced SCC increase the load bearing capacity compared with that of unfilled columns and reduces the lateral displacements. The load carrying capacity of the steel tube per unit volume decreases as the D/t ratio increases for the bare tube.

2.4.6 Summary on Composite Columns

A concrete filled structural hollow section provides architects and engineers with an aesthetically pleasing, robust and inherently fire resistant column. This publication contains design information for these columns for both the ambient temperature and fire conditions. The information is based on the European code for composite construction for the ambient temperature condition, BS EN 1994-1-1. The reports of earlier research work on composite columns shows the large deviations between theoretical and experimental strengths; these due to an enhanced load carrying capacity. CFST columns has concerned the considerations of researchers all over the world, and has now grown more significance due to the behavior of CFST columns and its benefits terminated the present conventional construction systems. Above the last 40 years has been made in the investigation of CFST columns (AIJ, 1997).As of the literatures reviewed From the past studies the essential facts on ultimate strength of the composite construction system is well understood, and the load carrying capabilities of CFST columns are more than that of hollow steel tubular columns, as well as due to the system's construction efficiency saves construction cost, time, and man ability, that's proved that the CFST columns are valid to high rise and long span structures**.** The researchers have studied the behavior of CFST columns, due to the value of L/D with strength of concrete. The studies led in the past, it was found that many analytical models were advanced and related with experimental results. As well as, finite element analysis using ANSYS models were developed to predict the ultimate load and behavior of columns. The international codes like ACI 318, AISC-LRFD, BS 5400, and AS 4100 were taken into consideration in the present study and these codes were found to underestimate the critical loads when compared with the test results. Eucode 4 was found to closely forecast the behavior of CFST columns and to treat the effect of long span loading separately (Kibriya, 2006).

2.4.7 Application of CFST Columns in Structure

The two opposite materials, structural steel and reinforced concrete, are presented and it is shown how composite action is attained in the case of composite slabs, beams, and columns. The most important and most commonly faced combination of construction materials is that of steel and concrete, with applications in multi-story, commercial buildings, and bridges. The materials can be used as concrete cores surrounded by steel tubes, where members consisting of steel and concrete performance together compositely. The different materials have almost the same thermal expansion, ideal combination of strengths with the concrete efficient in compression and the steel in tension, concrete protect steel from corrosion ion and thermal insulation at raised temperatures and additionally can restrain slender steel sections from local or lateral torsional buckling.Composite construction depends on the positions. Though, that engineers are progressively designing composite and mixed building systems of resistance and ductility Figure 2.10 shows some examples of application of the composite members (Şamhal, 2005). Concrete filled steel tube columns, CFST are increasingly useddue to the advantages and the cost of using in bridges and larger-span buildings (Abed et al., 2013).

Another application of CFST columns are structural truss hollow sections. Because of the attractiveness of their shape, to express a lightness, the geometrical properties determine their use and to avoid having a very large size column, leads to use hollow sections nearly cover all fields. It can be used in the roof of airport, railway station and stadium with larger load eccentricity ratio and slenderness ratio Figure 2.11a. CFST built-up columns can be achieved larger flexural rigidity with a smaller diameter columns, and column mainly subjected to the axial loads, large compressive strength characteristics of CFST column can be exerted so CFST are widely used in structural members, industrial buildings as given in Figure 2.11b, c (Han et al., 2014).

In general, a composite column must be intended for a definitive point of confinement state. For structural capability, the interior strengths and moments resulting from the most disapproving load. Combination not the design resistances of the composite cross-sections. While nearby clasping of the steel sections might be eliminated, the decrease in the compression resistance of the composite column because of general clasping ought to be considered, together with the effects of residual stresses and initial imperfections. Although local buckling of the steel sections might be eliminated, the decrease in the compression resistance of the composite column because of general clasping ought to be considered, together with the effects of residual stresses and initial imperfections. Additionally, the second effects in slender columns, and in addition the effect of creep and shrinkage of concrete under long-term loading in the event that they are significant. The reduction of flexural stiffness because of cracking of the concrete in the tension zone ought to likewise be considered. These are accommodated either explicitly empirically. In BS EN 1994-1-1(Şamhal, 2005).

2.4.7.1 Multi - StoreyCommercial Buildings

This kind of high building blocked on the site depends on the combination of concrete cores, steel frame and composite floor constructionwhichbecomes standard construction technique in several countries (Şamhal, 2005).

- Fleet Place house, off Holborn Viaduct has eight-storey high office in the city of London was comprehensively improved at the same time as the adjacent Thames link station Figure 2.12a, using concrete filled external circular hallow section CHS columns on each longitudinal face of the building and has clear spans on the inside. To support the existing pile caps, the CHS columns were kinked at first floor level, and linked with the behind building, where the columns were kinked at second and third floor levels. Which columns have a constant external diameter within this serial size, vary from 323.9*30 CHS at the first floor, 323.9*16CHS between second and fifth floors and 323.9*12.5CHS between sixth and seven floors. Tata Steel Celsius355 was used. The concrete infill used was to Grade 40 or Grade 60 depending on the vertical load.

- Peckham library, London, this library building is supported at the front by concrete-filled CHS columns, angled to form an irregular facade and enclosing a covered space, which is an extension of a new public square. There are 7 supporting columns, the length of each column is18metres, which are angled out of the vertical, the columns supporting steel tubular trusses at the fourth floor and a steel roof above, column at ground floor level height of 18 meters, and giving a height to width ratio of 37, and the line consists of a 323.9*20 at first floor level, these section sizes reduce to 323.9*6.3CHS members. The angling of the columns helps to provide additional stiffness against lateral loads and limits the development of bending moment in the columns. The concrete infill is reinforced with 8 T12 longitudinal bars with T6 links at 175centres. Tata Steel Celsius 355 was used Figure 2.12b.
- Queensberry house, London, to support the floors of six-storeys office and commercial buildings the steel columns CHS tubular columns used a tube-in-tube system in which one CHS section is placed inside a larger one, the column consists of a 457*10CHS outer tube and a 323.9*6.3CHS inner tube, and supports two floor beams on each side. With all the voids grouted after construction of the floor structure. There is a hull in the middle of the building, with 6 meters width, and 12 meters clear spans each side of the hull in the crosswise direction. Concrete joint bolted in the inner tube and welded on the outer tube. Tata steel Celsius 355 was used. Figure 2.12c.
- SEG Plaza, Shenzhen, China, the SEG Plaza in Shenzhen, China was the tallest building in the world using concrete-filled steel tubular columns. It has 76 storeys with a four level basement, each basement floor having an area of 9653m^2. The main structure is 291.6m high with an additional roof feature giving a total height of 361m. The diameter of the columns used in the building ranges from 900mm to 1600mm. Concrete was poured from the top of the column. The critical design loads for the SEG Plaza building were

seismic and wind loads. Therefore, rigid connections Figure 2.13d, between the steel beams and the concrete filled tubes were used (Şamhal, 2005).

2.4.7.2 Road Bridges

Steel structure is typically used with concrete as steel beams with concrete floor slabs, road bridges where concrete decks are favored. Arch bridges, Figure 2.13, in China an important advantage of using concrete filled tubes have been used in a large number of arch bridges to reduce construction cost, with relatively simple construction technology to perform the steel tube, because of the weight of a hollow steel tube is relatively low. The frequently used methods include cantilever launching and either horizontal or vertical "swing", where by each half-arch is rotated into position. The steel tubular structure is itself stable so that there is no need for formwork nor for a temporary bridge structure during concrete casting.Truss typology is adopt as a new in the arch ribs of CFST bridges , so in designthe ultimate bearing capacity of CFST truss archesestimated by equivalent beam-column method (Wei et al., 2009).

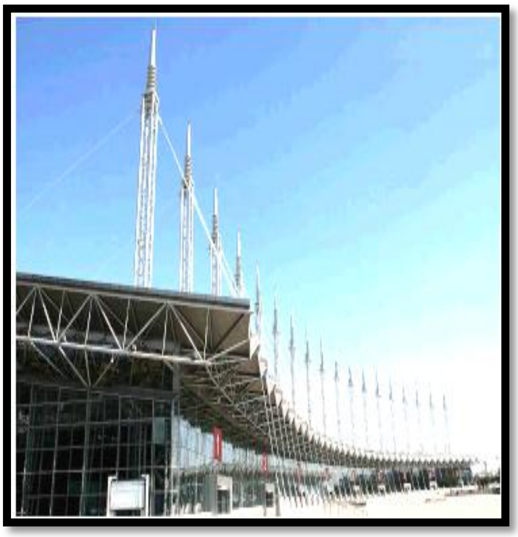
Truss arch rib can be classified as one type of CFST built-up columns. Developing country like China, incline to choice CFST arch bridge, with comparison to the developed countries, like USA and Japan, where steel arch bridges are chosen as the first CFST arch bridge is used in 1990, in China the common method to build arch bridges which is more economical. There are different cross sections of arch ribs such as singular tube arches, dumbbell type arches, and multi-tube type arches also called truss type, shown in Figure 2.14 (Chen and Wang, 2009).

CFST built-up columns applied for reducing the self-weight of spandrel structure, and decrease the arch rib deformation. As the pillar of deck arch bridge-Mendonghe River Bridge Figure 2.15. CFST built-up column is connected with CFST composite truss girders. The absence of the tedious process of framework preparation and steel fixing in the RC construction is the significant advantage for connection with CFST composite truss girders, this adopted in piers the beam bridges- Ganhaizi Bridge, located in Sichuan Province, China as given in Figure 2.16

a)b)

c)

Figure2.10 Typical composite multi- storey a) framed building, in London b) steel-frame building factory in Germany. c) The combination of concrete cores,steel frame and composite floor construction (Şamhal, 2005)

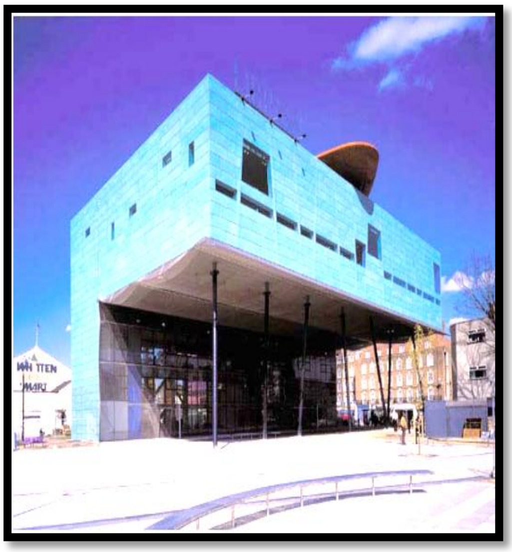


a)

b)

c)

Figure 2.11CFST Truss Structure a) Tianjin International Convention and Exhibition Center, China. b) Hengyang Heavy Machinery, China. c) Canton Tower, China, (Han et al.,2014)



a) b

)

c) d)

Figure 2.12 a) Fleet Place House, London, b) Peckham Library, London, and c) Queens berry House, London, d) SEG Plaza, Shenzhen, China (Şamhal, 2005)

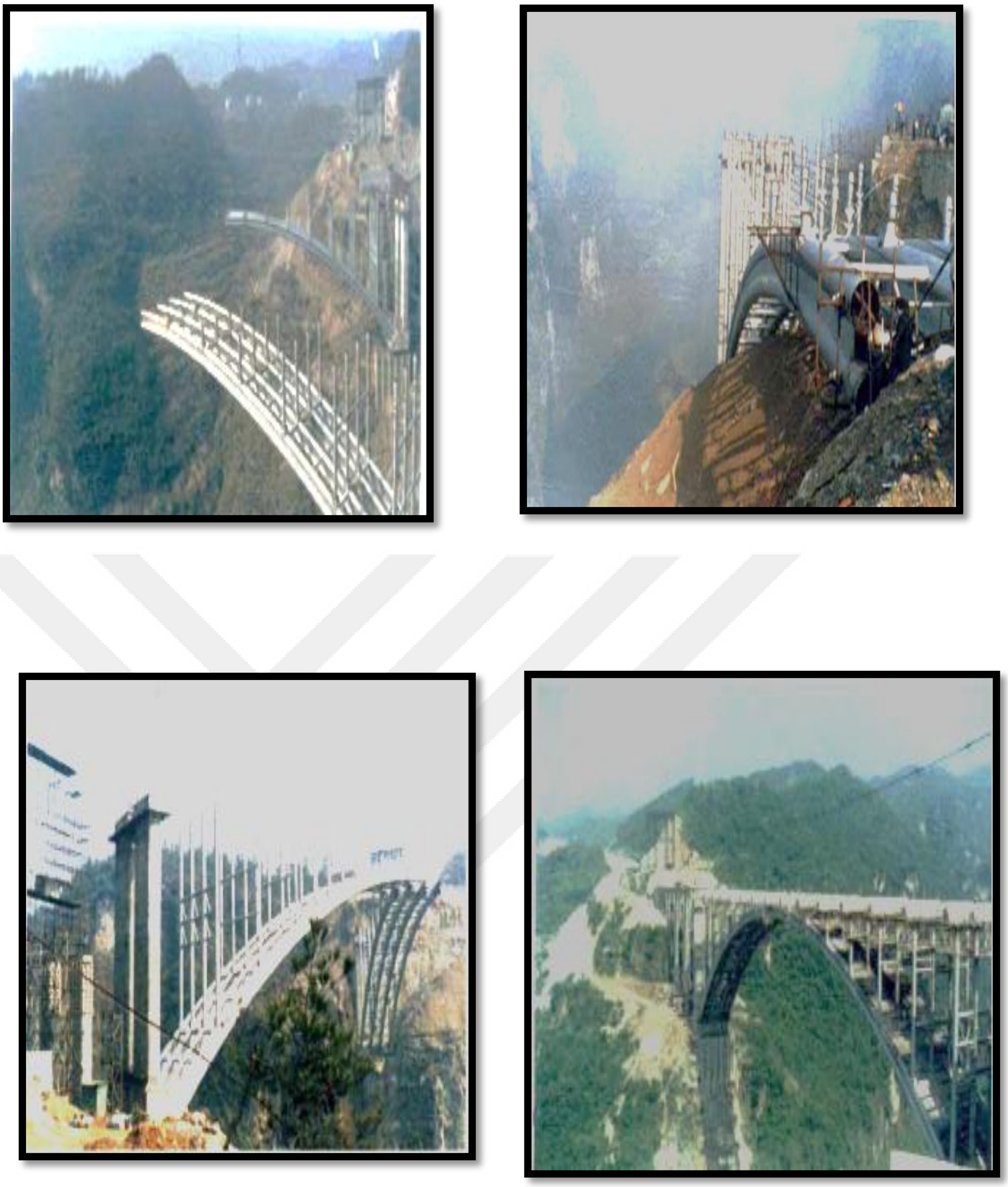


Figure 2.13 A concrete filled tubular arch bridge under construction (Photo courtesyOf Tsinghua University, China) Prof. LH Han, (Şamhal, 2005)

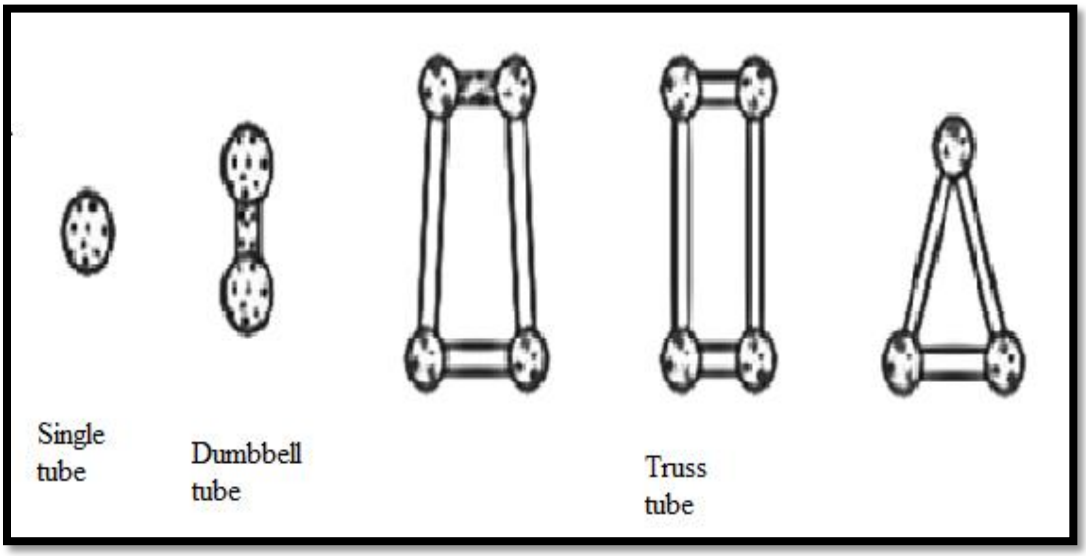


Figure 2.14 Cross – sectional type of CFST arch rib (Chen and Wang, 2009)

Figure 2.15 Built- up columns used for pillar (Mengdonghe River Bridge, China) (Huang, 2015)

Figure 2.16 Built- up columns used for continuous beam bridge (Ganhaizi Bridge, China) (Huang, 2015)

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The research methodology contained the experimental and numerical programs. In the first, the details of the study on SCC made with NS and FA were given. For this, materials used, specimens, casting and, test method were described. In the second, the details of the numerical analysiswere explained. For this, the calculation of axial capacity of the steel tubular column filled with SCC having NS and FA, key investigation parameters, and design codes were discussed.

3.2 Experimental program

3.2.1 Materials

The cement was used in all SCC mixtures is a normal Portland cement of CEM I 42.5 R (PC) which correspond to ASTM Type I. The class F FA was used. The properties of PC and FA are listed in a Table 3.1.

Table 3.1 Properties of PC and FA

Analysis report	**PC**	**FA**
Cao (%)	62.58	2.24
SiO_2 (%)	20.25	57.2
Al_2O_3 (%)	5.31	24.4
Fe_2O_3 (%)	4.04	7.1
Mg O (%)	2.82	2.4
SO_3 (%)	2.73	0.29
K_2O (%)	0.92	3.37
Na_2O (%)	0.22	0.38
Loss on ignition (%)	2.99	1.52
Specific gravity g/cm^3	3.15	2.04
Blaine fineness m^2 /Kg	326	379

As shown in Table 3.2, a polycarboxylic other type of super plasticizer (SP) with a specific gravity of 1.07 was used as a high range water reducing agents (HRWRA) to achieve the desired workability in all mixtures.

Table 3.2**Properties of SP**

Properties	**SP**
Name	Glenium 51
Color tone	Dark brown
State	Liquid
Specific gravity kg/l	1.07
Chemical description	Poly carboxylic-ether
PH- value	5.7

The coarse aggregate used in this study was river gravel with a nominal maximum size of 16 mm and the fine aggregate, a mixture of natural sand and crushed sand, was used in a production with a maximum size of 4 mm as shown in Table3.3. The particle size gradation of the aggregate mixture is presented in Figure 3.2.

Table 3.3 Properties of natural aggregates

Sieve size (mm)	**Normal weight aggregate**		
	Crushed sand	**River sand**	**Natural coarse agg.**
16	100	100	100
8	100	100	42.1
4	100	100	0
2	75.5	68.3	0
1	53.1	44.6	0
0.5	32.6	24.8	0
0.25	21.8	8.7	0
Specific gravity(g/cm^3)	2.45	2.66	2.72

Figure3.1NS picture

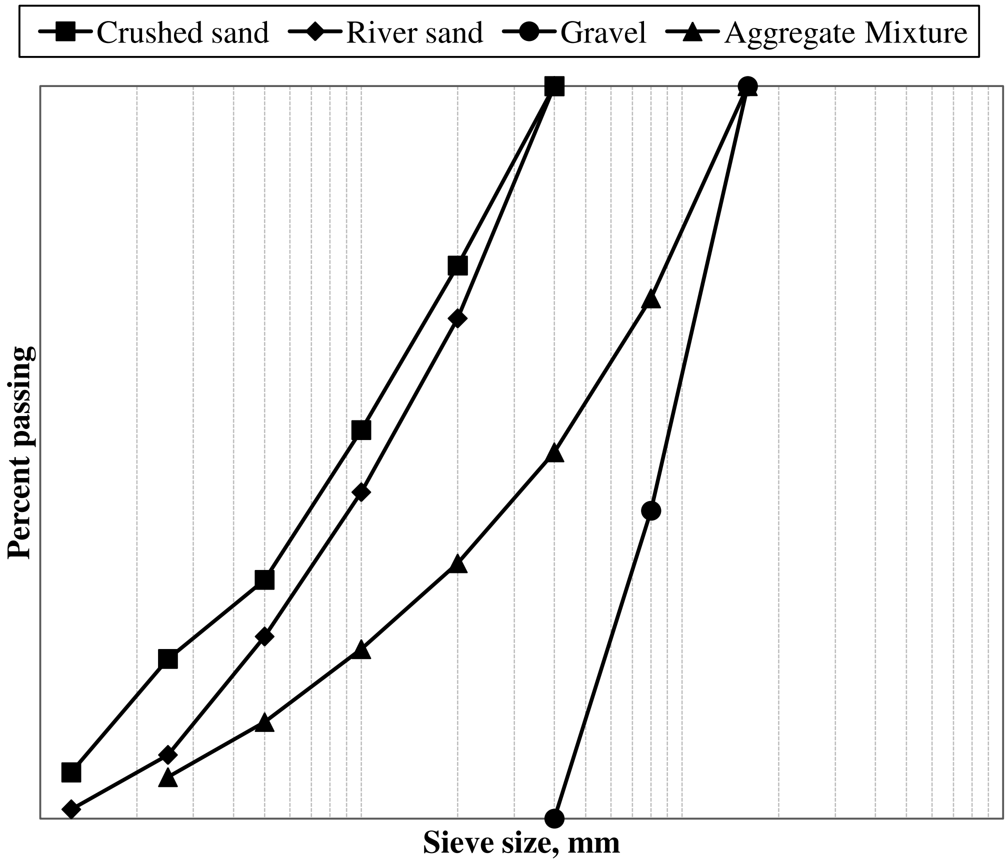


Figure 3.2 Particle size gradation

The dispersion–slurry of amorphous NS was used to improve segregation resistance for SCC as well as realized an effective way to develop high performance and SCC with improved workability, strength, and durability. A hydrophilic fumed silica with a specific surface of 150 m^2 /g used in this study .The properties of NS shown inTable 3.4

Properties	Unit	Typical value
Specific surface area (BET)	m^2/g	150 ±5
Average primary particle size	nm	14
Tapped density(Approximate value)	g/l	Ca.50
Bulk density(Approximate value)	g/l	Ca.30
Moisture (2 hours at 150C^0)	%	≤1.5
Ignition loss	%	≤1.0
PH- value	-	3.7 – 4.7
SiO_2 – content	%	99.8

.Table 3.4**Properties of NS**

3.2.2 SCC Mix Properties and Specimens

The mixtures were designed with total binder content of 570 kg/m^3 and at a w/b ratio of 0.33. Four SCC series were produced during this study and in each SCC series; the PC was substituted with NS at 0, 2, 4, and 6% replacement levels by weight. The SCC mixtures in the first series were produced without FA while in second, third, and fourth series the PC was also substituted with FA at 25, 50, and 75% replacement levels by weight, respectively. Totally 16 SCC mixtures were produced according to the above variables. The detailed mix proportions for SCCs are presented in Table 3.5. In mix ID, fly ash is represented by FA while nano-silica is denoted by NS. For example, FA25NS2 indicates that the mixture is designed with FA content of 25% and NS content of 2%. The concrete mixtures were given in Table 3.5 designed according to slump flow diameter of 750±50 mm which was achieved by using the SP at varying amounts. The mixing sequence and duration are very important in the SCC production. For this reason, mixing and batching procedure recommended by Khayat et al, (2000) was followed in this study in order to obtain the same homogeneity and uniformity in all SCCs. Regarding to this procedure, the fine and coarse aggregates were poured in a power-driven revolving pan mixer and allowed to mix homogeneously for 30s. After that about half of the mixing water was added into the mix and it was allowed to proceed the mixing for one moreminute. The aggregates, then, were left to absorb the water for 1 min. After wards, the powder materials (PC and/or FA and/or NS) were added to the wetted aggregate mixture for mixing another minute. After SP with remaining water was poured into the mixer, the mixture was mixed for 3 min and then left to rest for a 2 min. Finally, the concrete was mixed for additional 2 min to complete the production. After the mixing procedure had completed, fresh mixtures were tested.

All of the specimens were cast without any vibration or compaction. Specimens were cast from each mixture consisting of the following: - six 150 mm cubes, four 150 mm cubes, four 100x200 mm cylinders, and one 150x300 mm cylinder.

Immediately after casting and demolding, specimens were covered with polyethylene sheets and kept in the molds for 24 h in a laboratory. After that, all samples were subjected to water curing at 22 ± 2 °C until testing.

Table 3.5 Mixdesign for SCC (kg/m^3)

Mix	w/b	PC	FA	NS	Water	SP	Coarse agg.	Fine aggregate	
								sand	Crushed sand
FA0N0	0.33	570	0	0	188	3.4	836	668	167
FA0N2	0.33	559	0	11.4	188	10	825	660	165
FA0N4	0.33	547	0	22.8	188	15.7	816	653	163
FA0N6	0.33	536	0	34.2	188	21.4	807	646	161
FA25N0	0.33	428	143	0	188	2.9	812	650	162
FA25N2	0.33	416	143	11.4	188	7.0	805	644	161
FA25N4	0.33	405	143	22.8	188	14.3	794	635	159
FA25N6	0.33	393	143	34.2	188	20	785	628	157
FA50N0	0.33	285	285	0	188	2.3	789	631	158
FA50N2	0.33	274	285	11.4	188	5.7	782	626	157
FA50N4	0.33	262	285	22.8	188	12.8	771	617	154
FA50N6	0.33	251	285	34.2	188	17.1	764	611	153
FA75N0	0.33	143	428	0	188	1.7	765	612	153
FA75N2	0.33	131	428	11.4	188	4.3	760	608	152
FA75N4	0.33	120	428	22.8	188	11.4	749	599	150
FA75N6	0.33	108	428	34.2	188	14.3	744	595	149

3.2.3 Tests for Fresh Properties

The slump flow test is used to assess the horizontal free flow of SCC in the absence of obstructions and also to determine the flowability and deformability of SCC. T_{50} time that is the measured time for flowing of concrete to a diameter of 500 mm provides additional information about segregation resistance and uniformity of concrete which can be achieved from the visual observations during the test and/or measurement of T_{50} time (EFNARC, 2005). The equipment consists of a standard slump cone and flow table with a concentric diameter of 50 cm marked on it. The slump cone was filled with concrete without rodding, and then lifted up vertically. Then time for the flow to reach 50 cm diameter circle T_{50} is recorded. Then, the final diameter of the concrete is measured in two perpendicular directions. The average of the two measured diameters is taken, this is the slump flow, which is denoted as (D). Figure 3.3 shows the slump test.

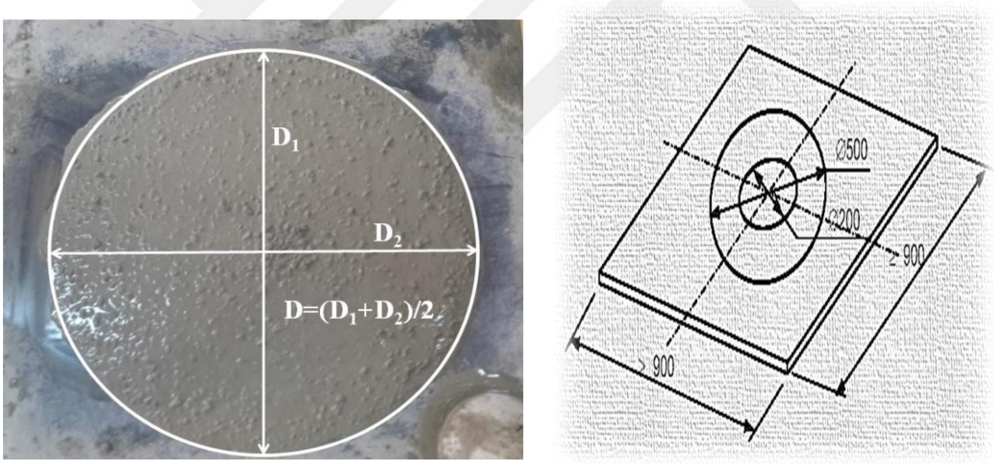


Figure 3.3 Measurement of slump flow diameter for SCCs

In evaluating the flowability and the viscosity of the mixtures, the V-Funnel test was conducted. The flow time is determined using a simple procedure which the funnel is completely filled with fresh concrete, and the flow time is measured as the time between the opening of the orifice and the complete emptying of the funnel.

The L-box test assesses the filling and passing ability of SCCs. And also, serious lack of stability (segregation) can be detected visually. Segregation may also be detected by subsequent sawing and inspecting sections of the concrete in the horizontal section. The L-box apparatus consists of a rectangular-section box in the shape of an 'L', with a vertical and horizontal section, separated by a moveable gate, in front of which vertical lengths of reinforcement bar are fitted as given in Figure 3.4. The vertical section is filled with concrete, and then the gate is lifted to let the concrete flow into the horizontal section. When the flow stops, the height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section. It indicates the slope of the concrete when at rest. This is an indication of passing ability, or the degree to which the passage of concrete through the bars is restricted. The horizontal section of the box can be marked at 200 mm and400 mm from the gate and the times taken to reach these points measured. These are known as the T200 and T400 times and are an indication of the filling ability.

Figure 3.4 L-Box test apparatus

ICAR rheometer, which is shown in Figure 3.5 a, was used to measure the rheology of the SCC mixtures. The container, which fresh concrete mixtures were poured up to a height of 305 mm, had 305-mm diameter. Firstly the fresh concrete was placed into the container and then four-bladed vane with the diameter, d, of 127 mm and height, h, of 127 mm was positioned in the center of the concrete mixtures. When vane was placed into the fresh concrete mixture, there was 89-mm spacing above and below the vane as shown in Figure3.5 b. The radii of the inner cylinder, R_i, and outer cylinder, R_o, are 63.5 and 152.5 mm, respectively. Outer cylinders are equipped with ribs to prevent slippage between the concrete and the steel surface (Saaket al, 2001). Breakdown speed and time, number of points, time per point, initial and final speed are input parameters, which were entered into software to obtain flow curves for each fresh concrete mixture. The vane was first rotated at a speed of 0.5 rps for a breakdown period of 20 s. Torque measurements were then recorded for seven speeds ranging in descending order from 0.5 to 0.05 rps. For analyzing rheological parameters of the fresh concrete properties, Eqn. (1) was used for plotting the flow curves in relative units after the best fit line was calculated for each mixture:-

$$T= G + HN \tag{3.1}$$

where T, G, H, and N are the torque (Nm), the intercept of this line with the T-axis (Nm), the slope of this line (Nm.s) related to plastic viscosity, and rotational speed (rev/s), respectively (Koehler, 2004; Koehler and Fowler, 2004).

When the Bingham model is applied on the rheological behavior of the SCC, some problems may occur since torque-speed relationship is not linear in the SCC. In order to solve these problems, the Herschel-Bulkley model Eqn. (3.2), which is the most common non-linear model also having a yield stress, can be used to describe the rheological behavior of the SCC (Larrard et al., 1998).

$$\tau = \tau_0 + K\dot{\gamma}^n \tag{3.2}$$

In the equation, exponent 'n' describe the non-linearity and if $n < 1$, $n > 1$, and $n = 1$, the SCC behave as shear thinning, shear thickening and the Bingham model, respectively. The results obtained from the rheometer were used in this model, and a better fit of the test data compared to the Bingham model was achieved. For this reason, the T-N relationship has been transformed to following expression to be able to calculate the fundamental rheological Herschel-Bulkley parameters (τ_0, K, and n).

$$T = G_{HB} + H_{HB}\,(N)^{J} \tag{3.3}$$

Where G_{HB}, H_{HB}, and J are parameters predicted by Herschel-Bulkley for a T-N relationship. After that, the fundamental rheological Herschel-Bulkley parameters were determined by Eqs. (3.4)- (3.6):

$$\tau_0 = \frac{G_{HB}}{4\pi h}\left(\frac{1}{R_i^2} - \frac{1}{R_o^2}\right)\frac{1}{ln\left({R_o}/{R_i}\right)} \tag{3. 4}$$

$$K = \frac{H_{HB}}{2^{2n+1}\pi^{n+1}h}n^n\left(\frac{1}{R_i^{2/n}} - \frac{1}{R_o^{2/n}}\right)^n \tag{3.5}$$

$$\text{n} = J \tag{3.6}$$

The Herschel-Bulkley equations were achieved after the fundamental rheological parameters of the Herschel-Bulkley model were determined. The other most suitable model describing the rheological behavior of the SCC is the modified Bingham model. This model can be considered as an extension of the Bingham model with a second order term, but also as a second order Taylor development of the Herschel-Bulkley equation (Feys et al., 2007).

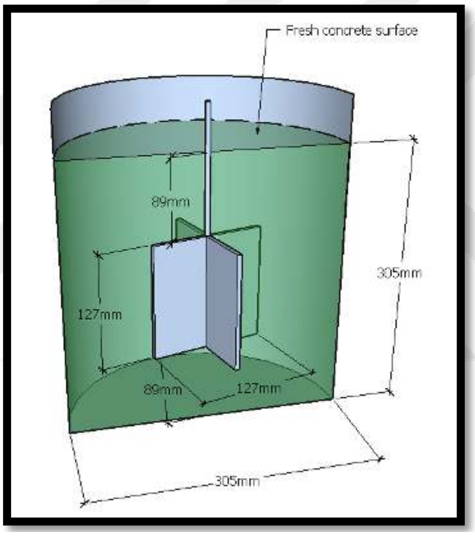
$$\tau = \tau_0 + \mu\dot{\gamma} + c\dot{\gamma}^2 \tag{3.7}$$

In the modified Bingham model, taking the ratio of second order term to the linear term can be applied to describe non-linear behavior, indicating shear thinning, shear thickening, and the Bingham model when $c/\mu < 0$, $c/\mu > 0$, and $c/\mu = 0$, respectively.The formulae given by Ferguson and Kemblowski (1999) supply the opportunity to transform 'N' and 'T' into the fundamental rheological parameters, shear stress and shear rate. Nehdi and Rahman (2004) have been customized these formulae as following Eqs. (3.8)- (3.9):

$$\tau = \frac{(R_i^2 + R_o^2)}{4\pi h R_i^2 R_o^2}T \tag{3.8}$$

$$\dot{\gamma} = \frac{(R_i^2 + R_o^2)}{(R_o^2 - R_i^2)} \tag{3.9}$$

a)



b)

Figure 3.5ICAR rheometer

3.2.4 Tests for Hardened Properties

Compressive strength measurement, cubical samples of 150 mm were tested with respect to ASTM C 39 (2012). The test is conducted on three cube samples from each mix at 28 and 90 days. For the sorptivity test, two test specimens having a dimension of Ø100 - 50 mm cut from Ø100 - 200 mm cylinder specimens were used. Before the test, the specimens were dried in an oven at about 105 ± 5 C until the constant mass was obtained and then allowed to cool to the ambient temperature in a sealed container.

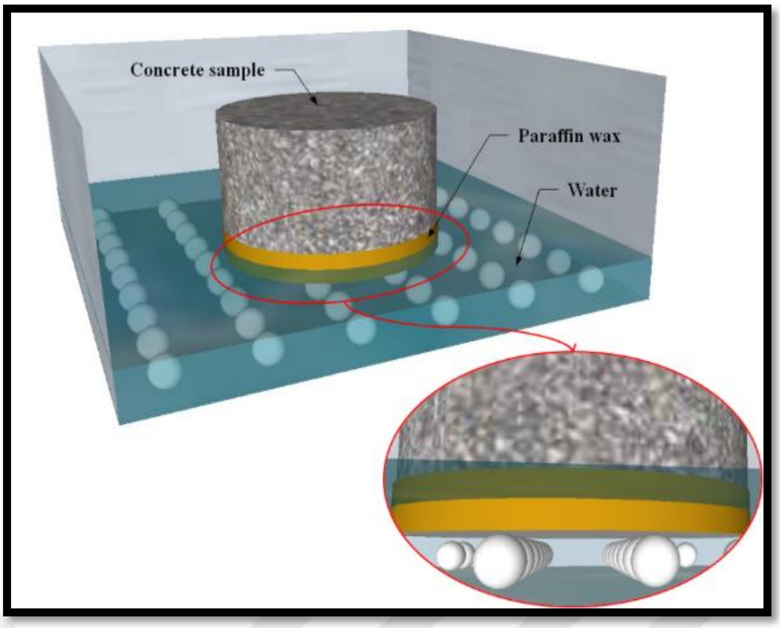


Figure 3.6 Detail sorptivity of measurement

Afterwards, the sides of the specimens were coated with paraffin wax; so that capillary suction was considered the dominant invasion mechanism. The sorptivity test was carried out by placing the specimens on glass rods in a tray such that their bottom surface up to a height of 3 mm is in contact with water. This procedure was considered to allow free water movement through the bottom surface. The specimens were removed from the tray and weighted at different time intervals up to 1 h to evaluate mass gain. The volume of water absorbed was calculated by dividing the mass gained by the nominal surface area of the specimen and by the density of water. These values were plotted against the square root of time. The slope of the line was defined as the sorptivity coefficient.

TS EN 12390-8(2002) was followed in the determination of the water permeability of SCCs at 28 and 90 days. For this, a 500 ± 50 k Pa downward pressure was applied to a 150 mm cube specimen for 72 h to penetrate the water throughout the specimen as shown in Figure 3.7.

Figure 3.7 Measurement ofwater permeability test setup

For chloride ion penetration as shown in Figure 3.8, two 50 mm thick disc samples cut from the midsection of each cylinder were used. Then, the discs were allowed to surface dry in air. In order to prevent evaporation of water from the saturated specimen, a rapid setting coating was applied onto the lateral surface of the specimens prior to a vacuum-saturation procedure for 2 h. Finally, the specimens were immersed in water in the curing room at 20^{o}C and 50% relative humidity for 18±2 h. The following the conditioning method given in ASTM C1202, 2012, the RCPT test were performed.

Figure 3.8 Photographic views of the RCPT test setup

Gas permeability was measured at 50 mm high disk specimens cut from the mid portion of Ø150×300 mm concrete cylinders with respect to the CEMBUREAU method recommended by Rilem (Rilem TC 116-PCD, 1999). Before the test, concrete samples were dried at 100 ±5 C, thus leading to relatively realistic values and then permitted to cool to ambient temperature in a sealed container. Oxygen gas was utilized as the permeating medium. An inlet gas pressure of 150, 200, 250, 300, 350, 400, 450, and 500 KPa were applied and gas permeability coefficients were computed for each level by using Hagen–Poiseuille relationship for laminar flow of a compressible fluid through a porous medium with small capillaries under steady-state condition as shown in Figure 3.9. The apparent gas permeability coefficient Ka can be calculated using the modified Darcy's equation as follows:-

$$Ka = \frac{2P2\ Q\ L\ \mu}{A\ (\ (P1)2-(P2\ )2)} \tag{3.10}$$

Where: - Ka is the gas permeability coefficient (m^2), P1 is the inlet gas pressure (N/ m^2), P2 is the outlet gas pressure (N/m^2), A is the cross-sectional area of the sample (m^2), L is the height of the sample (m), μ is the viscosity of oxygen (2.02×10^{-5} Ns/m^2), and Q is the volume flow rate (m^3/s).

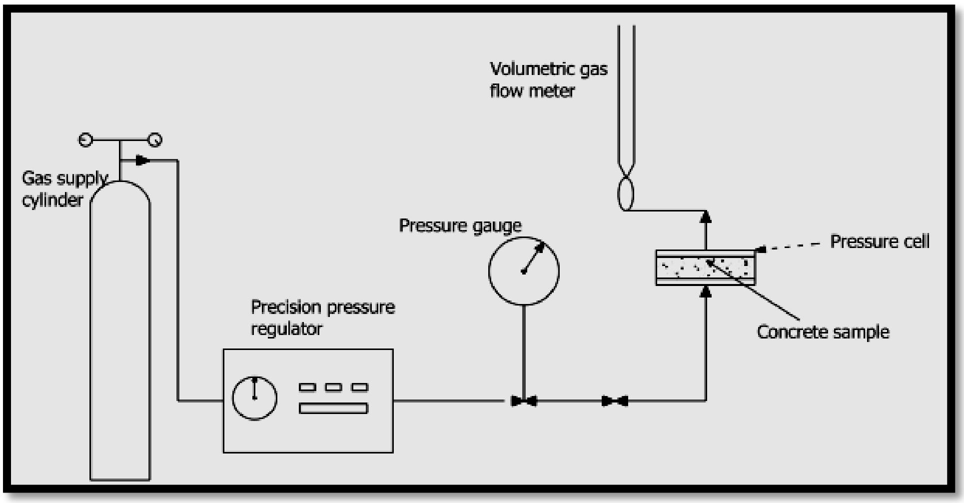


Figure 3.9 Schematic views of the permeability test setup.

3.3 Numerical Programs

3.3.1 Properties of CFST

The structural behavior of the concrete filled steel tube (CFST) columns as a composite columns, were studied under the effect of axial compression. Promoting from a collection data of experimental tests, an axial load carrying capacity (Pu) test results of the composite columns made with SCC were calculated through three different yield strengths of steel tube (185, 275, 450 MPa) and also three different D/t ratios (30, 60, 90). Ultimately, several main geometric and material properties taken as prophetic parameters such as D/t ratio, length of columns (L) , the compressive strengths of the concrete (fc) and yield strength of steel tube (fy) the test of ultimate axial load considered. The compression test of CFST columns is schematically depicted in Figure 3.10 in which the steel tube was loaded simultaneously with the concrete core. For each investigated code, the test specimens had 4 mm in thickness of circular steel tube and length to diameter ratio (L/D) of 2.5. The parameters of CFST columns applied in design codes are listed in Table 3.9 below. The details of mix proportion as well as compressive strength of concrete were imported from Table 3.4; in which totally 16 SCC mixtures were produce and the concrete specimens were 150 mm cubic. The concretes were produced by using

FA and NS the effect of aforesaid parameters on the pursuits would be observed, and discussed in detail.

In order to attain comparison of the database of CFST columns with various codes, a cylindrical specimens 150*300 mm, was used in test to obtained the compressive strength of concrete (fc') in codes. However, the results of compressive strength of SCC with and without nano silica were obtained through 150 mm cube test; as a result, conversion factors proposed by BS EN 206-1 (2000) were yielded to convert these results. BS EN 206 specifies the conversion factors according to kind and weight of concrete. The parameters as well as the conversion factor applied in design codes are in Table 3.7 below.

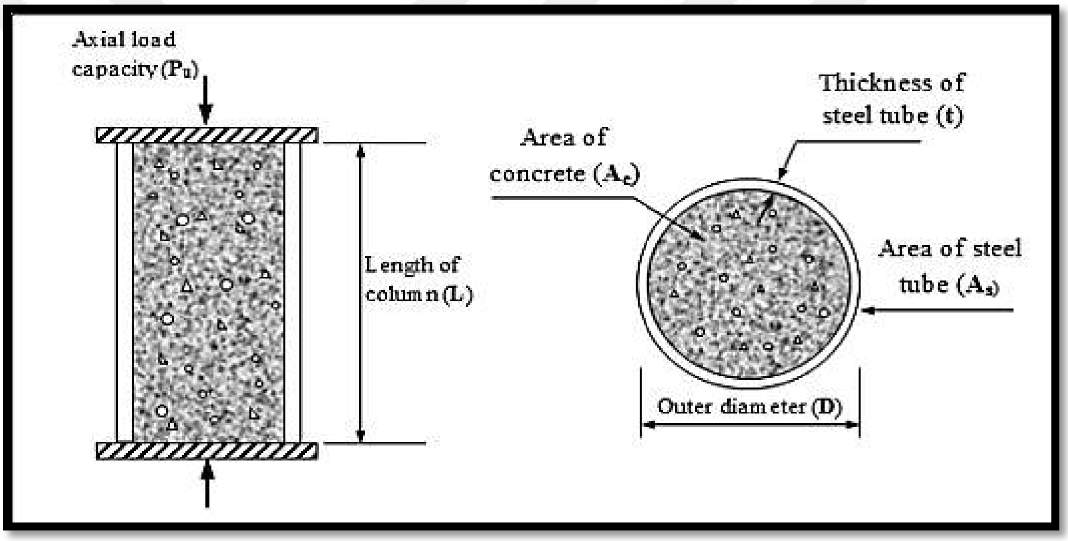


Figure 3.10 Test explaining of load applied to cross section of circular CFST columns

Table 3.6 Parameters of CFST columns applied in design codes

Diam. Ofst.tube mm	**Diam. Of conc. mm**	**Length of CFST mm**	**D/t**	**Area of concrete (Ac)mm^2**	**Area of steel (As) mm^2**	**Conc. moment of inertia(Ic) mm^4**	**Steel moment ofinertia (Is) mm^4**
120	112	300	30	9852.04	1457.7	10326440	71103641
180	172	600	60	42273.27	2965.7	84711312	1.22E+09
360	352	900	90	97314	4473.63	2.88E+08	6.31E+09

Table 3.7 Characteristics and standard compressive strength of concrete applied in BS EN 206 (BS EN 206-1, 2000)

Mix Code	Strength of 150mm cubes (fc') (MPa)	Conversion factor	Characteristic strength (fc')(MPa)
FA0NS0	65.5	0.83	55.90
FA0NS2	68.1	0.82	62.80
FA0NS4	76.4	0.80	65.60
FA0NS6	73.7	0.82	61.24
FA25NS0	58.8	0.82	53.92
FA25NS2	66.2	0.83	56.23
FA25NS4	72.9	0.82	64.24
FA25NS6	68.6	0.82	59.76
FA50NS0	50.1	0.80	45.98
FA50NS2	52.7	0.80	48.35
FA50NS4	63.7	0.83	58.86
FA50NS6	61.9	0.83	54.50
FA75NS0	29.8	0.80	30.81
FA75NS2	38.9	0.81	37.64
FA75NS4	51.0	0.83	52.83
FA75NS6	46.6	0.78	45.65

3.3.2 Calculation of Axial Capacity of Circular CFST Columns Recommended by Design Codes

Yield strength of steel tube (fy), fc', D/t, steel ratio and confining coefficient (ξ) are the details of relations would be presented for each design codes, to evaluate the axial load carrying capacity (Pu) results and make a good comparison, these a brief review of related standards must be given in different codes. Furthermore, manifold approaches and design philosophies have been adopted in these design codes.

3.3.2.1 Eurocode 4 (EC 4)

In all design codes, the regulations of the design methods are different there are circular, square, rectangular and circular hollow CFST structure design regulations. As well as, the code must be combining the design approach of both reinforced concrete columns and structural steelwork in order to dedicate the composite construction. The Eurocode 4, (2004) code was adopted in the present study, and determines the resistant capacity of a circular CFT stub column by adding the contribution of the steel tube and the concrete core and the confinement effect is considered. Indeed, the strength of the concrete is increased by the coefficient *ηc*because the concrete has a higher strength when a triaxial state of stress occurs. The strength of the steel tube is decreased by *ηa*because the effective yield stress of the steel is reduced by the round stresses.The axial load capacity of circular CFST columns can be calculated by:

$$Pu= (1 + \eta c\times \frac{t}{\boldsymbol{D}}\frac{fy}{\boldsymbol{fc}})\ f_{\acute{c}}\ Ac + \eta afyAs \quad (3.11)$$

Because the eccentricity of loading (e) is equal to zero

ηa = ηao and ηc= ηco(3.12)

$\eta c = 4{:}9 - 18.5\breve{\lambda} + 17\breve{\lambda}^{2}$ ($\eta c \geq 0$) (3.12a)

$\eta a = 0{:}25(3 + 2\breve{\lambda})$ ($\eta\ a \leq 1.0$) (3.12b)

$$\breve{\lambda} = \sqrt{\frac{NplR}{Ncr}}(3.12c)$$

N_{plR} =fyAs + $f_{\acute{c}}$ Ac (3.12d)

$Ncr = \frac{\pi\ 2(EI)eff\ 2}{I2}$(3.12e)

$$(EI)_{eff\ 2} = E_sI_s + K_eE_{cm}I_c(3.12f)$$

E_{cm} = 22000 [($f_{\acute{c}}$ + 8) /$10^{0.3}$] MPa(3.13)

Where:

*fc'*is the compressive strength of 150×300 mm cylinder specimens in MPa.
fy is the yield strength of steel tube.
Ac, As is cross section area of concrete and steel tube, respectively.
$\breve{\lambda}$ is the relative slenderness.
NPIR is characteristic value of the plastic resistance.

N_{cr} is the elastic critical force for the relevant buckling mode.

Ke is correction factor equal to 0.6.

Is, Icis the second moment of inertia of steel and concrete, respectively. Lis the length of CFT column.

Es is the modulus of elasticity of steel ≈ 200 MPa.

$(EI)_{eff2}$ is the effective flexural stiffness for calculation of relative slenderness.

E_{cm} is elastic modulus of concrete.

Proposed by Eurocode 2 and 4, (2004)

3.3.2.2 ACI-318R

American Concrete Institute (ACI-318R, 2005) use the formula for calculating the ultimate axial capacity of the circular CFST stub columns, neither of these specifications has taken into account the concrete confinement and the interaction between the concrete core and steel tube. The equation for axial capacity of a circular CFT stub column, Pu is given as:

$$Pu=0.85fc'Ac+fyAs \tag{3.14}$$

Where Acis the cross-sectional area of the concrete; and Asis the cross-sectional area of the steel tube.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Experimental Findings

4.1.1 Analysis of Fresh Behavior

The passing ability, viscosity, flow ability, as well as uniform aggregate distribution and maximum resistance to segregation are the most critical characteristics which can specify the filling ability and stability of self-compacting concrete in the fresh state. Each characteristic can be addressed by one or more test methods (EFNARC, 2005). For instance, the slump flow test is used to determine the flow ability while the T50 slump flow time and V-funnel flow time tests are used to measure the viscosity. A preferable SCC with good fluidity in the fresh state, requires the consent of at least one of above mentioned four critical properties. The SCC then must specify the class or target value defined in Table 3. In order to specify the flow ability, viscosity and passing ability of the manufactured SCRCs, slump flow diameter, T50 slump flow time, V-funnel flow time, L-box height ratio and L-box T20 and T40 flow times were measured and graphically depicted.

The SCC mixes produced in this study had the slump flow diameter changing between 700 and 800 mm, which were determined by taking the average of two measured diameters of flowed concrete as shown in Figure 3.3. The slump flow diameters of the SCC mixtures versus NS contents at different FA replacement levels are presented in Figure 4.1. The results indicated that the incorporating NS decreased the slump flow diameter, whereas the replacement of PC with FA increased it. NS contains small sized particles and had. large surface area. This feature of NS increases the demand for water when it is used in the concrete production. In this study, the water content was kept constant, but the amountof SP was increased to satisfy the requirements for the SCC. Despite this, the decreasing in the slump flow diameter was observed when NS content increased. According to EFNARC (2005), the SCC mixtures without FA at each NS replacement level can be classified as SF2, which is suitable for many normal applications such as walls and columns, while the SCC mixtures with 50% and 75% FA content at each NS replacement level can be categorized as SF3, which can be used for vertical applications in very congested structures, structures with complex shapes, or for filing under formwork. However, the SCC mixtures produced with 25% FA content can be classified as SF3 at 0% NS replacement level, whereas the SCC mixtures produced at 2%, 4%, and 6% NS replacement level can be categorized as SF2. The highest slump flow diameter, 790 mm, was obtained in the FA75NS0 mix while the lowest diameter, 710 mm, was obtained in FA0NS6. Mixes of FA0NS0, FA25NS0, FA50NS0, and FA75NS0 had the slump flow diameter of 735 mm, 760 mm, 770 mm, and 790 mm, respectively. The substituting of PC with NS at the replacement level of 6% decreased the slump flow diameter about 3.4%, 3.3%, 1.9%, and 3.2% in first, second, third, and forth SCC series, respectively. SP content was increased to achieve an acceptable slump flow diameter for the SCC mixtures and to minimize the reducing in slump flow diameter due to NS utilization. Moreover, the previous studies revealed that utilization of NS in the SCC production decreases the slump flow diameter (Jalal and Mansouri et al., 2013; Beigi MH, Berenjian et al., 2013).

Figures 4.3 and 4.4, demonstrate T50 slump flow and V-funnel slump flow time of the SCC mixtures regarding to NS content for each FA replacement level, respectively. Additionally, Figure 4.4 illustrates T50 slump flow time via V-funnel flow time of each mixture with respect to viscosity class according to (EFNARC, 2005). The results indicated that both T50 slump flow and V-funnel flow times were affected by NS content. Increasing NS content resulted in a higher T50 slump flow and V-funnel flow times. It can be clearly seen from Figure 4.3, a lower result for T50 slump flow time were obtained in the SCC series produced with 75% FA, while the highest times were observed in the SCC series produced without FA. The SCC mixtures manufactured without NS had the slump flow times of 3.7 s, 2.7 s, 2.1 s, and 1.4 s for FA contents of 0%, 25%, 50%, and 75%, respectively. When NS content increased to 6% of total binder content, these T50slump flow times increased up to 5.6 s, 4.7 s, 4.0 s, and 3.7s for the SCC mixes with FA contents of 0%, 25%, 50%, and 75%, respectively. V-funnel flow time was indicated same trend like T50 slump flow time. The lowest V-funnel flow times were observed in the SCC mixtures produced with 75% FA content, whereas the highest flow times were seen in the mixtures without FA. Increasing NS content resulted in systematical increasing of V-funnel flow time. V-funnel flow times for the SCC mixtures produced in this study were in the range of 7.3 s and 13.0 s. The highest V-funnel time was seen in the FA0NS6 mix while the lowest value of 7.3 s was observed in FA75NS0 mix. The similar effect of NS utilization was observed in the study of Beigi et al. (Beigi and Berenjian et al., 2013). The flowing time of fresh SCC increases since the use of NS in the SCC makes the fresh concrete more cohesive and viscous. The iteration of T50 slump flow and V-funnel flow times, which is presented in Figure 4.5, indicated that all SCC mixtures were in the boundaries of VS2/VF2 viscosity class specified by EFNARC (2005). Besides FA75NS0 mix that is in VS1/VF1 viscosity class. It can be concluded that such concretes may be helpful in limiting the formwork pressure or improving segregation resistance when the iteration between flow times is considered (Gesoğlu and Güneyisi, 2007).

L-box height ratio by means of H2/H1 was determined to specify the passing ability of the SCC mixtures. Three bar L-box test, which simulates more congested reinforcement (EFNARC, 2005), were used to perform this test and the results obtained from this test are presented in Figure 4.6. L-box height ratio must be equal or greater than 0.8 to certify that the SCC has the passing ability and when L-box height ratio is 1.0, it can be noted a perfect fluid behavior of the concretes is obtained (EFNARC, 2005). The results indicated that all SCC mixtures manufactured in this study satisfy the EFNARC limitation. It can be clearly seen from Figure 4.6, L - box height ratios of SCCs were greater than 0.9 and especially FA25NS0, FA50NS0, FA75NS0, and FA75NS2 mixes had L-box height ratio of 1.0 that is the indication of a perfect fluid behavior. FA replacement enhanced the passing ability of the SCC mixtures with and without NS. Although there was a reducing in L-box height ratio when NS content increased, the reducing is not so much. Moreover, T20 and T40, which are the distance of 20 and 40 cm along the horizontal section from the sliding door of the L-box which the mixture must be reached as shown in Figure 3.8, were also measured during the experimental study. T20 and T40 are L-box flow times and they are the indication about the easy flow of the SCC mixtures. The results are illustrated in Figure 4.7a and b for T20 and T40 flow time, respectively. It was observed that increasing NS content resulted in higher T20 and T40 flow time. The replacement of PC with FA also enhanced L-box flowing times. Namely, the utilization of FA in the production makes the concrete mixtures flow easily.

The torque (Nm) and rotational speed (rev/s) obtained from the rheometer are plotted and presented in Figure 4.8 (a, b, c, and d) for first, second, third, and forth SCC series, respectively. Applying the Bingham model for these data sometimes leads to negative yield stresses, since the relationship between torque and rotational speed relationship is not linear. For this reason, in order to describe the rheological behavior of SCC, the Bingham model was not applied to the experimental data in this study. The data obtained from the rheometer indicated that utilization of NS increased the torque values when the rotational speeds were same for each mixture. However, replacing PC with FA decreased the torque values. When both the Herschel-Bulkley and modified Bingham models were applied on the torque vs. rotational speed obtained from the rheometer, shear thickening behavior was observed in the SCCs manufactured in this study. Figure 4.8 (a, b, c, and d) demonstrates the shear rate and shear stress, relationship of the Herschel-Bulkley model for the SCC mixtures with FA contents of 0%, 25%, 50%, and 75%, respectively. The exponent ‘n’ values for the mixtures were greater than 1.0 that is the indication of shear thickening behavior. The exponent ‘n’ values changing between 1.377 and 1.479 were obtained in this study. The lowest values were seen in the SCC mixtures produced with 75% FA content while the highest values were obtained in the SCC mixtures without FA. Incorporation of FA resulted in lower exponent ‘n’ values, namely lower shear thickening. However, the utilization of NS increased the exponent ‘n’ values. The SCCs produced without NS had the exponent ‘n’ values of 1.467, 1.425, 1.402, and 1.377 whereas the SCCs manufactured with 6% NS had the exponent ‘n’ values of 1.479, 1.438, 1.406, and 1.390 for FA replacement levels of 0%, 25%, 50%, and 75%, respectively. The change in the exponent ‘n’ value with respect to NS content is presented in Figure 4.9. Although the exponent ‘n’ values were increased due to the use of NS, increasing was not so high.

In addition to the Herschel-Bulkley model, the modified Bingham model was applied to data obtained from the rheometer. The shear rates and shear stresses obtained from using the modified Bingham model are plotted in Figure 4.10 (a, b, c, and d), for the SCC mixtures produced with FA contents of 0%, 25%, 50%, and 75%, respectively. The ‘c/ì’ coefficients, which were achieved by taking the ratio of second order term to the linear term of equations given in Figures, indicated that the SCC mixtures produced in this study indicated shear thickening behavior. The SCC mixtures produced without NS had the ‘c/ì’ coefficients of 1.316, 1.107, 1.005, and 0.885 when PC was replaced with FA at levels of 0%, 25%, 50%, and 75%, respectively. It can say, according to these coefficients, the use of FA decreased the ‘c/ì’ coefficients, namely shear thickening of the SCC. However, increasing NS content from 0% to 6% resulted in higher the ‘c/ì’ coefficients. The coefficients for the SCC mixtures produced by NS content of 6% were 1.378, 1.183, 1.036, and 0.953 for first, second, third, and forth SCC series, respectively. The detailed relationship between the ‘c/ì’ coefficients regarding to NS content for each FA replacement level can be clearly seen in Figure 4.11. Consequently, when the rheology of SCC is regarded, the plastic viscosity could not be given due to the non-linearity of the relationship between the shear stresses and the shear rates.

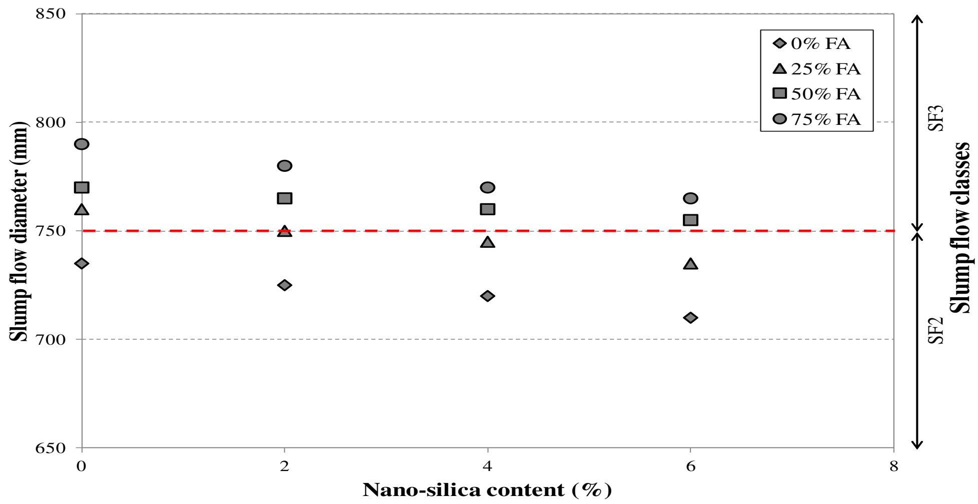


Figure 4.1 Variation of slump flow diameter and slump classes of SCC

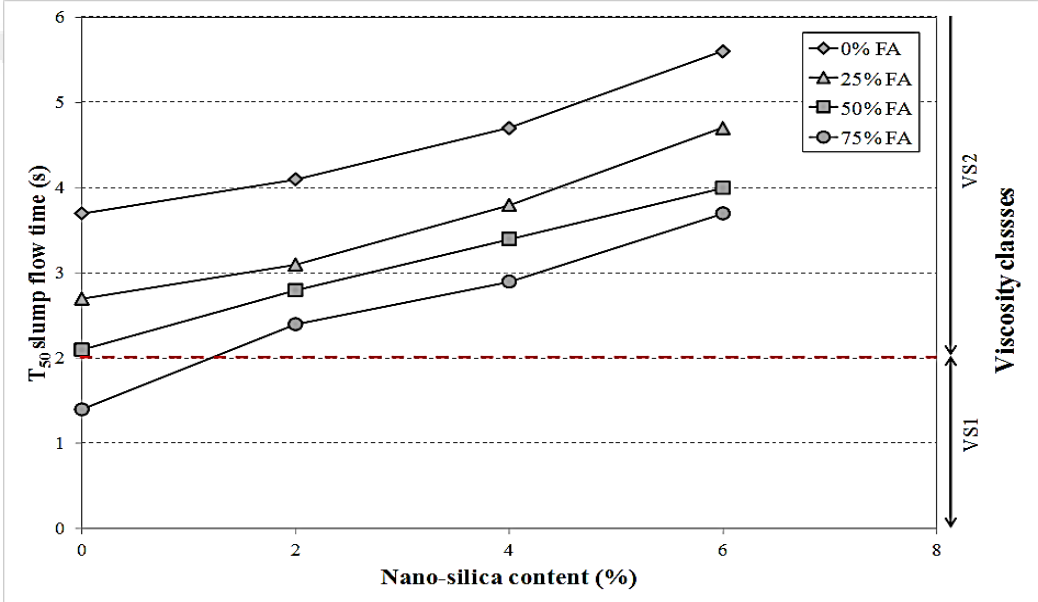


Figure 4.2 Variation of T50 slump flow time of SCC

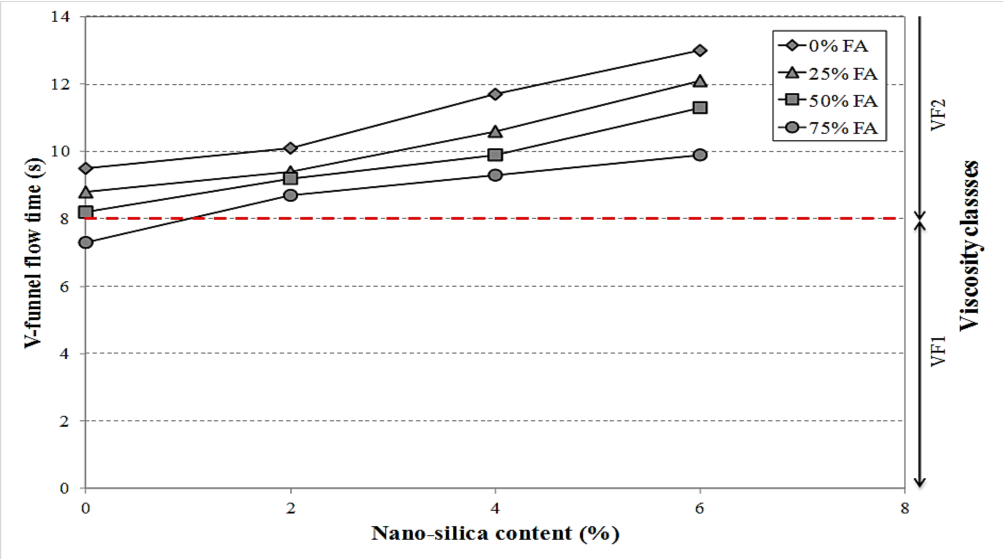


Figure 4.3 Variation of V-funnel flow time and viscosity of SCC

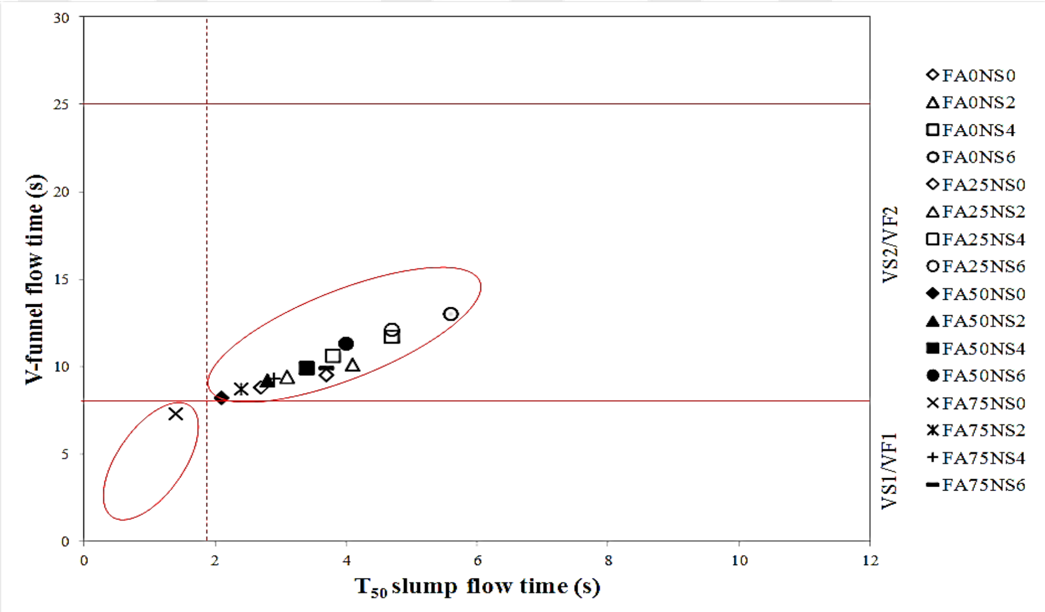


Figure 4.4T50 slump flow time vs.V-funnel flow time for SCC

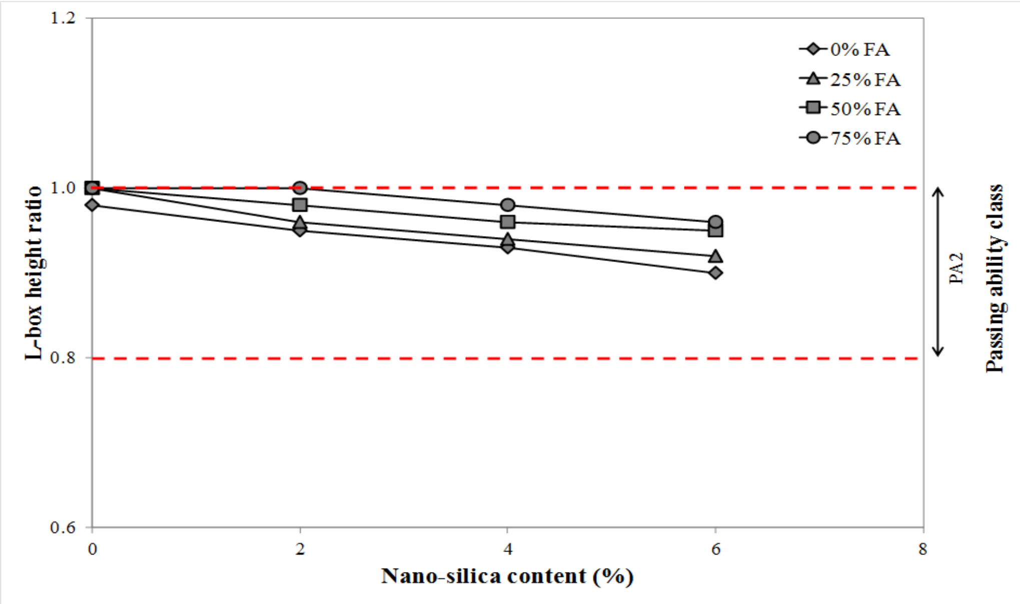
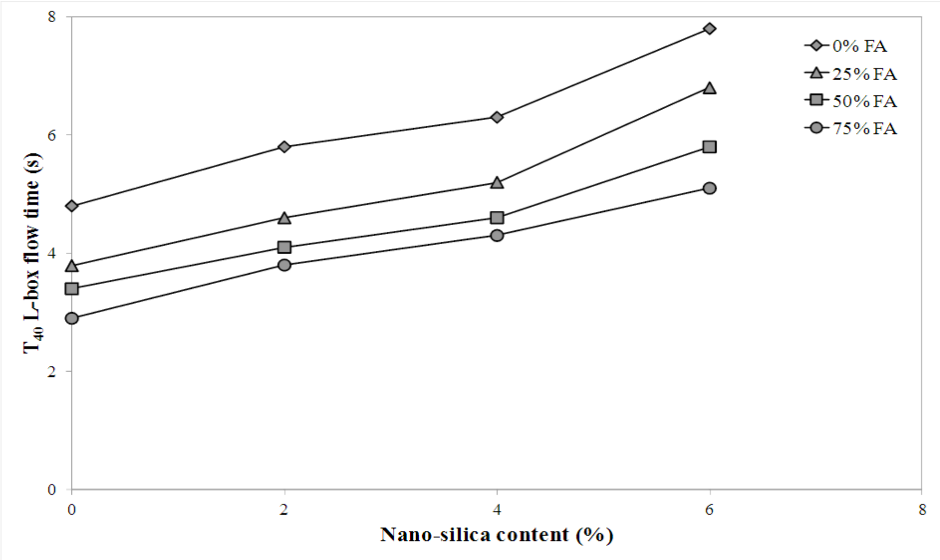
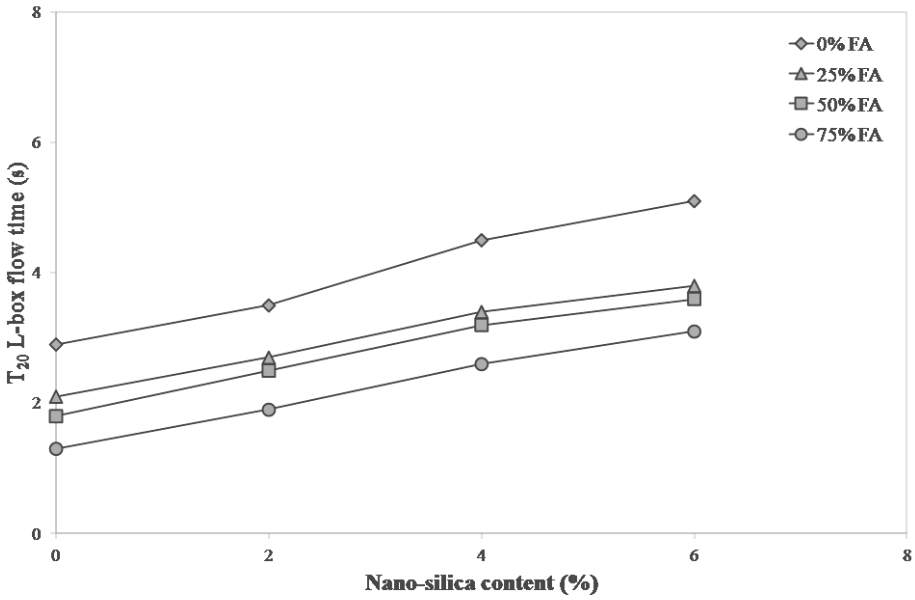


Figure 4.5 Variation of L-box height ratio and passing ability classes of SCC

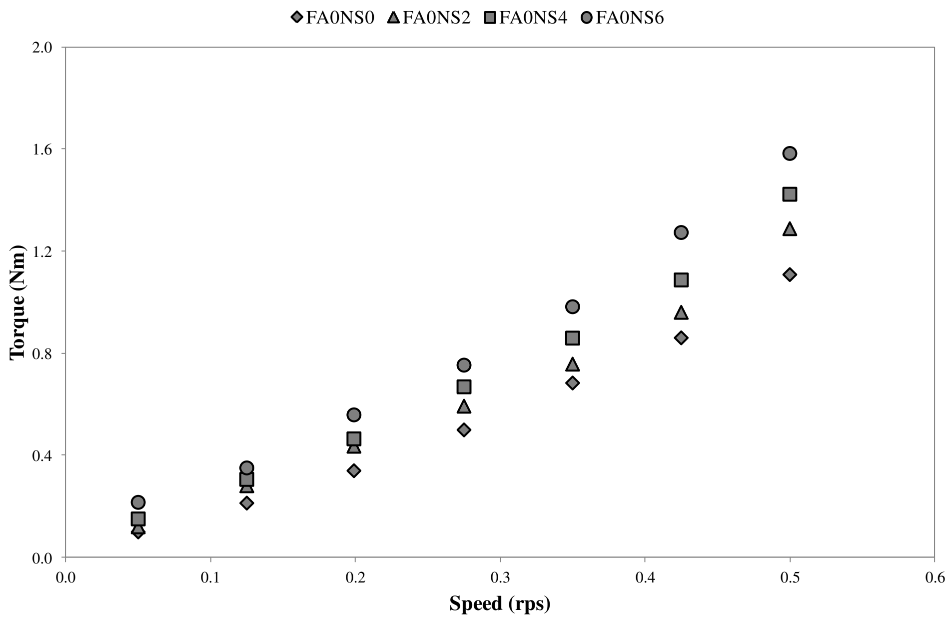


a)

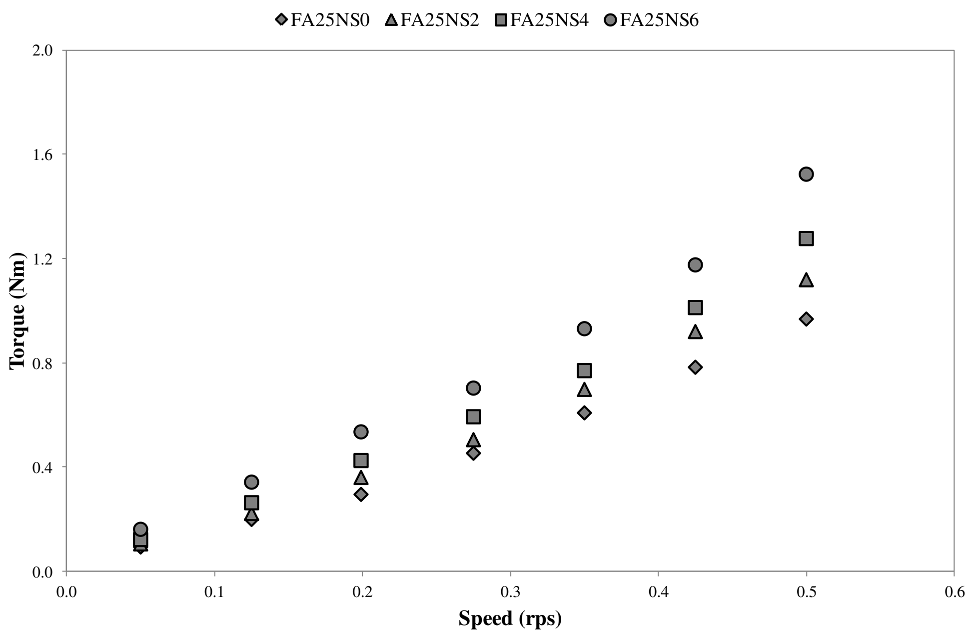


b)

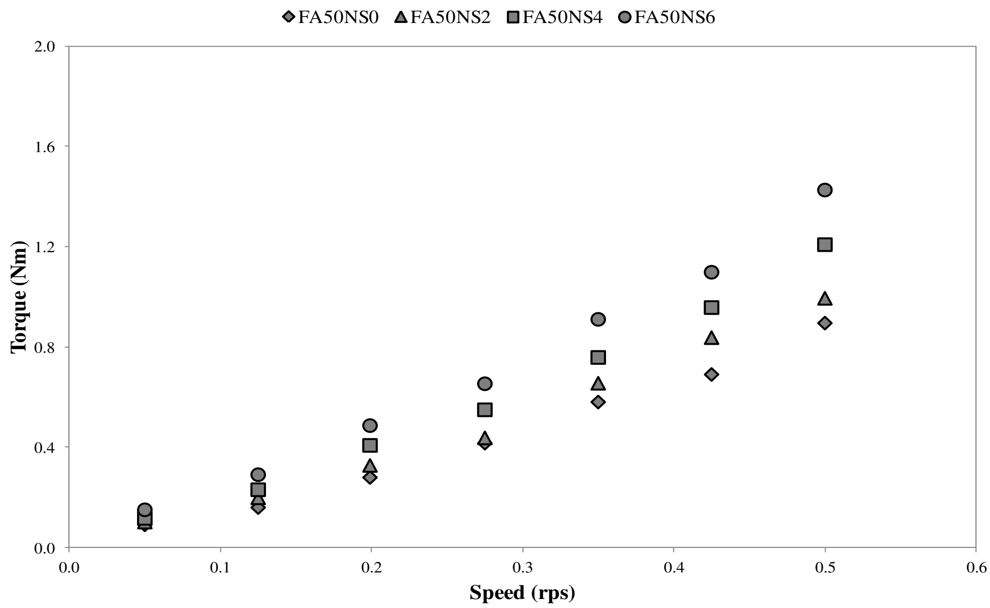
Figure 4.6 Variation of a) T20 and b) T40 L-box flow time of SCC


FA0NS0 FA0NS2 FA0NS4 FA0NS6
Torque (Nm)
Speed (rps)
2.0
1.6
1.2
0.8
0.4
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6

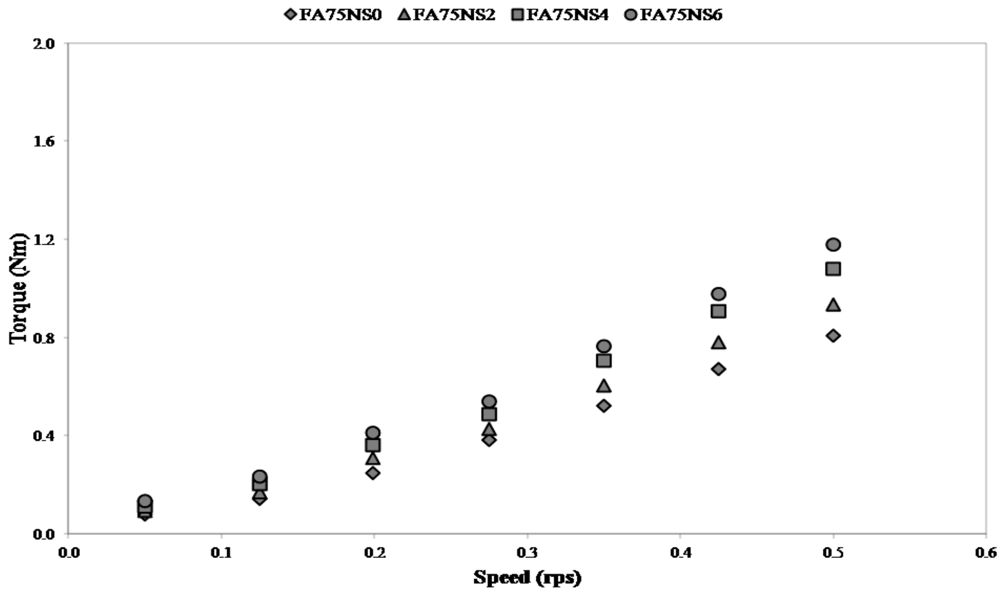
a)


FA25NS0 FA25NS2 FA25NS4 FA25NS6
Torque (Nm)
Speed (rps)
2.0
1.6
1.2
0.8
0.4
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6

b)

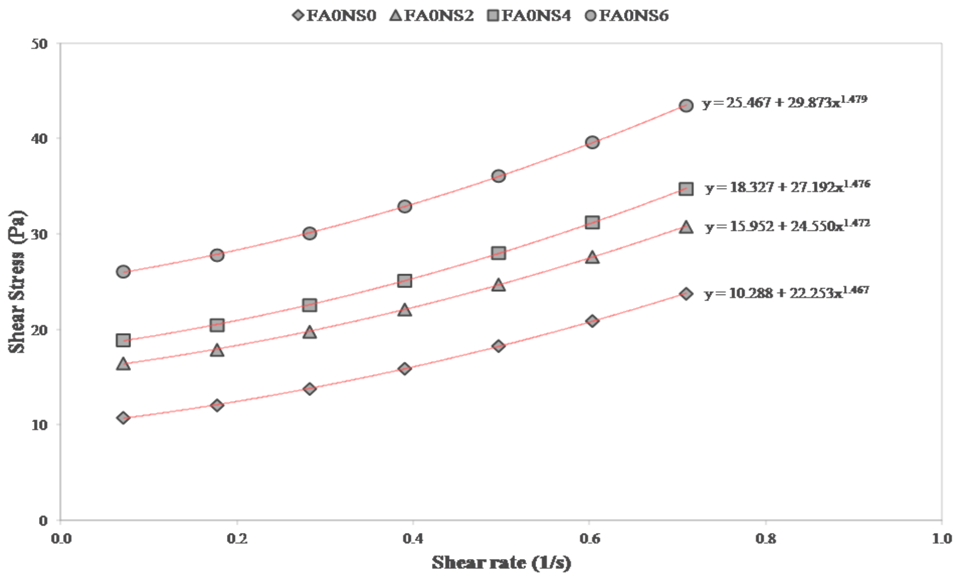


c)

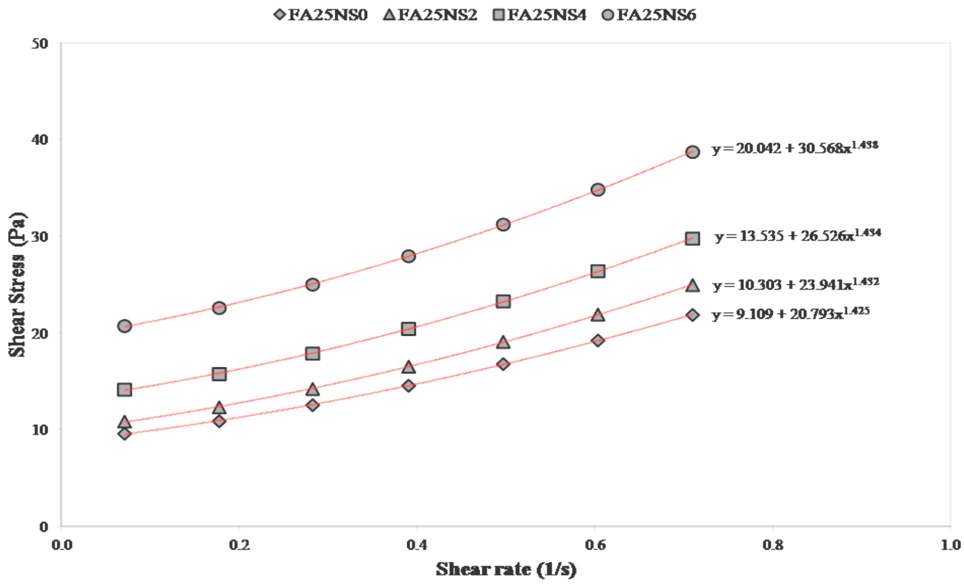


d)

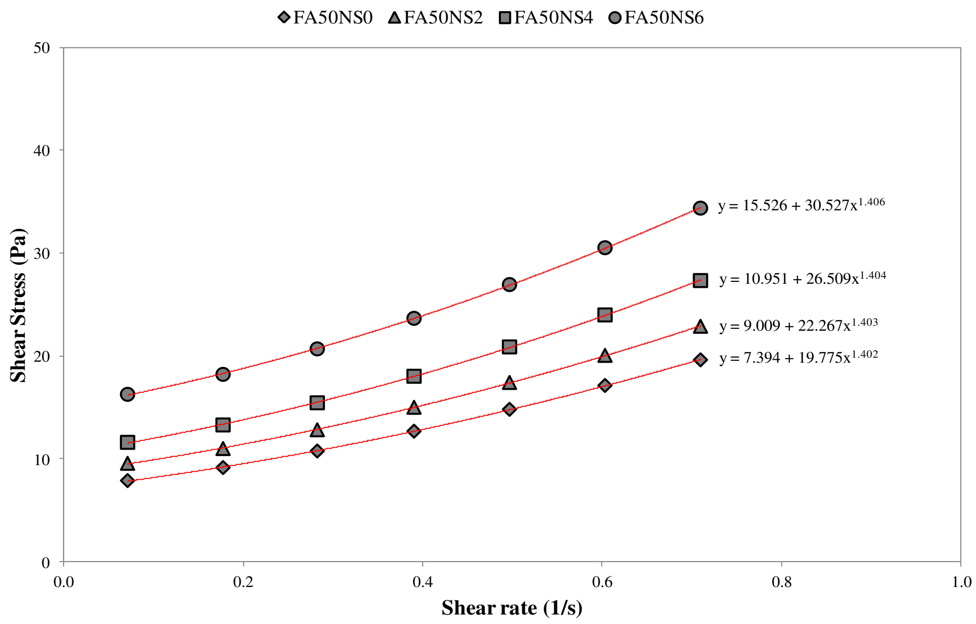
Figure 4.7 Torque vs rotational speed for SCC with a) 0%, b) 25%, c) 50%, and d) 75% FA


FA0NS0 FA0NS2 FA0NS4 FA0NS6
y = 25.467 + 29.873x1.479
y = 18.327 + 27.192x1.476
y = 15.952 + 24.550x1.472
y = 10.288 + 22.253x1.467
Shear Stress (Pa)
Shear rate (1/s)

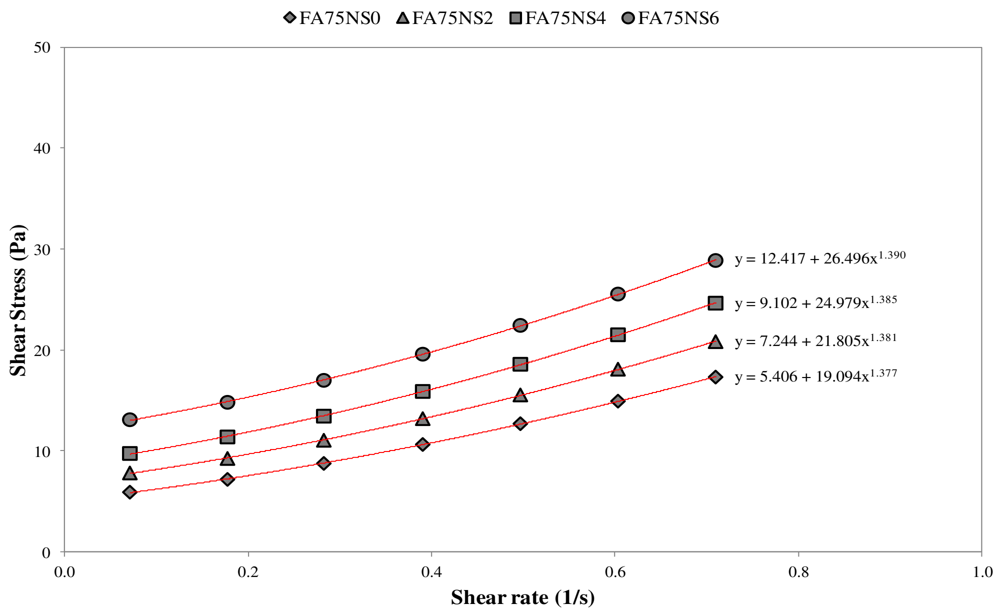
a)


FA25NS0 FA25NS2 FA25NS4 FA25NS6
y = 20.042 + 30.568x1.438
y = 13.535 + 26.526x1.434
y = 10.303 + 23.941x1.432
y = 9.109 + 20.793x1.425
Shear Stress (Pa)
Shear rate (1/s)

b)



c)



d)

Figure 4.8 Application of the Herschel-Bulkley model for SCC a) 0%, b) 25%, c) 50%, and d) 75% FA contents

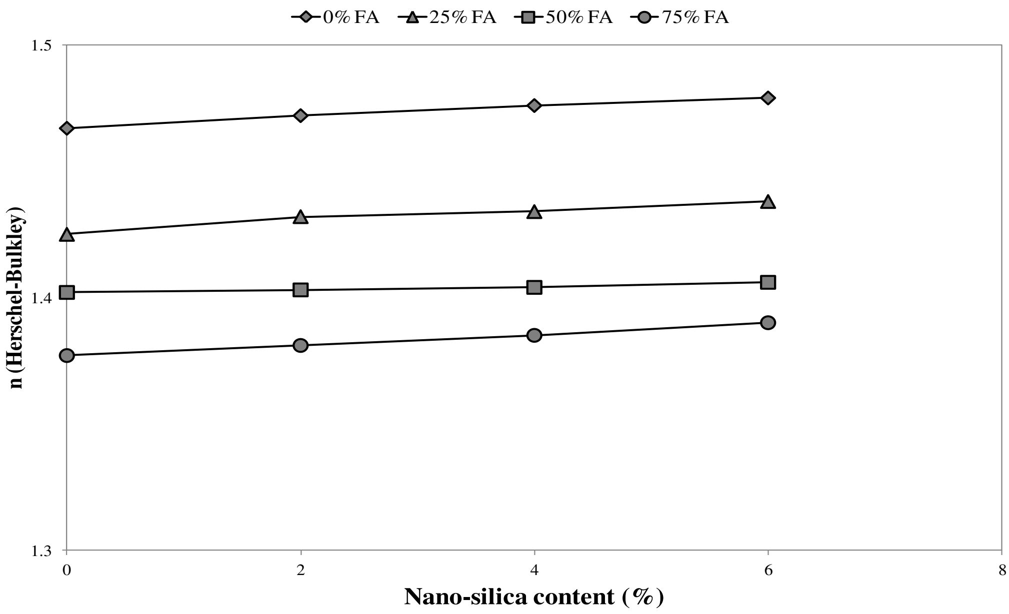
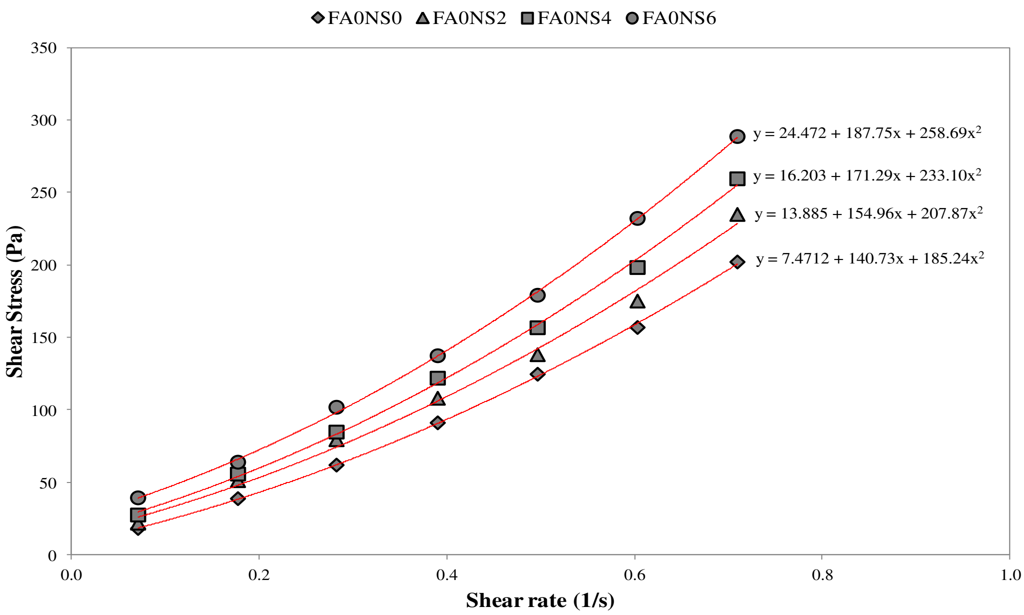
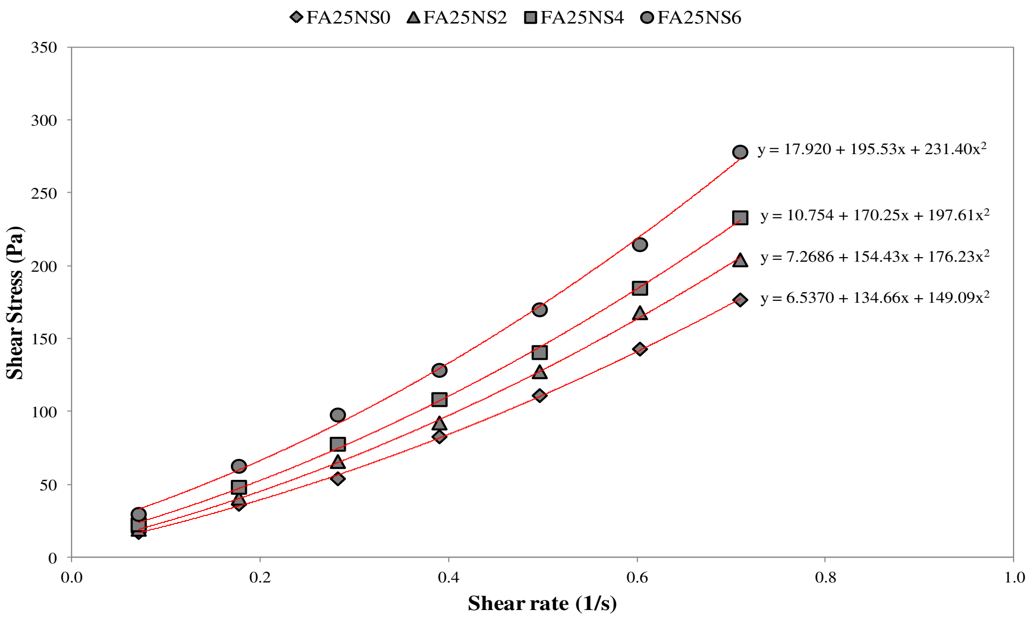


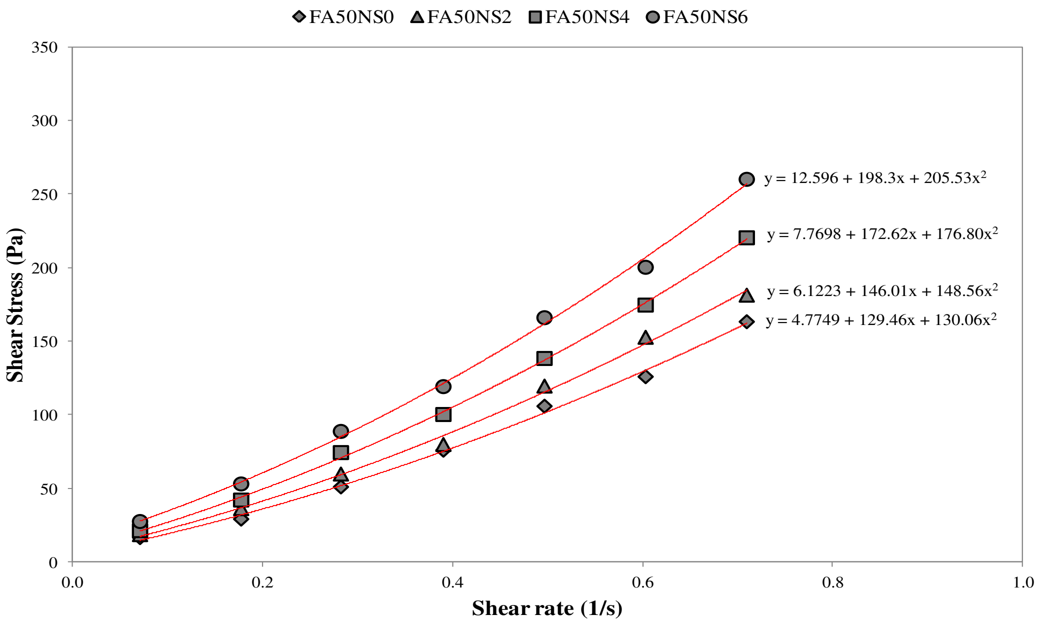
Figure 4.9 Variation in exponent 'n' values (Herschel-Bulkley)



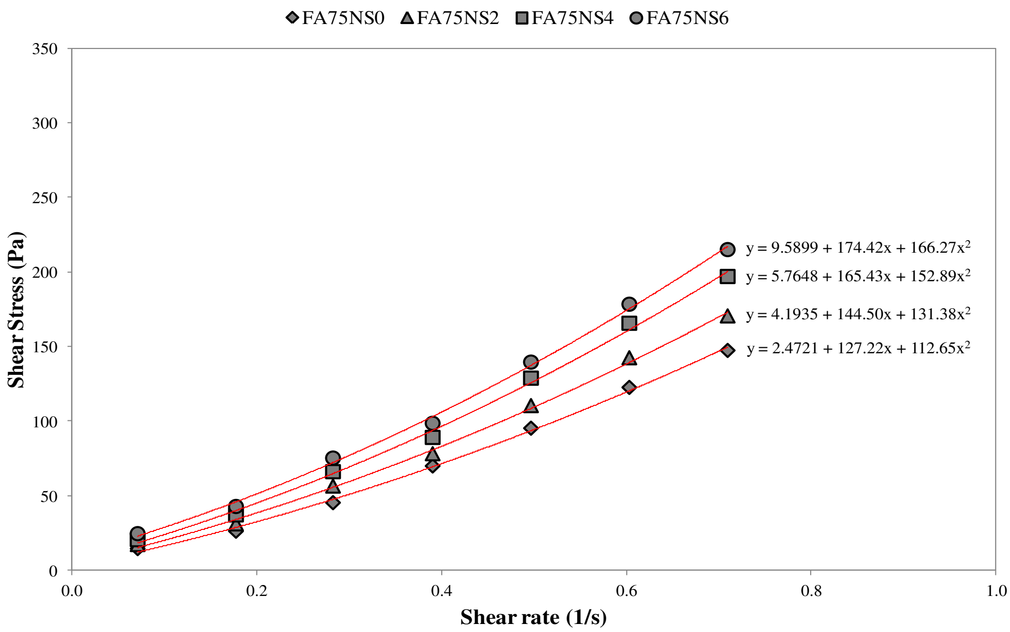
a)


FA25NS0 FA25NS2 FA25NS4 FA25NS6
y = 17.920 + 195.53x + 231.40x²
y = 10.754 + 170.25x + 197.61x²
y = 7.2686 + 154.43x + 176.23x²
y = 6.5370 + 134.66x + 149.09x²
Shear Stress (Pa)
Shear rate (1/s)

b)


FA50NS0 FA50NS2 FA50NS4 FA50NS6
y = 12.596 + 198.3x + 205.53x²
y = 7.7698 + 172.62x + 176.80x²
y = 6.1223 + 146.01x + 148.56x²
y = 4.7749 + 129.46x + 130.06x²
Shear Stress (Pa)
Shear rate (1/s)

c)



d)

Figure 4.10 Application of the modified Bingham model of the rheological data for SCC with a)0%, b) 25%, c) 50%, and d) 75% FA contents

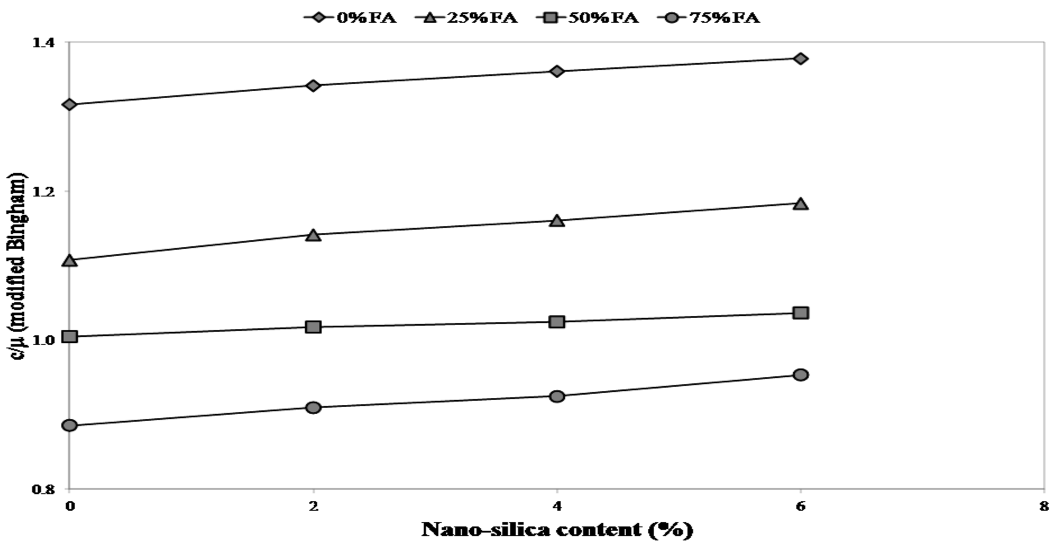
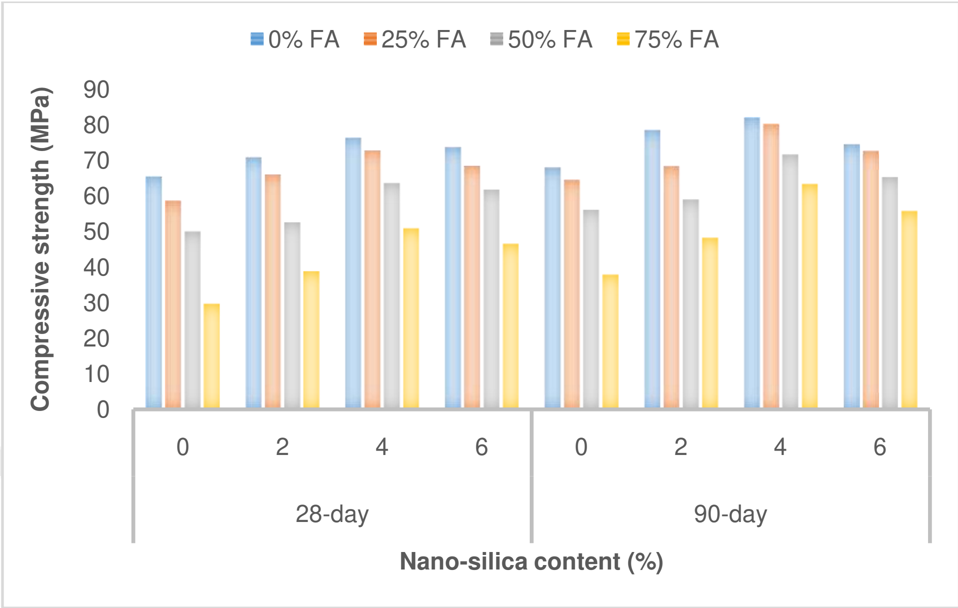
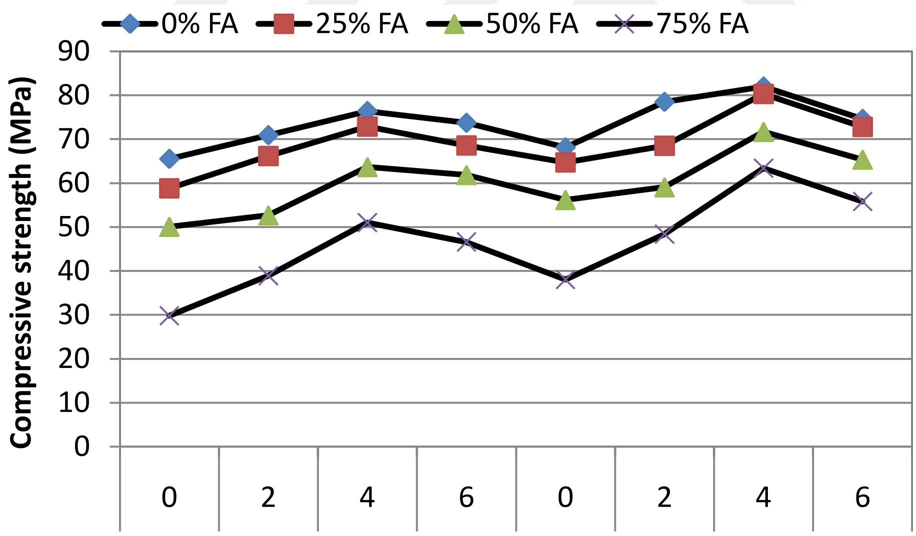


Figure 4.11 Variation in c/µ values (modified Bingham)

4.1.2 Analysis of Hardened Behavior

The summary of the test results relevant to the compressive strength of the concretes having different mix proportions at 28 and 90 days for SCCs produced are and graphically presented in Figure 4.12. The overall compressive strength ranged from (29.8 - 65.5) MPa of reference SCCs without NS at 28 days age and (38 – 68.1) MPa at 90 day age. The use of PC + FA reduced compressive strength of six mixes, with increasing the replacement level of FA. Replacing PC with 75% FA caused a reduction in the compressive strength of about 54.5%. However, this adverse effect of FA seemed to be remedied by the combined use of the mineral admixtures. Interestingly, the concrete containing 25% FA and 4% NS achieved the highest compressive strength of all mixtures contain PC +FA +NS. There was a gradual increase in the compressive strength of the concretes having NS including FA. The increase ratios for mixes with NS+FA compare with mixes without NS ranging (12.6, 24 , 16.7) %, (5.2 ,27.2 ,23.6) %, (30.5 , 71.1 , 56.4) % in the NS ratio (2 ,4 ,6) respectively at 28 days while the ratios are (6.0 , 24.1 ,12.5) % (5.2 ,27.6 ,16.4) % (27.4 ,66.8 ,46) % respectively at 90 days. Therefore, the test results suggested that it was the FA among the mineral admixtures used that governed the reduction in the compressive strength of the SCCs. The concrete with S, on the other hand, had generally comparable strength values to that of the control concrete (Gesoğlu and Güneyisi et al., 2008). The reason why the addition of nano-SiO2 can increase the compressive strength and compressive strength of concrete composites containing fly ash may be closely related to the specific nanometer effect of nano-SiO2 particles. Above all, nano-SiO2 particles, possessing a high specific surface area, can react with $Ca(OH)_2$ and produce C–S–H condensed gel. Hence, during the course of the pozzolanic reaction, the amounts and dimensions of the crystals of the $Ca(OH)_2$ are reduced and C–S–H gel, produced by pozzolanic reaction, forms a denser transition zone (Zhang and Zhao et al., 2014). In addition to the nucleation effect, nano-SiO2 may have acted as a reactive filler which reduces bleeding and increases packing density of solid materials by occupying the space between cement and fly ash particles (Zhang and Islam et al, 2012). Nano particles can fill a notable part of voids existing in the matrix of cement paste even in agglomerated manner, due to their ultra-fine dimension. Furthermore, when small amounts of nano particles are uniformly dispersed in the cement paste, they act as a nucleus to tightly bond with cement hydrate and also to promote hydration of cement due to their high activity, which is favorable for the strength of cement mortar (Bahadori and Hosseini, 2012).





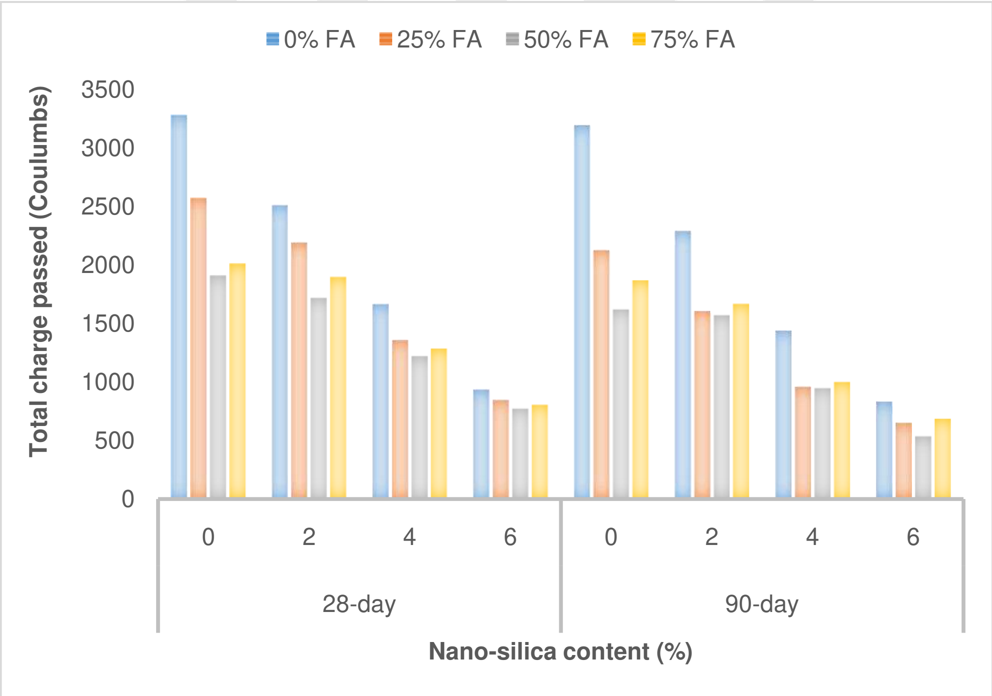
Nano-silicacontent (%)

Figure 4.12 Compressive strength of SCCs

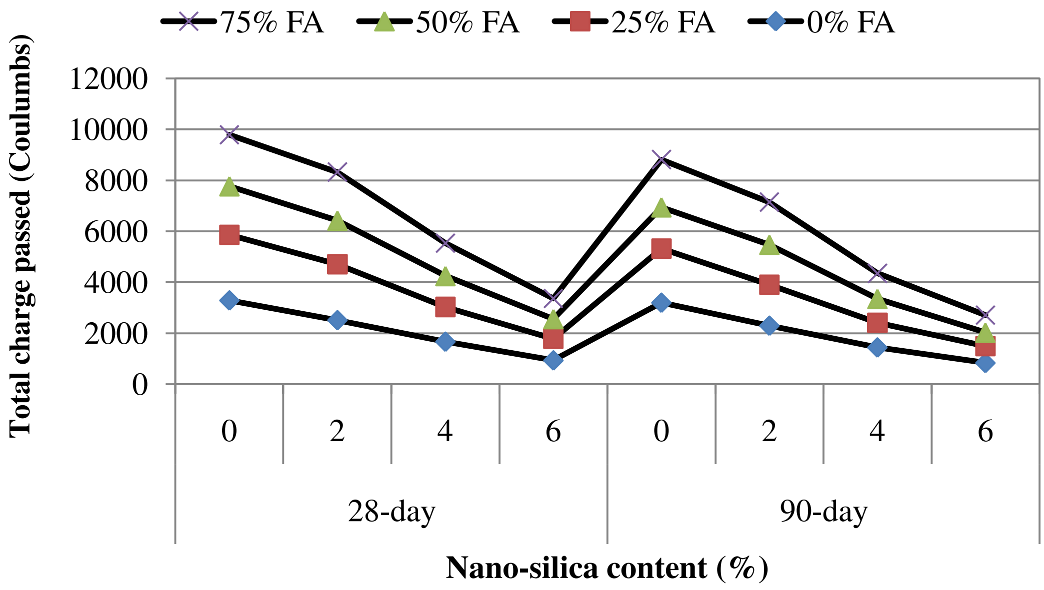
The penetration of water with chloride and other aggressive ions in concrete is the most important influence affecting the chemical and physical process of deterioration. The microstructure of concrete that is at most controlled by this process is related with water permeation and the transport of ions in concrete (Oh et al., 2002). Test results for the rapid chloride ion permeability are given in Table 4.1, and Figure 4.12. The control concrete showed the lowest resistance to the chloride permeability such that the total charge passed being about (3284- 3194) C respectively at the age (28, 90) day through this concrete rated the permeability as moderate due to the fact that most concretes produced in this study generally were in "low - very low" chloride permeability class according to (ASTM C1202, 2012). However, there is a marked reduction in chloride permeability of the concretes when the mineral admixtures were incorporated. It was observed in Table 4.3 that the total charge passed through the concretes with PC + FA rated the permeability as low and very low, irrespective of the replacement level of FA. However, SN seemed to be more effective in making the concretes resistant to chloride ingress. The concretes with FA +NS had permeability values generally ranged (223 -1900) C at 28 days, (537 – 1670) C at 90 days, thus indicating low to very low rating. Indeed, of all (16) concrete mixtures the highest resistance to chloride permeability was acquired for the mixture containing 4% NS and 75% FA, namely FA75NS4. The total charge passed through these concretes was measured as low as (773, 537) C at (28 – 90) day age which rated the permeability as very low. The low permeability of the concretes with mineral admixtures may be attributed to transformation large pores to fine pores or pore refinement (Marsh and Day et al., 1985, Chia and Zhang, 2002, Güneyisi and Özturan et al., 2007). Moreover the relative difference between 28 and 90 days proved that the pozzolanic activity of FA was more effective at later ages than at early ages (EFNARC, 2005). Additionally test results were conformed to values obtained from water permeability tests. This report was approved by (Zhang and Gjorv, 1991b); set that there was a relation directly between water permeability and chloride ion penetration.

Table 4.1permeability class according to ASTM C1202 (2012)

Mixes	Chloride permeability			
	28 days	Chloride ion Penetrability	90 days	Penetrability class
FA0NS0	3284	Moderate	3149	Moderate
FA0NS2	2511	Moderate	2294	Moderate
FA0NS4	1667	Low	1441	Low
FA0NS6	935	Very low	836	Very low
FA25NS0	2575	Moderate	2130	Moderate
FA25NS2	2193	Moderate	1610	Low
FA25NS4	1360	Low	962	Very low
FA25NS6	850	Very low	654	Very low
FA50NS0	1910	Low	1620	Low
FA50NS2	1719	Low	1570	Low
FA50NS4	1220	Low	946	Very low
FA50NS6	773	Very low	537	Very low
FA75NS0	2015	Moderate	1868	Low
FA75NS2	1900	Low	1670	Low
FA75NS4	1285	Low	1001	Low
FA75NS6	809	Very low	687	Very low



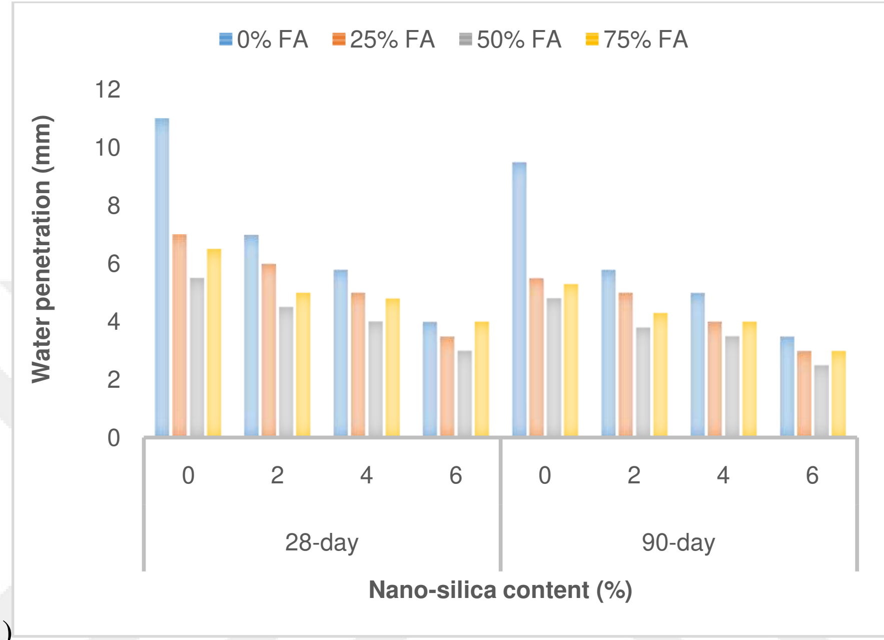
a)



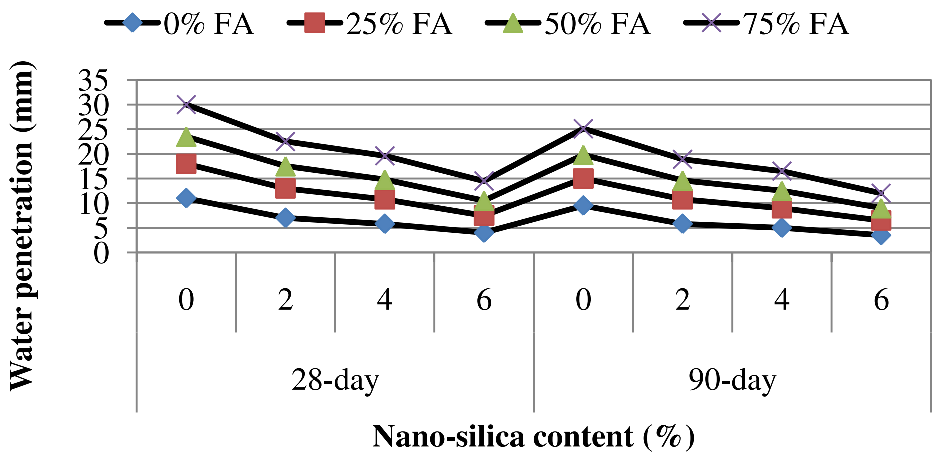
b)

Figure 4.13 Variations in the total charge passed for SCC

Water permeability test dealings the depth of water penetration into concrete in which a fluid may flow throughout a permeable form as a result of differential pressure. The variations of the water permeability of the SCCs with respect to the replacement percentages of the NS and FA are demonstrated in graphically shown in Figure 4.15 a and b at 28 and 90 days, respectively. It was observed that the water permeability of all mixes was lower than 11 mm. The increased porosity can result in an increment of pore connectivity of concrete. As water can penetrate through porous media.The highest water permeability of 11 mm was achieved for the reference concrete FA0NS0. However, the concretes with PC+FA, PC +S or PC+FA+S had a water permeability ranging from 3 to 7 mm at 28 days and 2.5 to 5.8 at 90 days. The concrete produced with FA and S showed better performance than that produced by the only FA or S or without them due to the fact that the structure is to be more dense with a few containing micro pores in its structure when using mineral admixtures. Therefore, using any of the mineral admixtures provided a marked reduction in the water permeability of SCCs when compared to that of the reference concrete. Especially, the use of FA and S in mix FA6NS50 provided a reduction of about 72.7 -73.7 % at 28 and 90 days, respectively in the water penetration depth of the concrete. The water permeability test provide information about the pore structure of the concrete and the continuity of these pores, and concretes probable durability against the aggressive medium. According to DIN 1048 (1991) and TS EN 12390/8 (2002) guidelines, concretes can be considered resistant to chemical attacks if the water penetration depth was less than 30 mm when in contact with aggressive environment.



a)



b)

Figure 4.14 Variations in the water permeability for SCC

As recommended by RILEM TC 116-PCD (1999), apparent gas permeability coefficient was computed for each inlet pressure of (150-500) KPa and the average of them is graphically shown in Figure 4.15. The test results clearly demonstrated that the substitution of FA and NS considerably decreased the apparent gas permeability coefficient depending on the replacement level of the PC. The highest and lowest gas permeability coefficients at 28 and 90 days were measured for FA25NS0 as (2.715 – 2.498) x10-16 m and for FA75NS6 as (1.093 - 0.979) x10-16 m, respectively. Since the transport properties of concretes are strongly depending on its pore structure, the raising of gas permeability of concrete can be attributed to the increased pore structure in concretes due to fact that nano size of such silica reduced the width of the interfacial transition zone apart from the chemical process associated with pozzolanic activity of FA and NS which in turn diminished the permeability, authors concluded limited observations on this very important aspect of concrete with pozzolanic material such as FA, silica are consistent with the view expressed by Manmohan and Mehta (2001) that the transformation of large pores to fine pores, as a consequence of the pozzolanic reaction between Portland cement paste and fly ash, substantially reduces permeability in cementations systems, Besides, extremely fine particle size of nano-SiO2 may have accelerated cement and FA hydration by providing high number of nucleation sites for precipitation of cement hydration products in the FA concrete composites. In addition to the nucleation effect, nano-SiO2 may have acted as a reactive filler which increases packing density of solid materials by occupying the space between cement and FA particles (Zhang et al., 2012).

The variants of the water sorptivity coefficient at 28 and 90 days, according to the replacement percentages of the NS and FA are demonstrated in Table 4.6, and Figure 4.16. And presents the sorptivity test results of the SCCs measured at 28 and 90 days, respectively. The sorptivity index value changes between 0.0688 and 0.0951 mm/min$^{0.5}$, and 0.0403 and 0.0958 mm/min$^{0.5}$was measured at 28-days and 90-day, respectively. The results indicated that utilization of NS in the SCC production systematically decreased the sorptivity index of the mixtures at both ages. However, the effect of the NS incorporating on the 90-day sorptivity index was more than the 28-day index.

Namely, the increasing the NS content from 0 to 6% resulted in decreasing of 28-day sorptivity index values as much as 23.7, 21.4, 18.8, and 18.7% in the first, second, third, and fourth SCC series, respectively, while the decreasing amounts of 90-day sorptivity index values were about 32.7, 27.0, 36.2, and 28.8% in the first, second, third, and fourth SCC series, respectively. This might be due to the secondary reaction between the calcium hydroxide of the cement paste and the silicon dioxide of the NS. In addition to nano-silica enhancement, fly ash utilization was also improved permeability of the SCC is regarding to sorptivity index. The sorptivity index values were decreased by increasing the FA content till 50%. At the 75% replacement level, the small amount of increment was determined. Although there was an increase in the sorptivity index values at 75% replacement level of FA, the values were lower than the values of the SCC that did not include FA. As seen from Figure 4.6(a, b), the best sorptivity index values of 0.688 and 0.403 were achieved in the FA50NS4 mixture at 28 and 90 days, respectively. It was caused due to balling effect of NS at high replacement level. The NS utilization at high percentages, such as more than 4% generally aggravates the permeability properties of concretes due to the fact that nano-silica had a high surface area and contains nano scaled particle that had tendency to coagulate when it was used at high replacement level

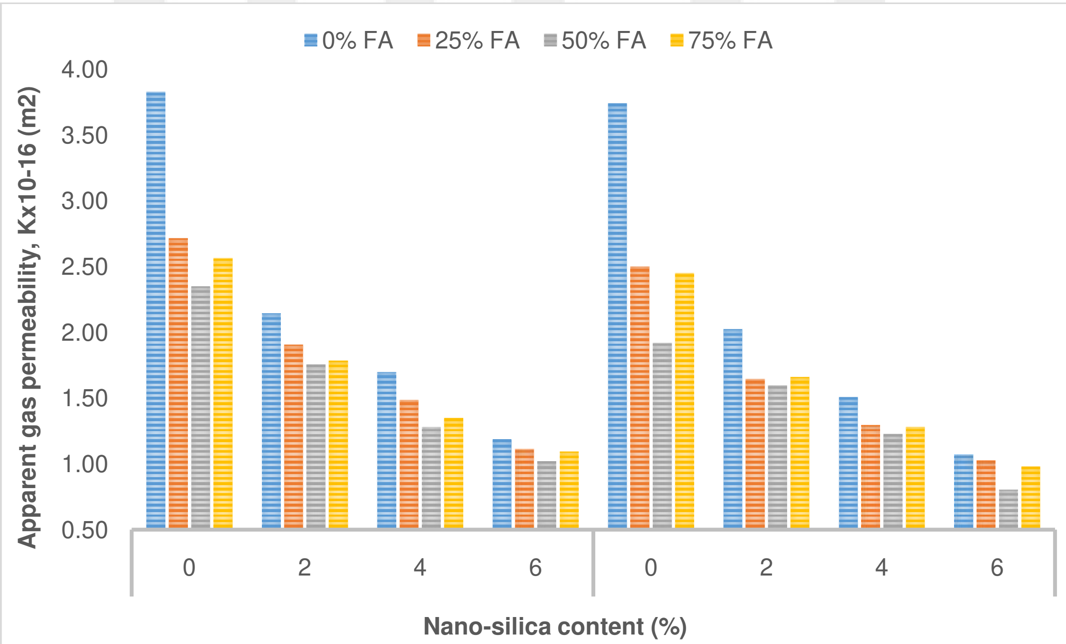


Figure4.15 Variations in the apparent gas permeability

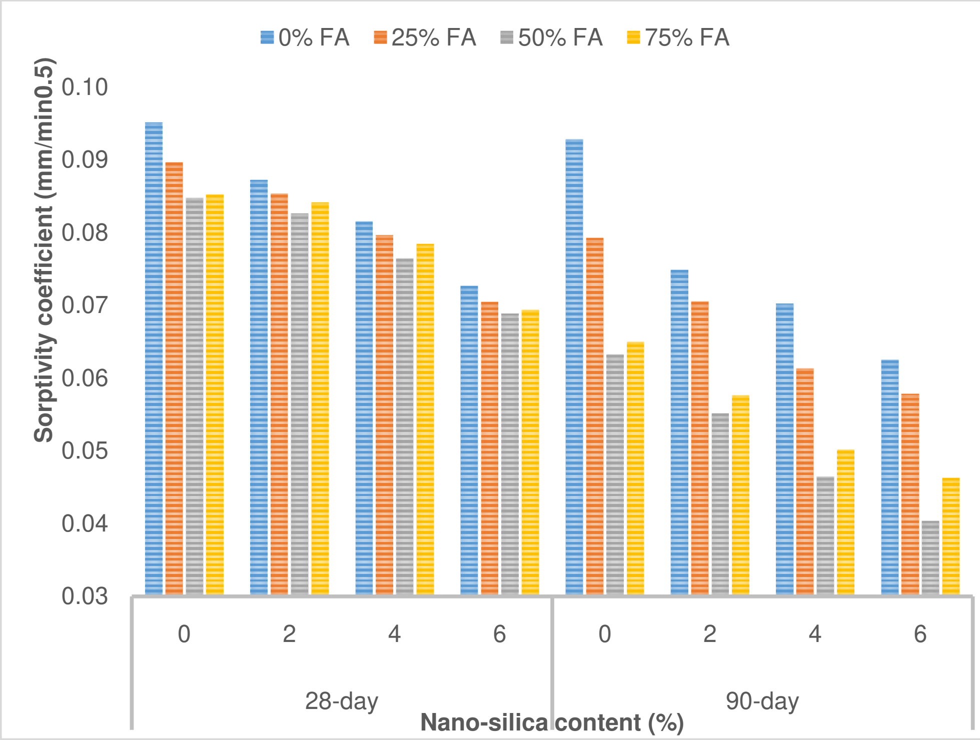


Figure 4.16 Variations in sorptivity coefficient

4.1.3 Statistical Analysis

The analysis of variance (ANOVA) was used to find out that whether an independent variable has an effect on a dependent variable or not. The effectiveness of the test parameters was determined by the general linear model analysis of variance (GLM-ANOVA) which is an important statistical analysis and diagnostic tool which helps to quantify the dominance of a control factor by reducing the control variance. The fresh properties such as slump flow diameter, T_{50} slump flow time, V-funnel flow time, and L-box height ratio of SCCs were analyzed separately and assigned as dependent variable while FA and NS content were selected as independent factors. The software, called Minitab used to analyze the test results obtained from this study and the analysis were carried out at a 0.05 level of significance to specify the statistical significant experimental parameters on the fresh properties SCC. The statistical analysis results achieved from GLM-ANOVA are presented in Table 4.2. The P-values in the fifth columns show the significance of the test parameters on the fresh properties. P- Value less than 0.05 means that the parameter is acceptable as a significant factor on the test result. Besides, percent contribution, which is calculated by the division of the sequential sum of squares of independent variables to the total sequential sum of squares, was also determined to have an idea about the degree of effectiveness of each independent variable on the dependent variable. When the percent contribution of one parameter is higher, the effectiveness of that parameter on the analyzed property is higher. Likewise, if the percent contribution is low, the contribution of the factors to that particular response is less. The statistical analysis results indicated that all fresh properties of SCC were affected by FA and NS content regarding the P-values obtained from the two-way ANOVA. Moreover, the statistical analysis also revealed that the dependent parameters, T_{50} slump flow time, V-funnel flow time, and L-box height ratio, were more affected by NS content than FA content when the percent contribution values of independent variables were considered while FA content was more effective on slump flow diameter than NS content.

Table 4.2 Result of statistical analysis on fresh state

Dependent variable	Independent variable	Sequentialsm of squares	Comput-ed F	P value	Significant	Contribu -ting (%)
Slump flow diameter	FA content	6354.69	369.73	0.000	Yes	84.75
	NS content	1092.19	63.55	0.000	Yes	14.57
	Error	51.56	-	-	-	0.68
	Total	7498.44	-	-	-	-
T_{50} slump flow time	FA content	8.1369	143.07	0.000	Yes	47.14
	NS content	8.9519	157.40	0.000	Yes	51.87
	Error	0.1706	-	-	-	0.99
	Total	17.2594	-	-	-	-
V-funnel flow time	FA content	11.0125	33.63	0.000	Yes	32.66
	NS content	21.7225	66.33	000	Yes	64.43
	Error	0.9825	-	-	-	2.91
	Total	33.7175	-	-	-	-
L-box height ratio	FA content	0.0046688	16.36	0.001	Yes	33.01
	NS content	0.0086187	30.20	0.000	Yes	60.94
	Error	0.0008562	-	-	-	6.05
	Total	0.0141437	-	-	-	-

In order to find out the statistical significance of the experimental test parameters in a quantitative manner, general linear model analysis of variance (GLM-ANOVA) was performed at the 0.05 level of significance. GLM-ANOVA is an important statistical analysis and diagnostic tool which helps in reducing the error variance and quantifies the dominance of a control factor. In the analysis, the measured properties for SCLCs such as compressive strength, Water penetration, Rapid chloride permeability, Apparent gas permeability were assigned as the dependent variables while the concrete age, FA content, NS content was selected as the independent factors. GLM-ANOVA was performed and the effective test parameters and their percent contributions on the above mentioned properties of the results were presented in Table 4.3. If the P value of the test system is less than 0.05, the independent variable is accepted as a significant factor in the test results. As observed in Table 4.3, except the effect of using FA on Apparent gas permeability test results, the P-values on all measured test results was less than 0.05. This situation can be interpreted that the variability of test results must be defined by the independent variables with a significance being less than 0.05. Contribution of independent variables on the test results are also given in Table 4.3. The percentage contributions define the degree effectiveness of the independent factors on the measured property. When the percent contribution of one parameter is higher, the effectiveness of that parameter on the analyzed property is higher. Likewise, if the percent contribution is low, the contribution of the factors to that particular response is less. The statistical analysis results indicated that all fresh properties of SCC were affected by FA and NS content regarding the P-values obtained from the two-way ANOVA. Moreover, the statistical analysis also revealed that the dependent parameters, compressive strength, water penetration, rapid chloride permeability, apparent gas permeability were more affected by NS content than FA content when the percent contribution values of independent variables were considered while FA content was less effective on apparent gas permeability than NS content.

Table 4.3 Results of statisticalanalysis on hardened state

Dependent variable	Independent variable	Sequential sum of squares	Computed F	R-square (%)	P value	Signific -ance	Contrib-ution (%)
Compressive strength	Concrete age	311.25	38.62	96.21	0.000	YES	6.1
	NS content	1144.53	47.34		0.000	YES	22.4
	FA content	3450.80	142.73		0.000	YES	67.7
	Error	193.42	-		-	-	3.8
	Total	5100.00	-		-	-	-
Soprtivitiy index	Concrete age	0.0027733	113.66	90.84	0.000	YES	43.4
	NS content	0.0019165	26.18		0.000	YES	30.0
	FA content	0.0011166	15.25		0.000	YES	17.5
	Error	0.0005856	-		-	-	9.1
	Total	0.006392	-		-	-	-
Water penetration	Concrete age	6.213	9.91	85.19	0.004	YES	6.1
	NS content	53.403	28.39		0.000	YES	52.6
	FA content	26.941	14.32		0.000	YES	26.5
	Error	15.047	-		-	-	14.8
	Total	101.605	-		-	-	-
Rapid chloride permeability	Concrete age	496506	9.74	92.34	0.000	YES	3.1
	NS content	1175703	76.86		0.000	YES	73.6
	FA content	2487485	16.27		0.005	YES	15.6
	Error	1223309	-		-	-	7.7
	Total	15960003	-		-	-	-
Apparent gas permeability	Concrete age	0.2035	3.04	90.55	0.000	YES	1.2
	NS content	13.2633	66.13		0.000	YES	78.2
	FA content	1.8999	9.47		0.094	NO	11.1
	Error	1.6046	-		-	-	9.5
	Total	16.9712	-		-	-	-

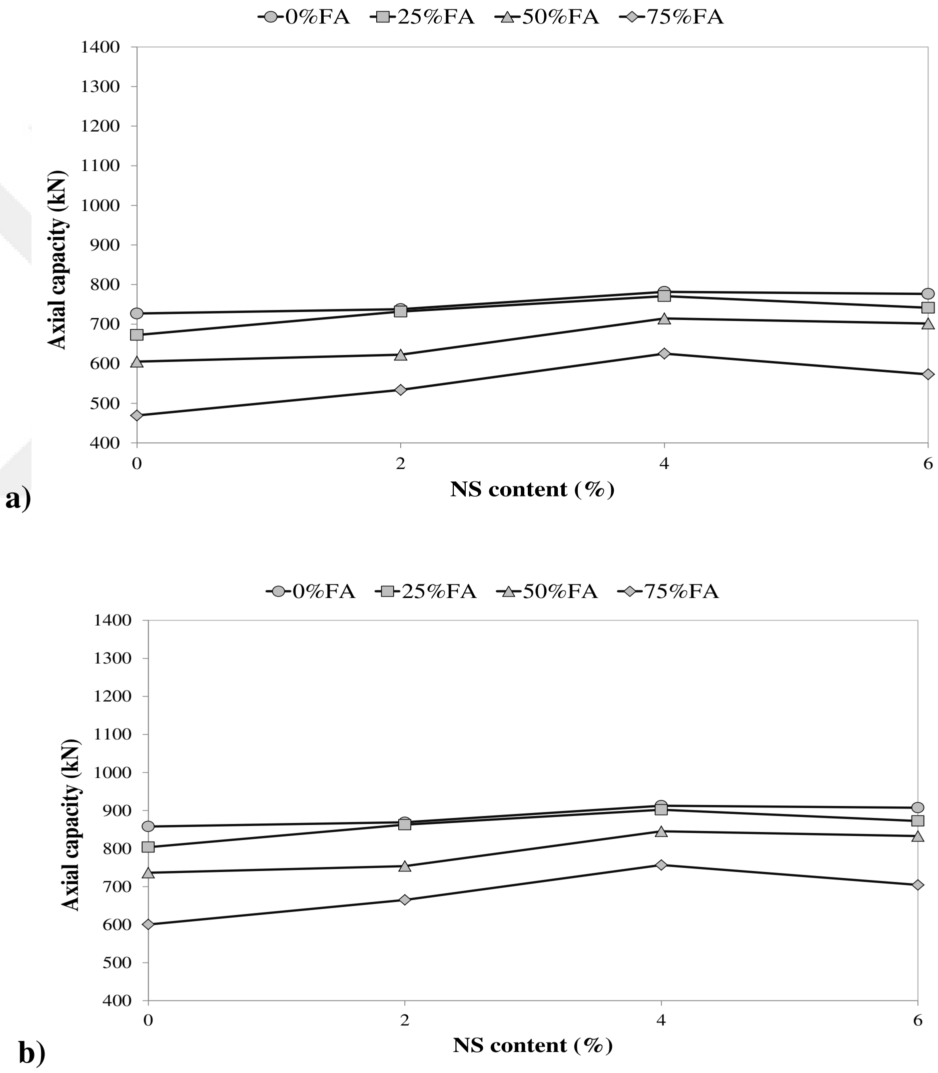
4.2 Numerical Findings

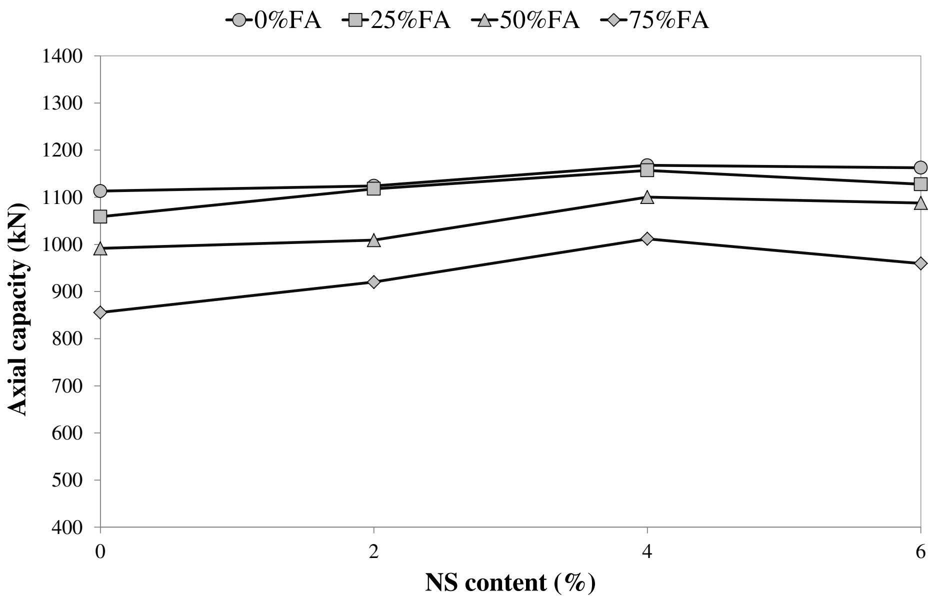
4.2.1 Axial Capacity of CFST Columns According to Design Codes

The compressive strength of SCC mixtures were used in the calculation of the ultimate strength of the steel tubular columns by using ACI and Eurocode 4 formulae. The relation between 28 and 90 days ultimate column strength (calculated by using ACI and Eurocode 4 formulae) and NS/FA contents are presented in Figures 4.17 – 4.20 with respect to D/t ratio of 30, 60, and 90, and steel yielding strength of 185, 275, and450 MPa. The relations are also given with respect to D/t ratio and steel yielding strength in Tables 4.4 and 4.5. The results indicated that the ultimate strength of steel tubular columns filled with SCC is strongly affected by concrete compressive strength. Utilization of NS till replacement level of 4% increased the SCC compressive strength and increasing in the compressive strength directly increased the ultimate strength of the steel tubular columns. However, at the replacement level of 6%, decreasing in the compressive strength of SCC was observed at all FA contents. This is also caused decreasing in the ultimate strengths of CFST calculated by both formulae. On the contrary to NS, the utilization of FA decreased the compressive strength of SCC. This situation resulted in lower ultimate strength of steel tubular columns determined by both formulae. Moreover, the ultimate strengths determined by ACI formula were lower than that calculated by using Eurocode 4. Calculating the ultimate strength of the steel tubular columns filled with compressive strength at different D/t ratio showed that increasing the concrete surface area is increasing the ultimate strength. Also, utilization steel tubular with higher yielding strength is remarkably increased the ultimate strength of the columns.

4.2.2 Comparison of Design of ACI and EC4

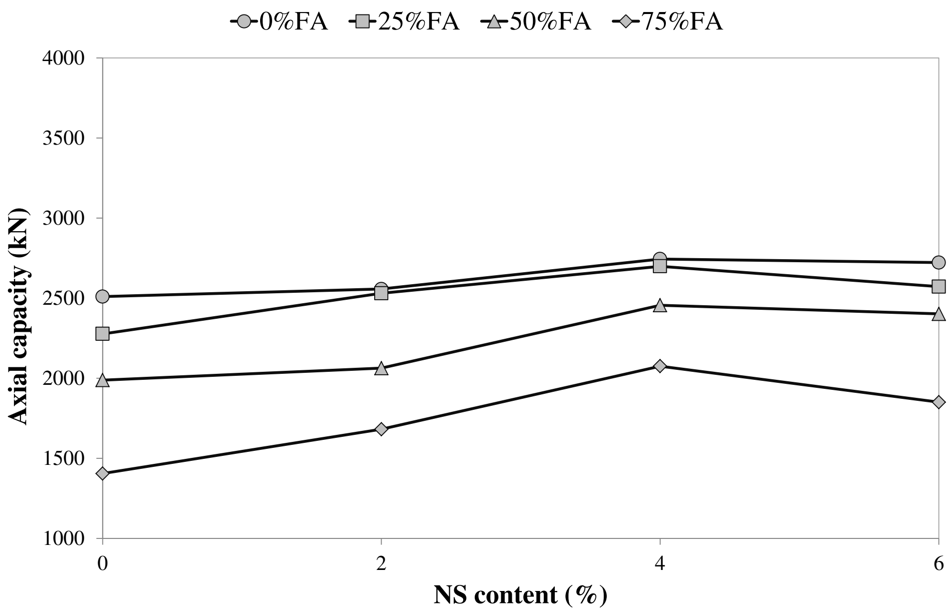
The relationship between 28 and 90-day axial capacity of the composite columns with D/t ratio for Eurocode 4 and ACI are represented in Figure 4.21and 4.22) Fy=185, b) fy=275, and c) fy=450 MPa, respectively. Which the increment appears in axial capacity due to the D/T ratio increasing, in both ACI and Eurocode4, the same results is given in Figures 4.23 about the performance of Eurocode 4 and ACI code to predict the capacity of the CFST columns at 28 and 90 days. Figures 4.24 and 4.25 are represent the interaction between the normalized axial capacities based on Eurocode 4/ACI code and D/t ratio, infill compressive strength of section at 28 and 90 days respectively. In addition, in Figure 4.26, the correlation between the design code provisions for the composite sections having different SCC mixtures was given. Results indicated that there is a strong relation between the ultimate strength calculated by ACI and Eurocode 4 formulae.





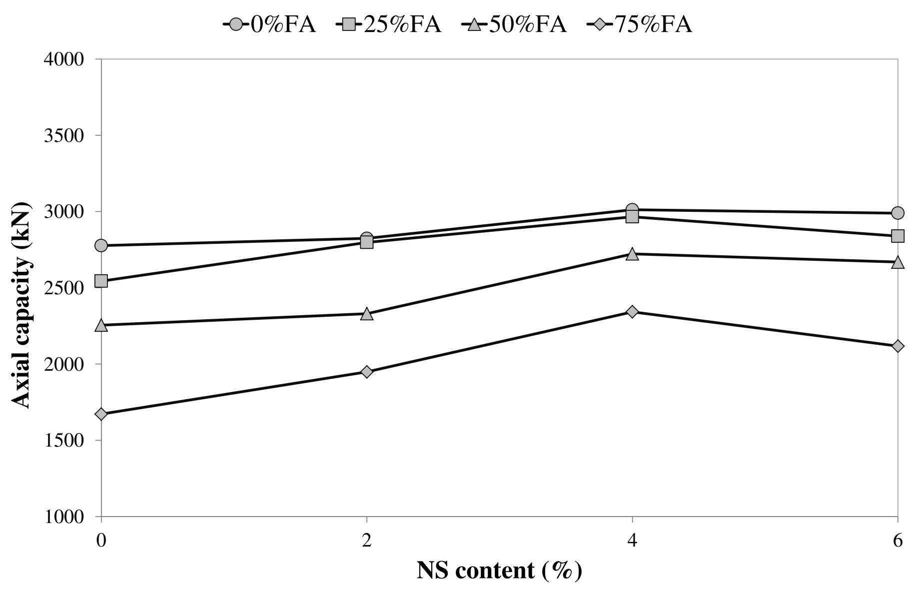
0%FA
25%FA
50%FA
75%FA
1400
1300
1200
1100
1000
900
800
700
600
500
400
Axial capacity (kN)
0
2
4
6
NS content (%)

c)

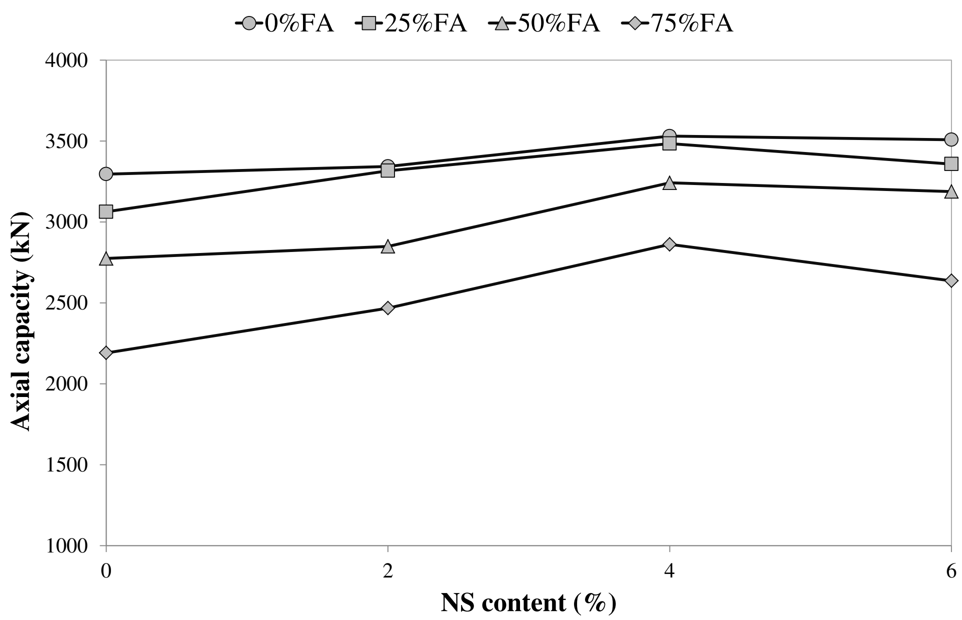


0%FA
25%FA
50%FA
75%FA
4000
3500
3000
2500
2000
1500
1000
Axial capacity (kN)
0
2
4
6
NS content (%)

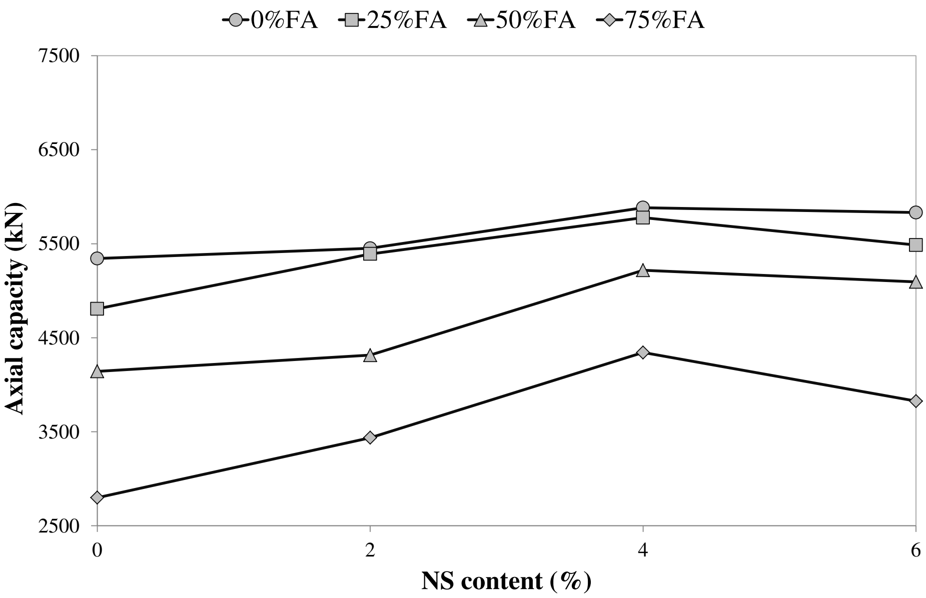
d)


0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
NS content (%)
4000
3500
3000
2500
2000
1500
1000
0
2
4
6

e)

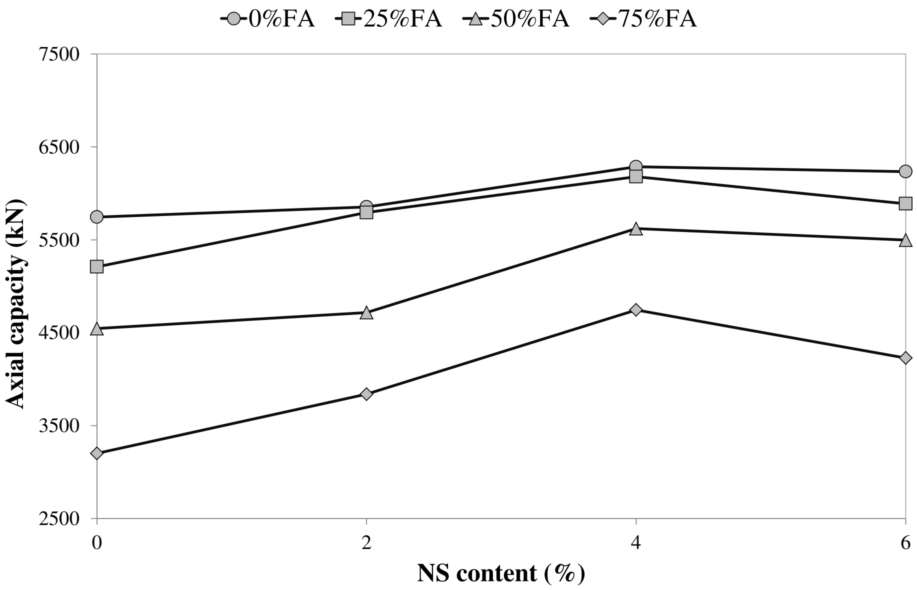

0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
NS content (%)
4000
3500
3000
2500
2000
1500
1000
0
2
4
6

f)



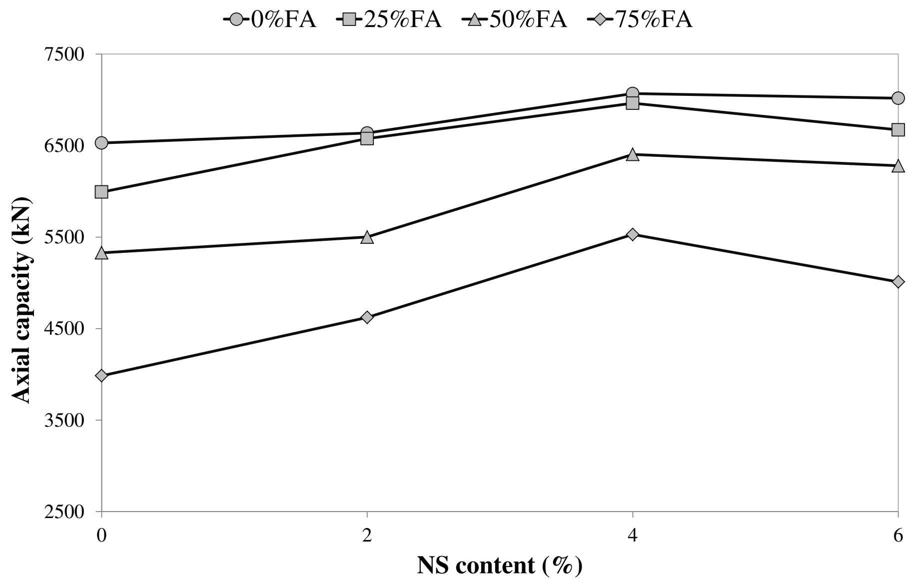
0%FA
25%FA
50%FA
75%FA
7500
6500
5500
4500
3500
2500
Axial capacity (kN)
0
2
4
6
NS content (%)

g)



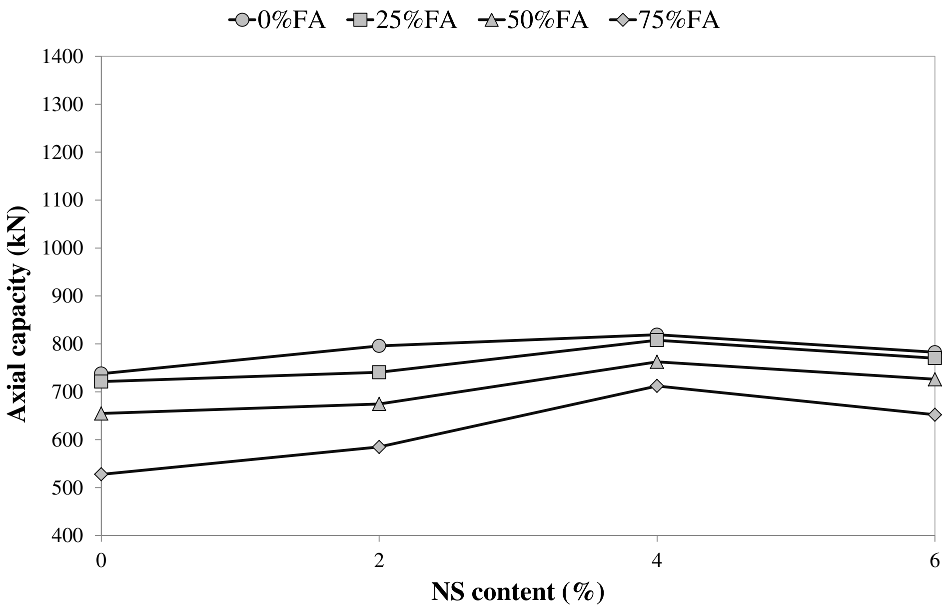
0%FA
25%FA
50%FA
75%FA
7500
6500
5500
4500
3500
2500
Axial capacity (kN)
0
2
4
6
NS content (%)

h)

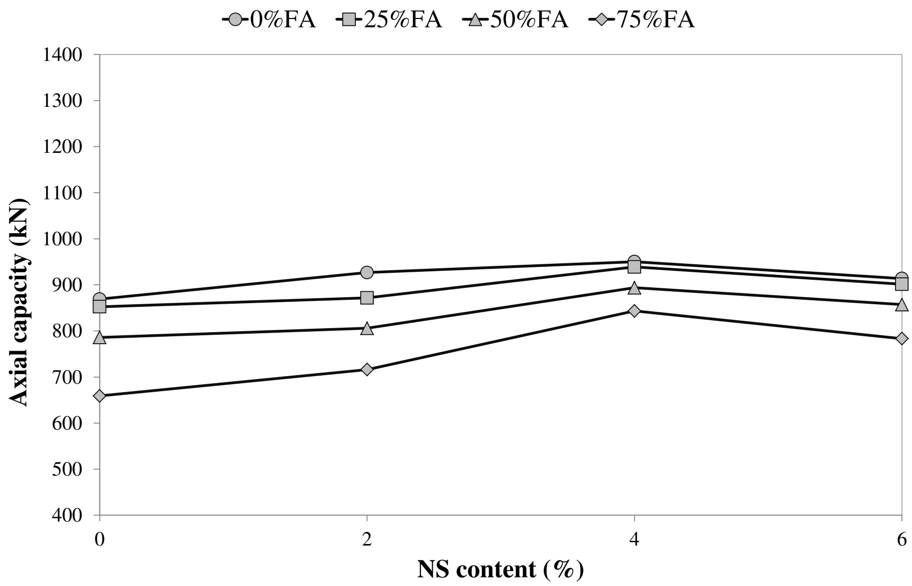


i)

Figure 4.17 Axial capacity of the CFST columns having different SCC mixtures at 28 days according to ACI code with: a) D/t=30 - fy=185, b) D/t=30 - fy=275, c) D/t=30 - fy=450, d) D/t=60 - fy=185, e) D/t=60 - fy=275, f) D/t=60 - fy=450, g) D/t=90 - fy=185, h) D/t=90 - fy=275, and i) D/t=90 - fy=450 of tubes

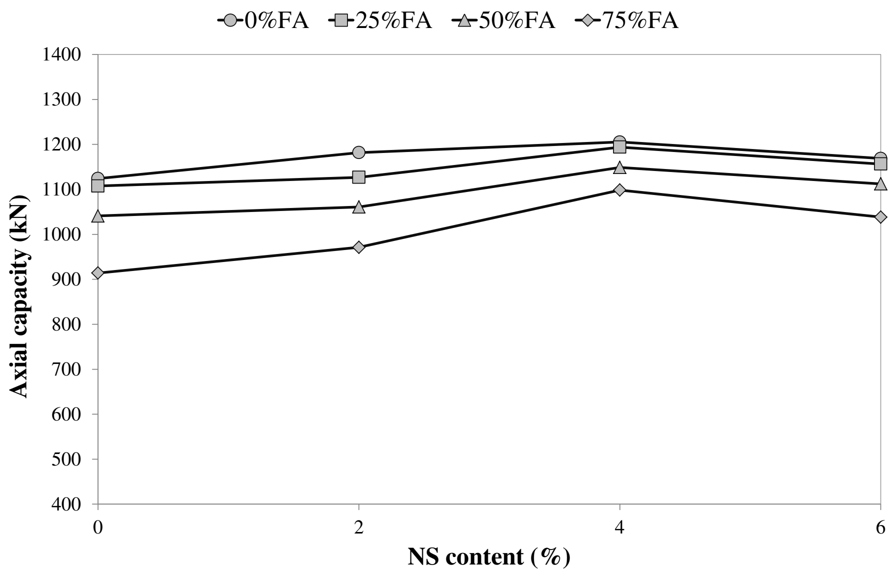


a)



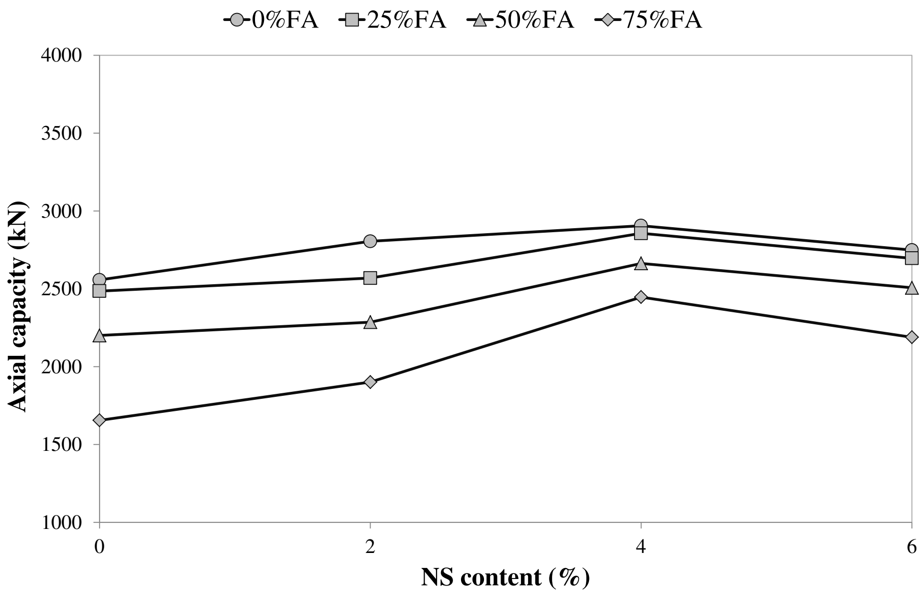
0%FA
25%FA
50%FA
75%FA
1400
1300
1200
1100
1000
900
800
700
600
500
400
Axial capacity (kN)
0
2
4
6
NS content (%)

b)



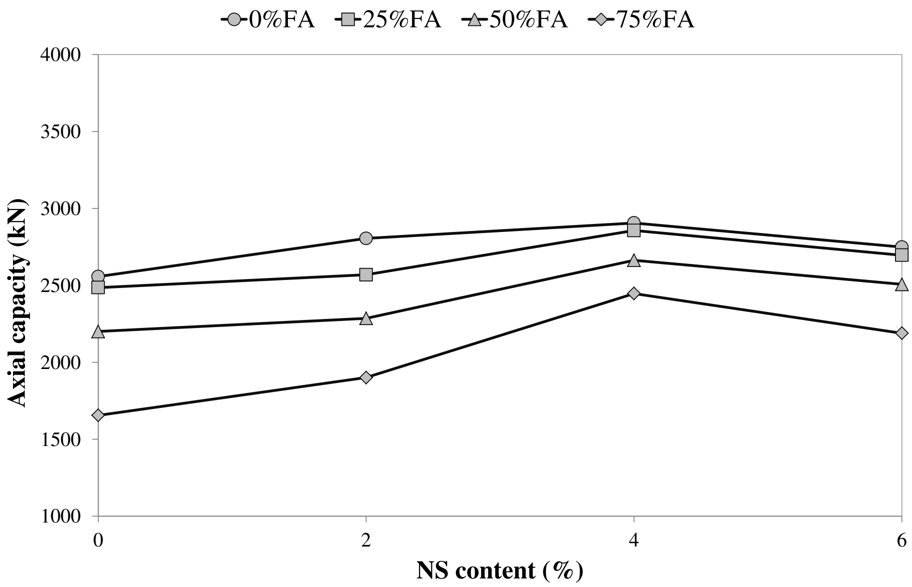
0%FA
25%FA
50%FA
75%FA
1400
1300
1200
1100
1000
900
800
700
600
500
400
Axial capacity (kN)
0
2
4
6
NS content (%)

c)



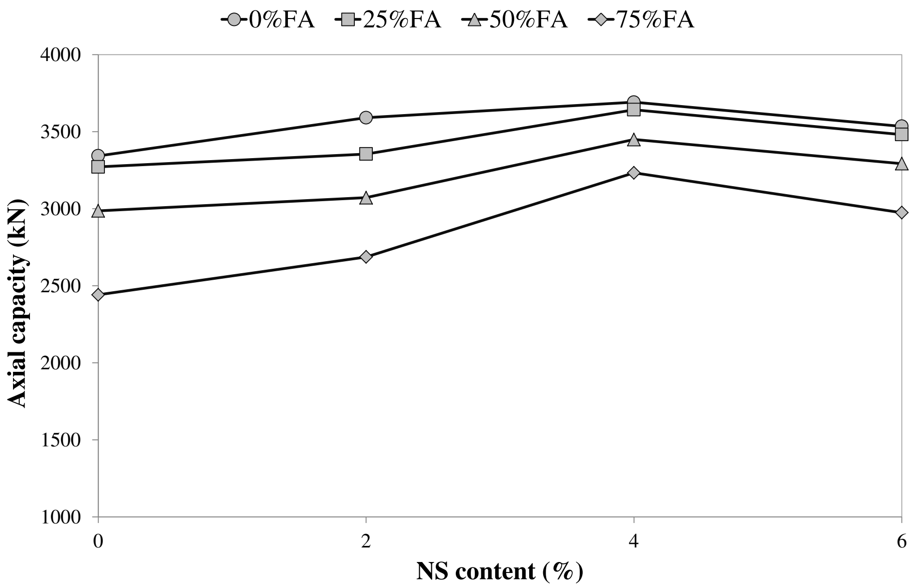
0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
4000
3500
3000
2500
2000
1500
1000
0
2
4
6
NS content (%)

d)



0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
4000
3500
3000
2500
2000
1500
1000
0
2
4
6
NS content (%)

e)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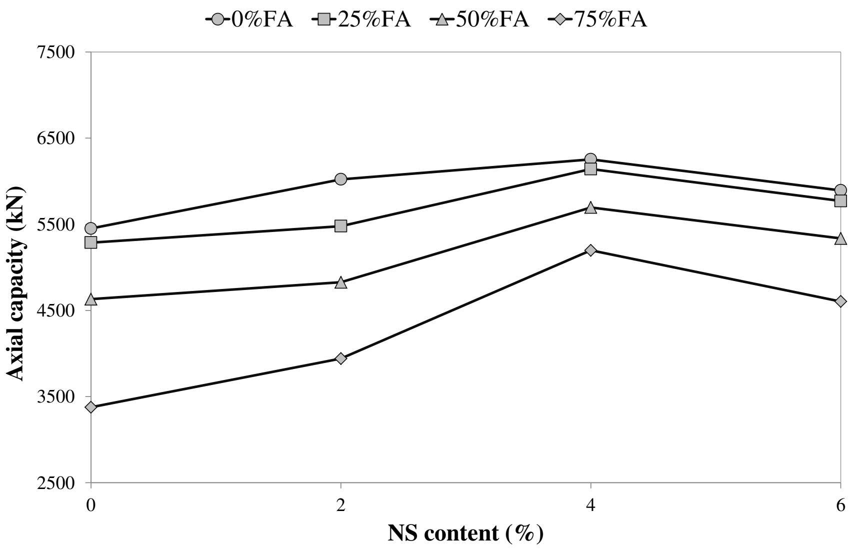
50%FA
75%FA
4000
3500
3000
2500
2000
1500
1000
Axial capacity (kN)
0
2
4
6
NS content (%)

f)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75%FA
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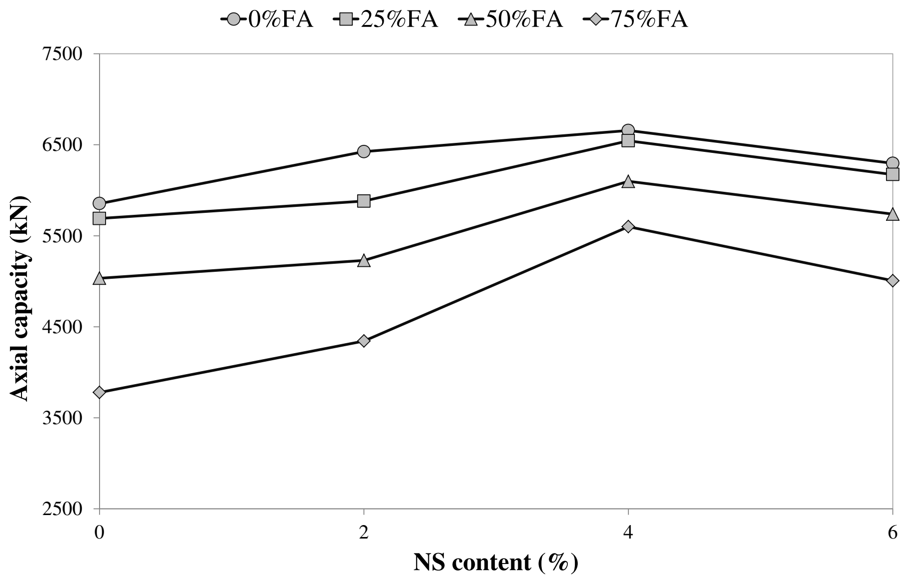
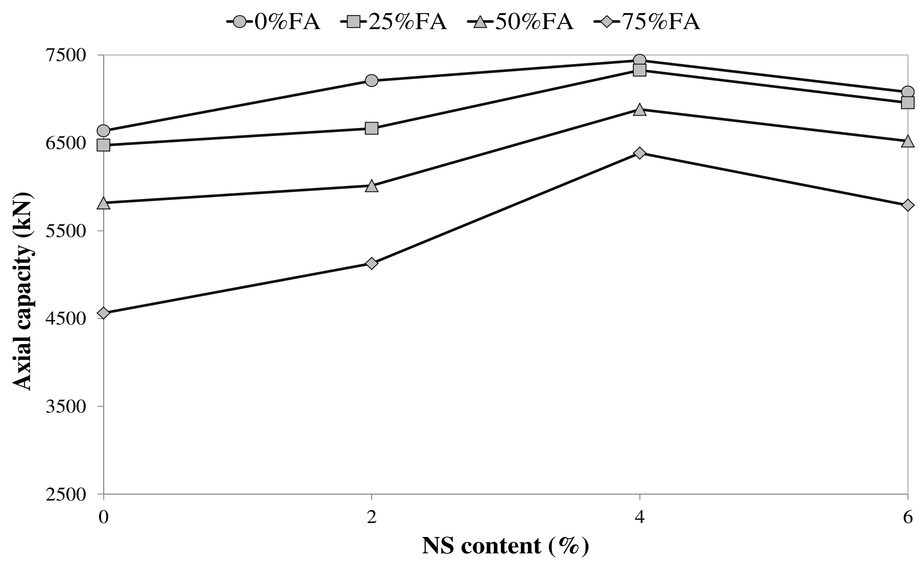
6500
5500
4500
3500
2500
Axial capacity (kN)
0
2
4
6
NS content (%)

g)

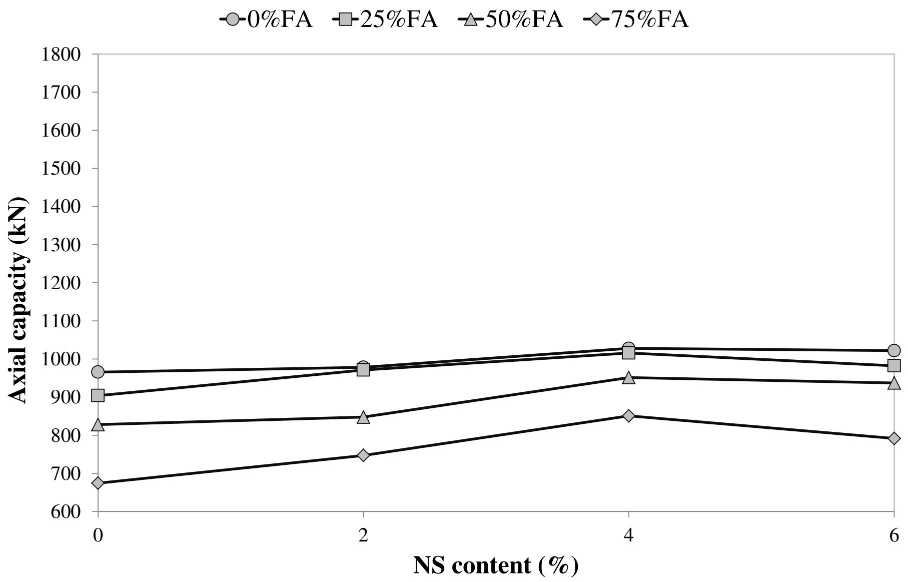


h)



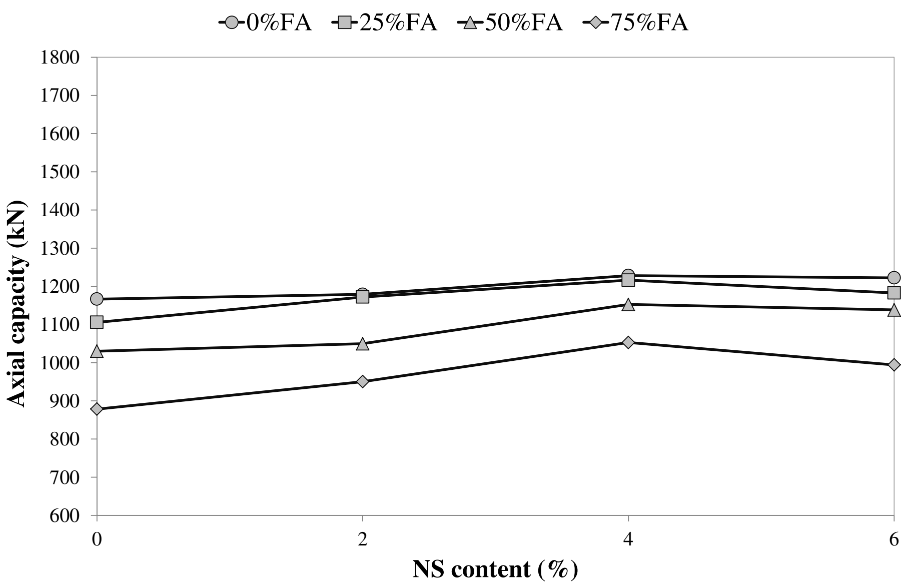
i)

Figure 4.18 Axial capacity of the CFST columns having different SCC mixtures at 90 days according to ACI code with: a) D/t=30 - fy=185, b) D/t=30 - fy=275, c) D/t=30 - fy=450, d) D/t=60 - fy=185, e) D/t=60 - fy=275, f) D/t=60 - fy=450, g) D/t=90 - fy=185, h) D/t=90 - fy=275, and i) D/t=90 - fy=450 of tubes



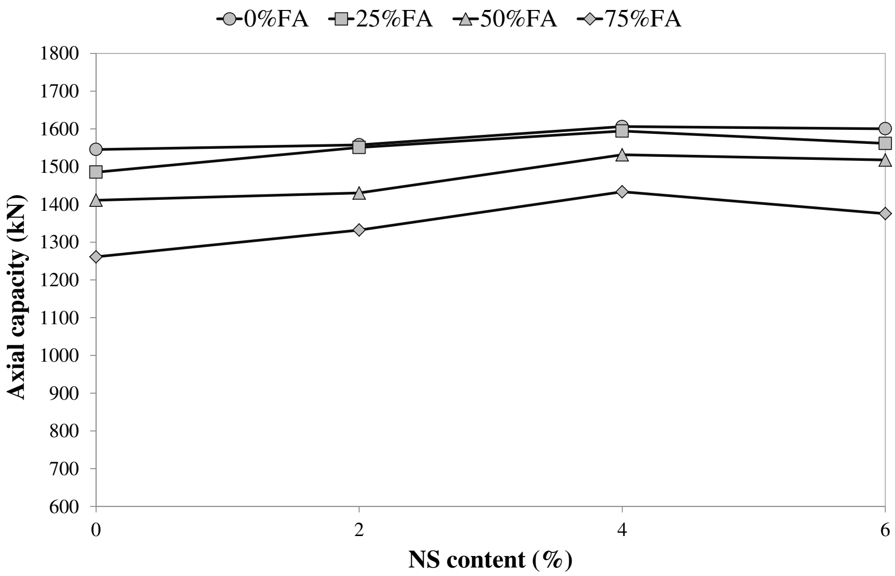
0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
0
2
4
6
NS content (%)

a)

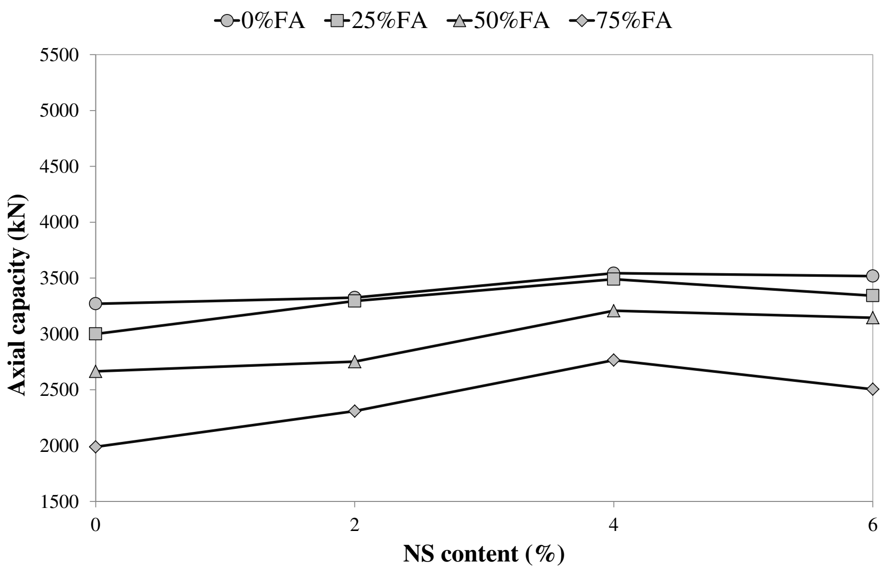


0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
0
2
4
6
NS content (%)

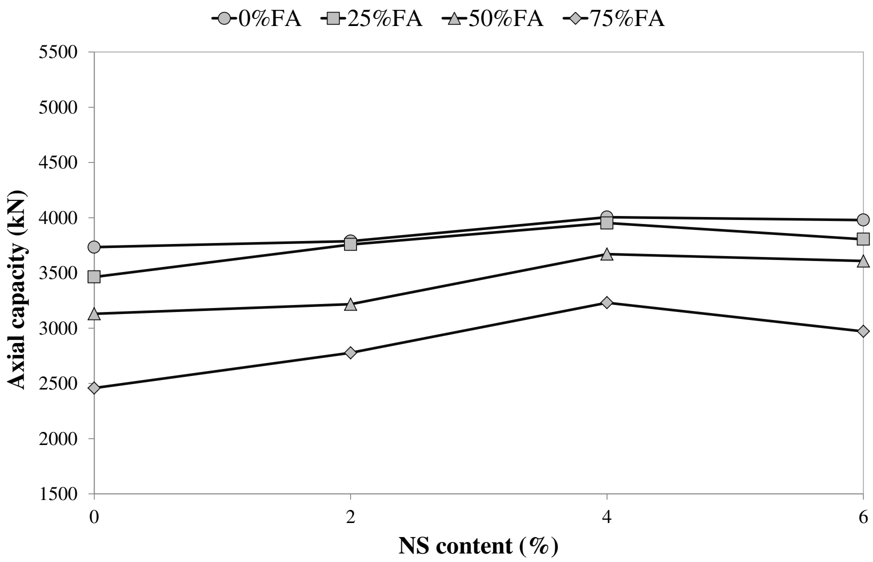
b)


0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
NS content (%)

c)


0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
NS content (%)

d)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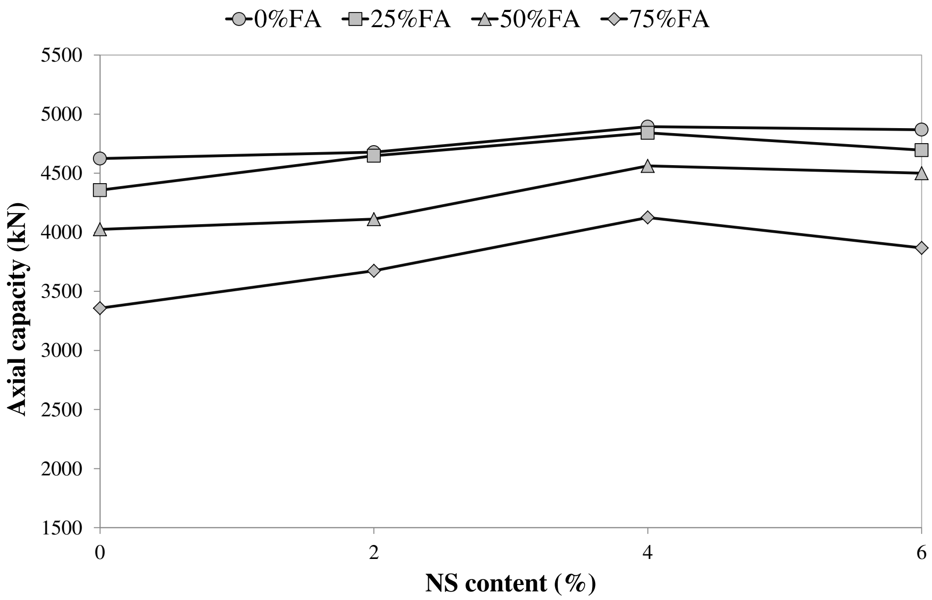
25%FA
50%FA
75%FA
Axial capacity (kN)
NS content (%)
5500
5000
4500
4000
3500
3000
2500
2000
1500
0
2
4
6

e)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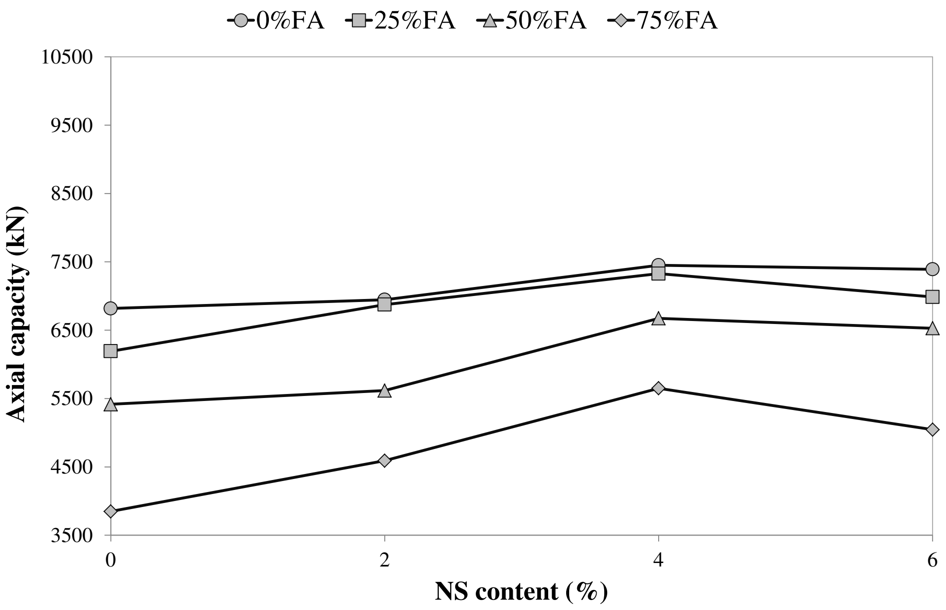
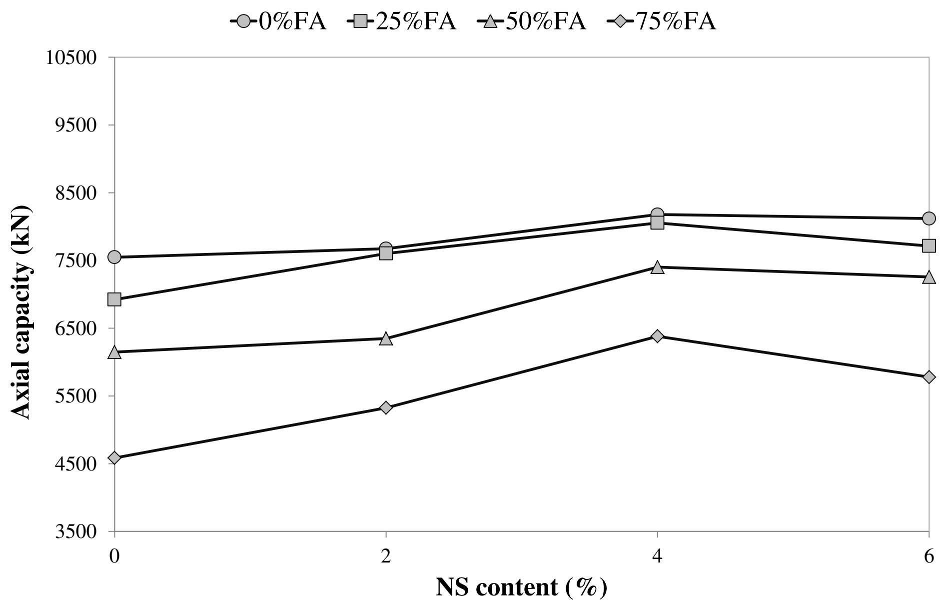
50%FA
75%FA
Axial capacity (kN)
NS content (%)
5500
5000
4500
4000
3500
3000
2500
2000
1500
0
2
4
6

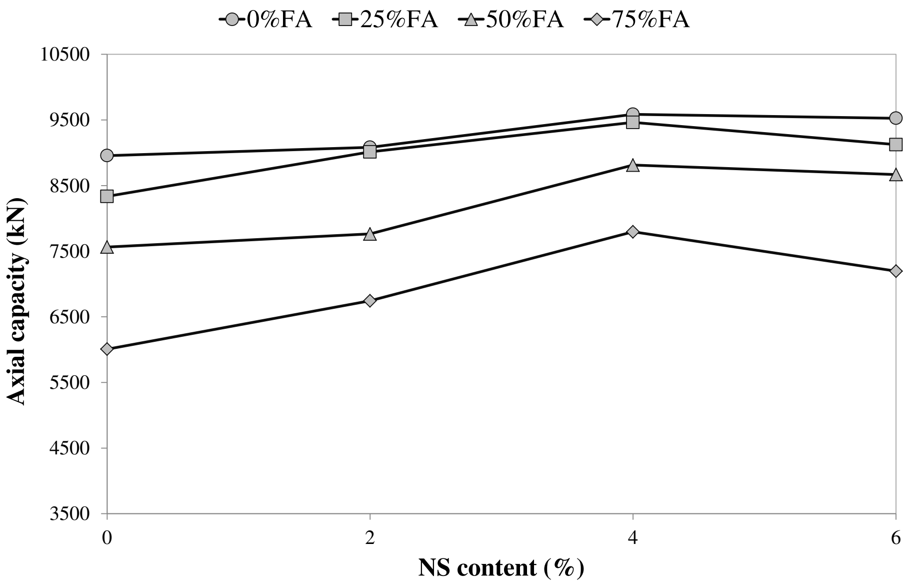
f)


0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
NS content (%)
10500
9500
8500
7500
6500
5500
4500
3500
0
2
4
6

g)

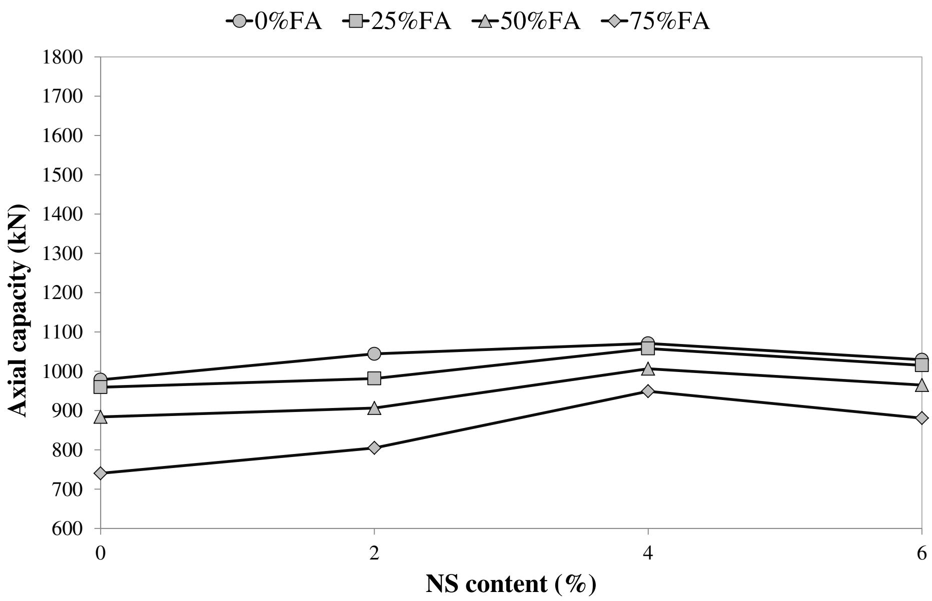

0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
NS content (%)
10500
9500
8500
7500
6500
5500
4500
3500
0
2
4
6

h)

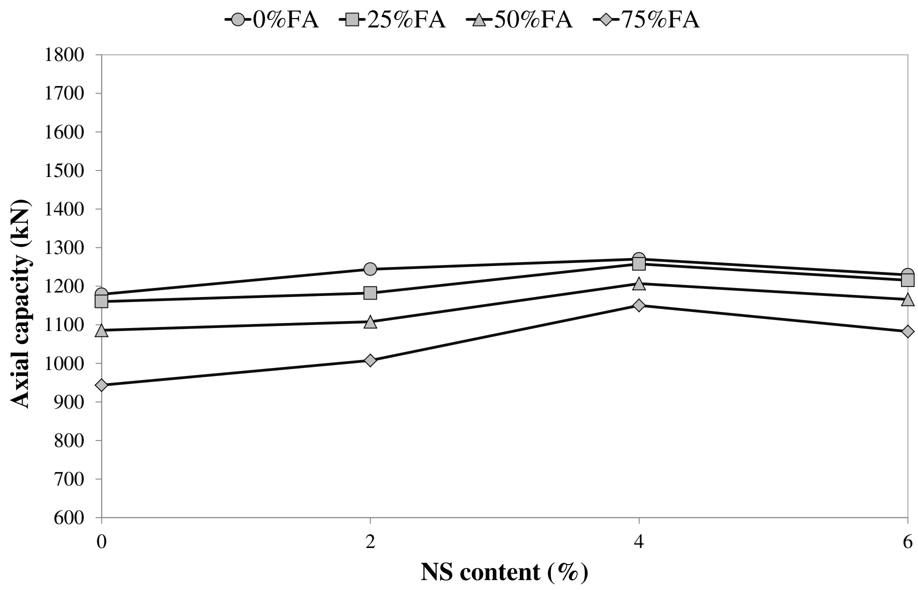


i)

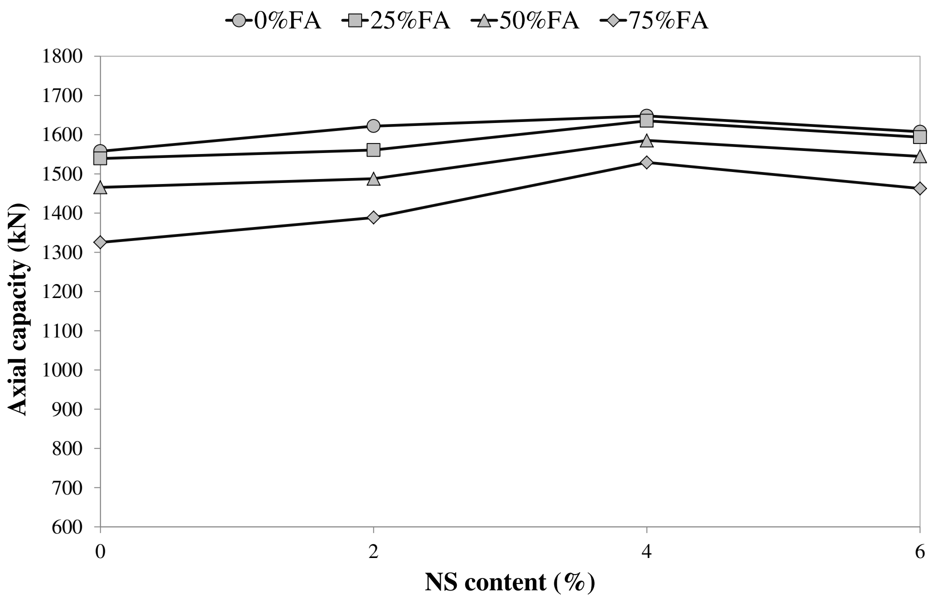
Figure 4.19 Axial capacity of the CFST columns having different SCC mixtures at 28 days according to Eurocode 4 with: a) D/t=30 - fy=185, b) D/t=30 - fy=275, c) D/t=30 - fy=450, d) D/t=60 - fy=185, e) D/t=60 - fy=275, f) D/t=60 - fy=450, g) D/t=90 - fy=185, h) D/t=90 - fy=275, and i) D/t=90 - fy=450 of tubes



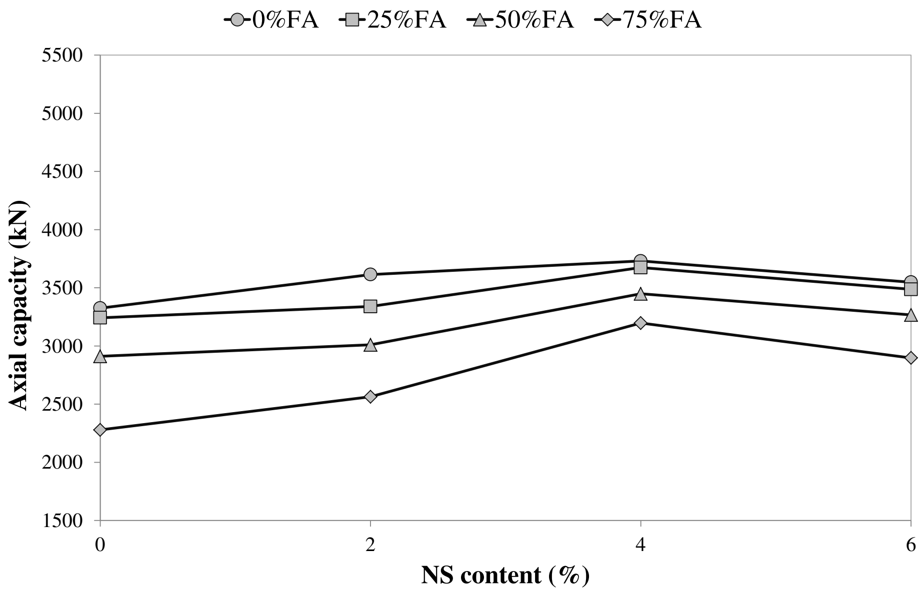
a)


0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
0
2
4
6
NS content (%)

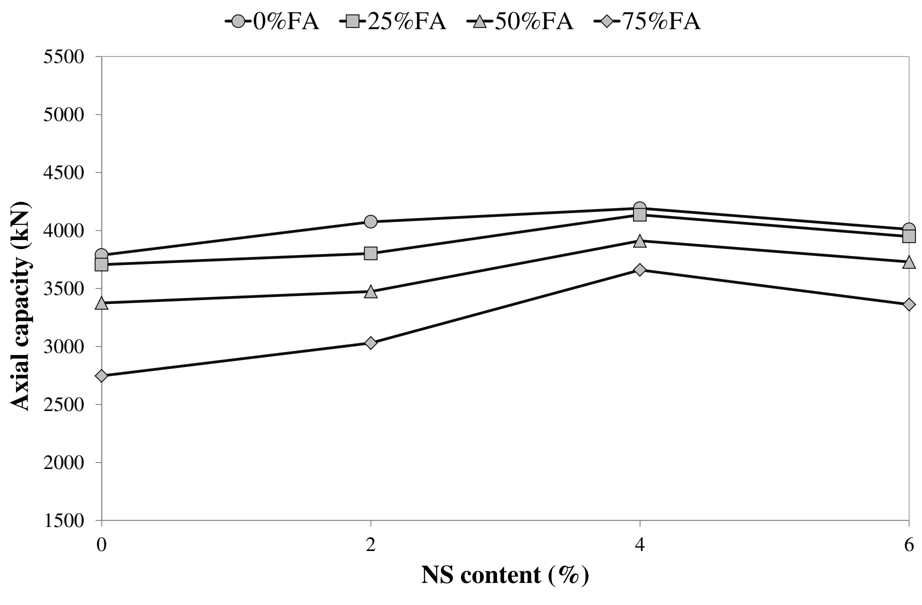
b)


0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
0
2
4
6
NS content (%)

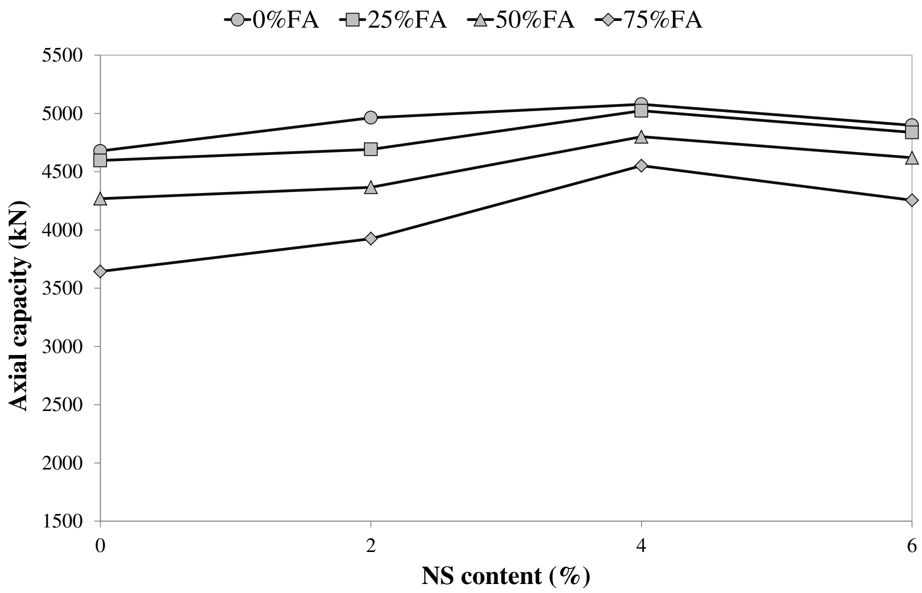
c)


-○-0%FA -□-25%FA -△-50%FA -◇-75%FA
5500
5000
4500
4000
3500
3000
2500
2000
1500
Axial capacity (kN)
0
2
4
6
NS content (%)

d)

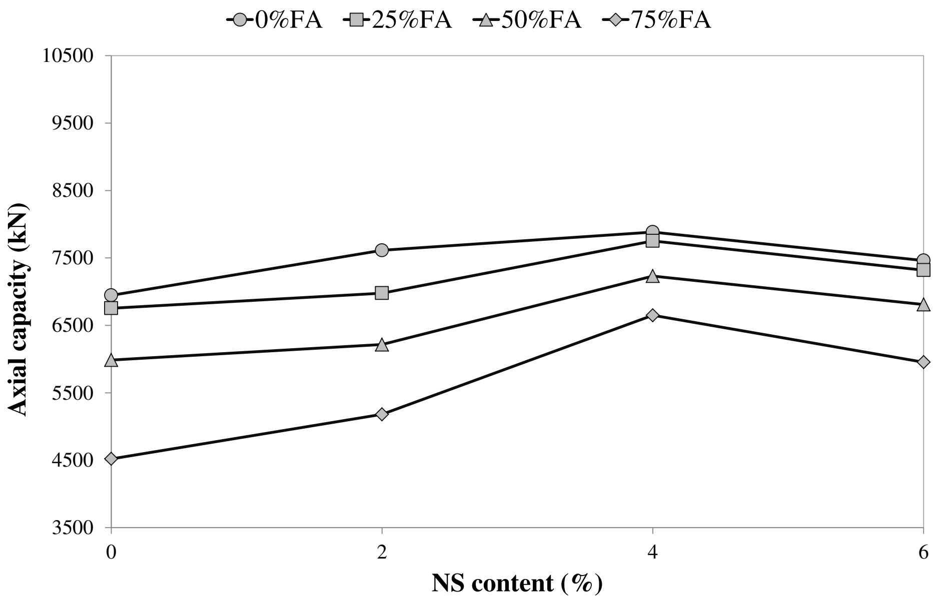

-○-0%FA -□-25%FA -△-50%FA -◇-75%FA
5500
5000
4500
4000
3500
3000
2500
2000
1500
Axial capacity (kN)
0
2
4
6
NS content (%)

e)



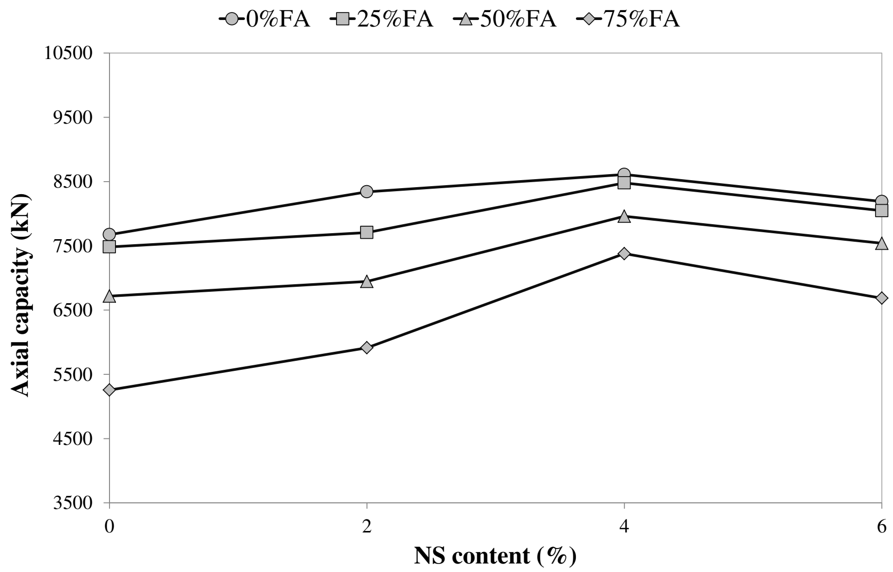
0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
NS content (%)
5500
5000
4500
4000
3500
3000
2500
2000
1500
0
2
4
6

f)

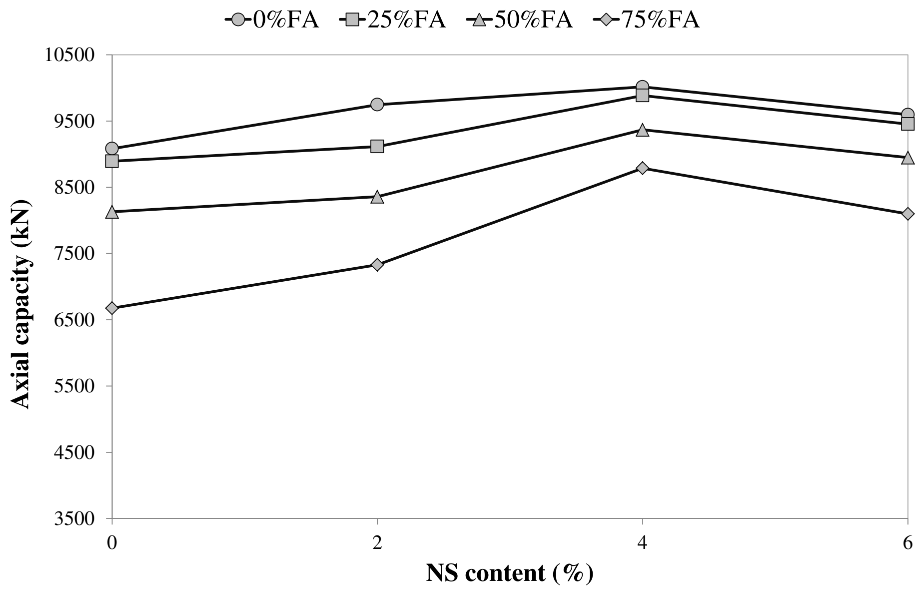


0%FA
25%FA
50%FA
75%FA
Axial capacity (kN)
NS content (%)
10500
9500
8500
7500
6500
5500
4500
3500
0
2
4
6

g)



h)



i)

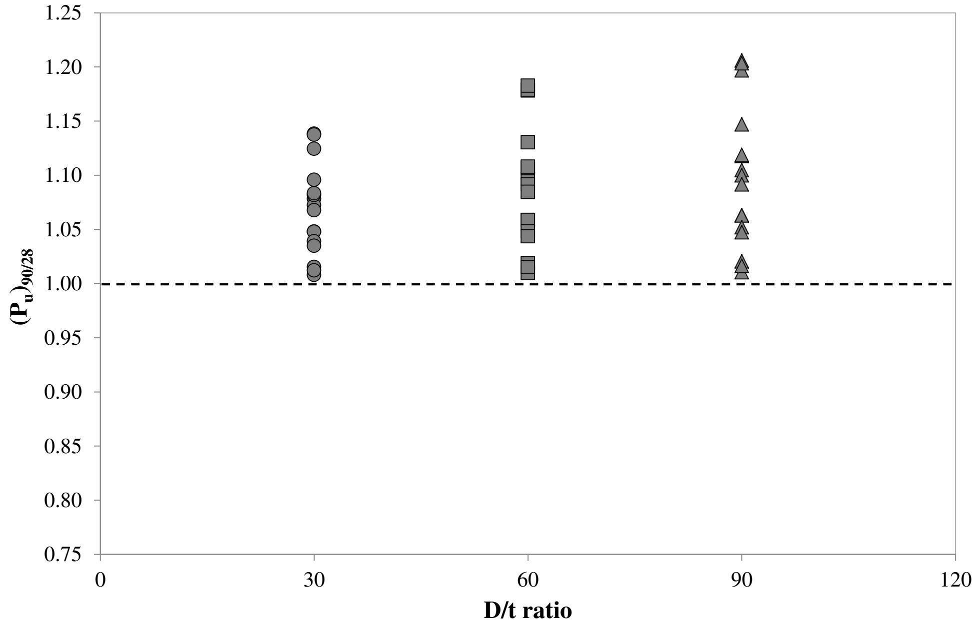
Figure 4.20 Axial capacity of the CFST columns having different SCC mixtures at 90 days according to Eurocode 4 with: a) D/t=30 - fy=185, b) D/t=30 - fy=275, c) D/t=30 - fy=450, d) D/t=60 - fy=185, e) D/t=60 - fy=275, f) D/t=60 - fy=450, g) D/t=90 - fy=185, h) D/t=90 - fy=275, and i) D/t=90 - fy=450 of tubes

Table 4.4 Ultimate strength results calculated by using ACI formulae

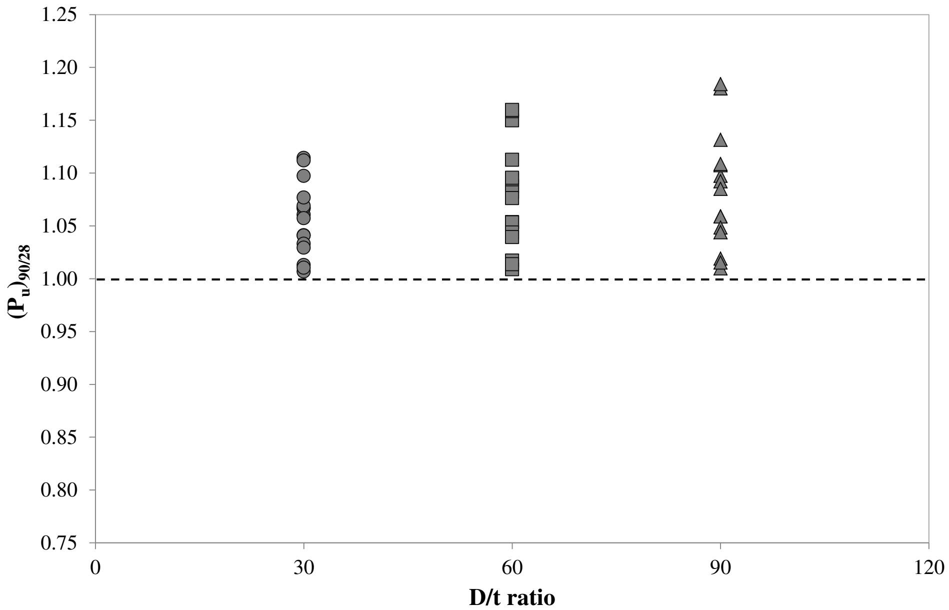
Mixture ID	fy (MPa)	$(P_u)_{ACI}$					
		28-day			90-day		
		D/t=30	D/t=60	D/t=90	D/t=30	D/t=60	D/t=90
FA0NS0	185	726.8	2510.0	5342.6	737.8	2557.4	5451.7
	275	858.0	2776.9	5745.2	869.0	2824.3	5854.4
	450	1113.1	3295.9	6528.1	1124.1	3343.3	6637.3
FA0NS2	185	737.8	2557.4	5451.7	795.6	2805.2	6022.2
	275	869.0	2824.3	5854.4	926.8	3072.1	6424.9
	450	1124.1	3343.3	6637.3	1181.9	3591.1	7207.8
FA0NS4	185	781.5	2744.8	5883.3	819.0	2905.8	6253.8
	275	912.7	3011.7	6285.9	950.2	3172.7	6656.5
	450	1167.8	3530.7	7068.8	1205.3	3691.7	7439.4
FA0NS6	185	776.3	2722.6	5832.0	782.5	2749.1	5893.1
	275	907.5	2989.5	6234.6	913.7	3016.0	6295.7
	450	1162.6	3508.5	7017.5	1168.8	3535.0	7078.6
FA25NS0	185	672.6	2277.3	4807.1	721.2	2486.0	5287.4
	275	803.7	2544.2	5209.7	852.4	2752.9	5690.1
	450	1058.8	3063.2	5992.6	1107.5	3271.9	6473.0
FA25NS2	185	731.7	2530.9	5390.8	740.6	2569.2	5478.9
	275	862.8	2797.8	5793.5	871.8	2836.1	5881.5
	450	1117.9	3316.8	6576.3	1126.9	3355.1	6664.4
FA25NS4	185	770.8	2699.0	5777.7	807.6	2856.9	6141.4
	275	902.0	2965.9	6180.3	938.8	3123.8	6544.0
	450	1157.1	3484.9	6963.2	1193.9	3642.8	7326.9
FA25NS6	185	741.3	2572.1	5485.7	770.1	2696.0	5770.9
	275	872.4	2839.0	5888.3	901.3	2962.9	6173.5
	450	1127.5	3358.0	6671.2	1156.4	3481.9	6956.4
FA50NS0	185	605.3	1988.8	4142.9	654.7	2200.9	4631.1
	275	736.5	2255.7	4545.5	785.9	2467.8	5033.7
	450	991.6	2774.7	5328.4	1041.0	2986.8	5816.6
FA50NS2	185	622.7	2063.6	4315.0	674.6	2286.1	4827.4
	275	753.9	2330.5	4717.6	805.8	2553.0	5230.0
	450	1009.0	2849.5	5500.5	1060.9	3072.0	6012.9
FA50NS4	185	714.2	2456.1	5218.5	762.6	2663.6	5696.2
	275	845.4	2723.0	5621.1	893.8	2930.5	6098.8
	450	1100.5	3242.0	6404.0	1148.9	3449.5	6881.7
FA50NS6	185	701.6	2402.2	5094.4	726.1	2507.0	5335.7
	275	832.8	2669.1	5497.1	857.3	2773.9	5738.3
	450	1087.9	3188.1	6279.9	1112.4	3292.9	6521.2
FA75NS0	185	469.3	1405.3	2799.6	527.7	1655.8	3376.2
	275	600.5	1672.2	3202.2	658.9	1922.7	3778.8
	450	855.6	2191.2	3985.1	914.0	2441.7	4561.7
FA75NS2	185	533.8	1682.0	3436.6	584.9	1901.3	3941.5
	275	665.0	1948.9	3839.2	716.1	2168.2	4344.1
	450	920.1	2467.9	4622.1	971.2	2687.2	5127.0
FA75NS4	185	625.6	2075.8	4343.1	712.1	2447.1	5197.8
	275	756.8	2342.7	4745.7	843.3	2714.0	5600.5
	450	1011.9	2861.7	5528.6	1098.4	3233.0	6383.3
FA75NS6	185	573.2	1851.0	3825.6	652.0	2189.1	4604.0
	275	704.4	2117.9	4228.3	783.2	2456.0	5006.6
	450	959.5	2636.9	5011.2	1038.3	2975.0	5789.5

Table 4.5 Ultimate strength result calculated by EC4 formula

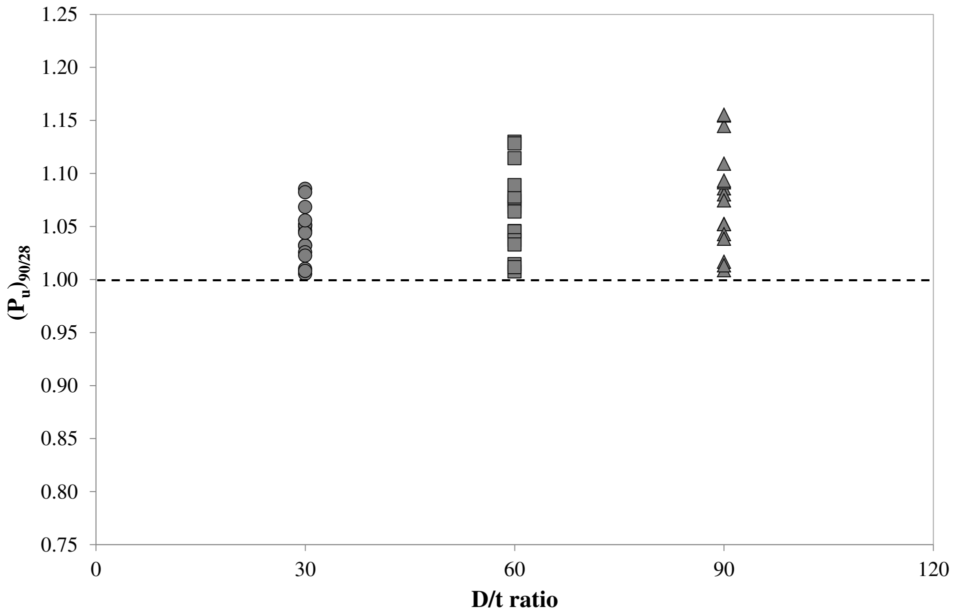
Mixture ID	fy (MPa)	$(P_u)_{EC4}$					
		28-day			90-day		
		D/t=30	D/t=60	D/t=90	D/t=30	D/t=60	D/t=90
FA0NS0	185	965.9	3270.3	6818.6	978.5	3325.5	6946.3
	275	1166.6	3733.1	7547.3	1179.1	3788.0	7674.7
	450	1545.6	4623.6	8956.7	1557.8	4678.1	9083.5
FA0NS2	185	978.5	3325.5	6946.3	1044.2	3613.8	7613.7
	275	1179.1	3788.0	7674.7	1244.1	4075.1	8340.6
	450	1557.8	4678.1	9083.5	1621.9	4963.2	9746.8
FA0NS4	185	1028.2	3543.5	7451.1	1070.9	3730.9	7884.7
	275	1228.3	4005.1	8178.3	1270.6	4191.7	8611.0
	450	1606.3	4893.7	9585.2	1648.0	5079.0	10016.2
FA0NS6	185	1022.3	3517.6	7391.1	1029.3	3548.5	7462.6
	275	1222.4	3979.3	8118.5	1229.4	4010.1	8189.8
	450	1600.6	4868.1	9525.6	1607.4	4898.6	9596.7
FA25NS0	185	904.3	2999.9	6192.3	959.5	3242.5	6754.1
	275	1105.7	3464.0	6922.6	1160.4	3705.4	7482.9
	450	1485.5	4356.4	8334.5	1539.4	4596.1	8892.6
FA25NS2	185	971.4	3294.7	6875.0	981.6	3339.2	6978.0
	275	1172.1	3757.4	7603.6	1182.2	3801.7	7706.4
	450	1551.0	4647.7	9012.7	1560.9	4691.7	9115.1
FA25NS4	185	1016.0	3490.1	7327.5	1058.0	3674.0	7753.1
	275	1216.2	3952.0	8055.1	1257.7	4135.0	8479.6
	450	1594.4	4840.9	9462.4	1635.3	5022.7	9885.4
FA25NS6	185	982.4	3342.6	6986.0	1015.2	3486.7	7319.6
	275	1182.9	3805.1	7714.3	1215.4	3948.6	8047.1
	450	1561.6	4695.1	9123.0	1593.7	4837.5	9454.5
FA50NS0	185	828.1	2664.9	5416.1	884.1	2911.1	5986.6
	275	1030.3	3130.6	6148.4	1085.7	3375.6	6717.4
	450	1411.2	4025.4	7563.6	1465.8	4268.6	8130.2
FA50NS2	185	847.8	2751.7	5617.2	906.6	3010.2	6216.1
	275	1049.8	3216.9	6348.9	1108.0	3474.2	6946.3
	450	1430.4	4111.1	7763.3	1487.8	4366.5	8358.1
FA50NS4	185	951.6	3207.6	6673.5	1006.6	3449.0	7232.2
	275	1152.5	3670.7	7402.5	1206.9	3911.0	7959.9
	450	1531.7	4561.7	8812.5	1585.3	4800.2	9367.7
FA50NS6	185	937.3	3145.0	6528.4	965.1	3266.8	6810.5
	275	1138.4	3608.4	7257.8	1165.9	3729.7	7539.2
	450	1517.7	4499.7	8668.3	1544.8	4620.2	8948.7
FA75NS0	185	674.7	1988.8	3848.1	740.4	2278.7	4520.7
	275	878.6	2458.0	4585.0	943.6	2746.3	5255.6
	450	1261.2	3357.7	6007.2	1325.5	3644.0	6674.8
FA75NS2	185	747.3	2309.1	4591.2	805.0	2563.4	5180.8
	275	950.4	2776.5	5325.8	1007.5	3029.5	5913.7
	450	1332.3	3674.0	6744.7	1388.7	3925.1	7329.9
FA75NS4	185	851.0	2765.8	5650.0	949.2	3197.2	6649.3
	275	1053.0	3231.0	6381.7	1150.2	3660.3	7378.4
	450	1433.6	4125.1	7795.9	1529.3	4551.3	8788.5
FA75NS6	185	791.8	2505.0	5045.5	881.0	2897.5	5955.0
	275	994.4	2971.5	5778.8	1082.6	3362.0	6685.8
	450	1375.7	3867.5	7195.7	1462.8	4255.1	8098.8


1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0
30
60
90
120
D/t ratio
(Pu)90/28

a)

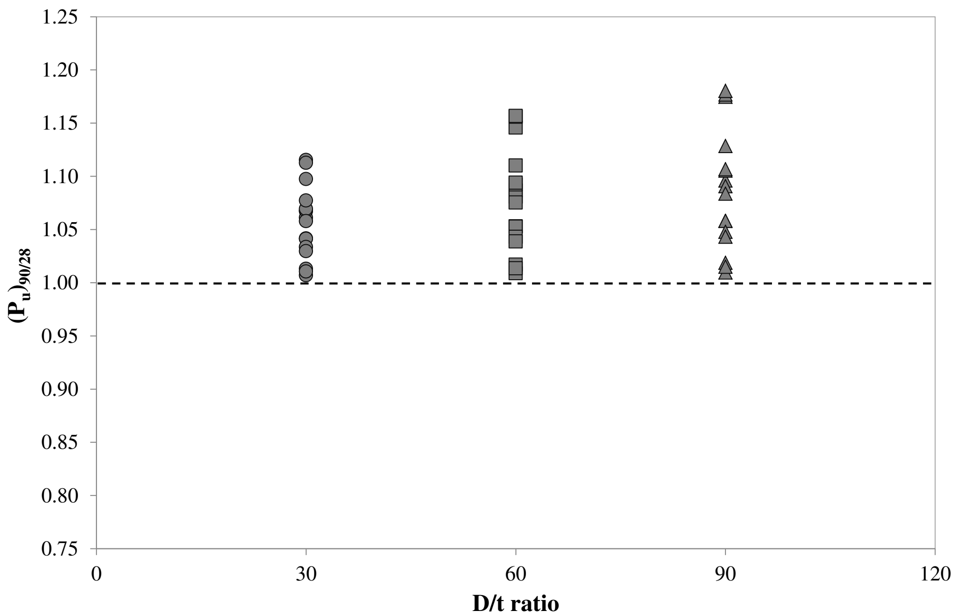

1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0
30
60
90
120
D/t ratio
(Pu)90/28

b)

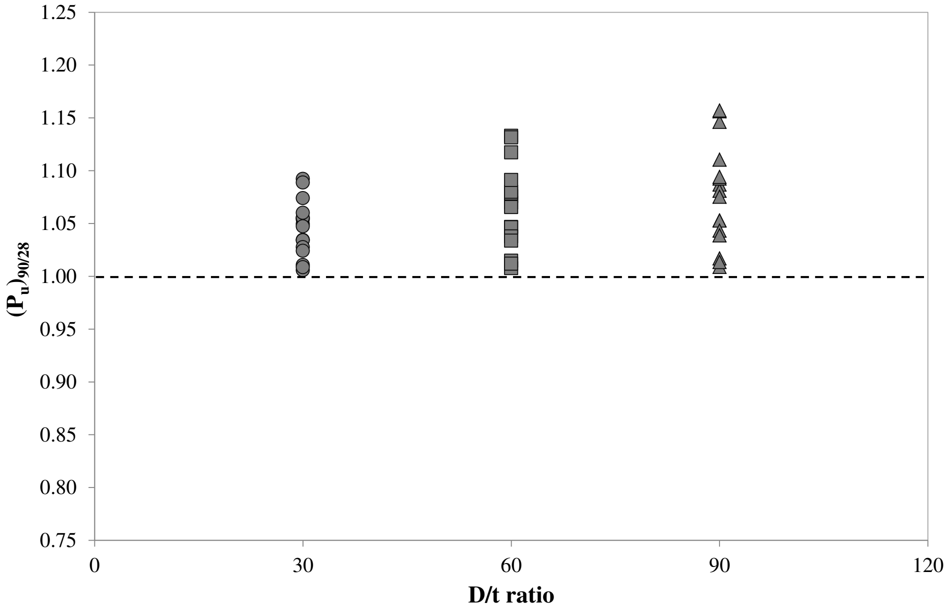


c)

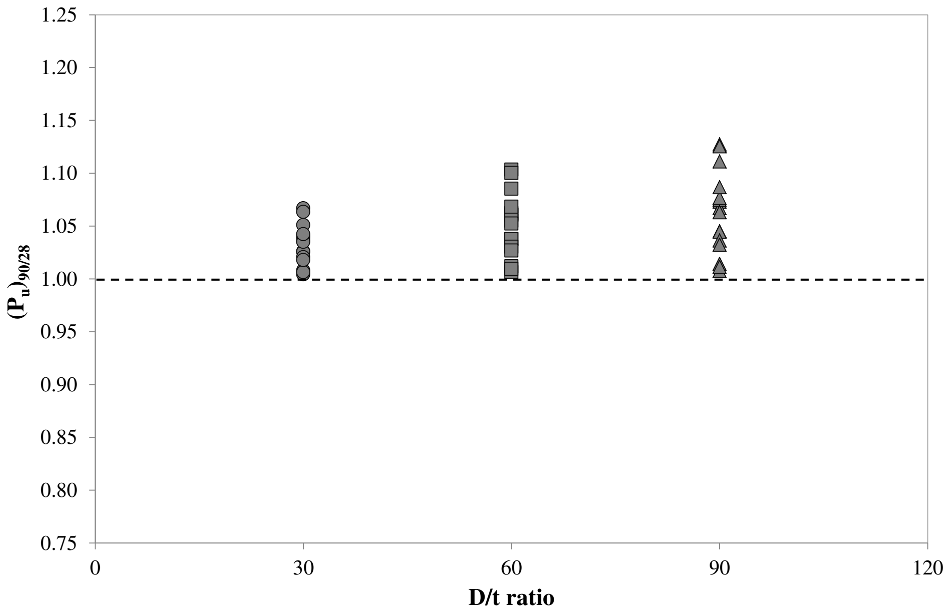
Figure 4.21 Relationship between 28 and 90-day axial capacity of the composite columns with D/t ratio for Eurocode 4 at: a) Fy=185, b) f_y=275, and c) f_y=450 MPa



a)



b)



c)

Figure 4.22 Relationship between 28 and 90-day axial capacity of the composite columns with D/t ratio for ACI code at: a) fy=185, b) f_y=275, and c) f_y=450 MPa

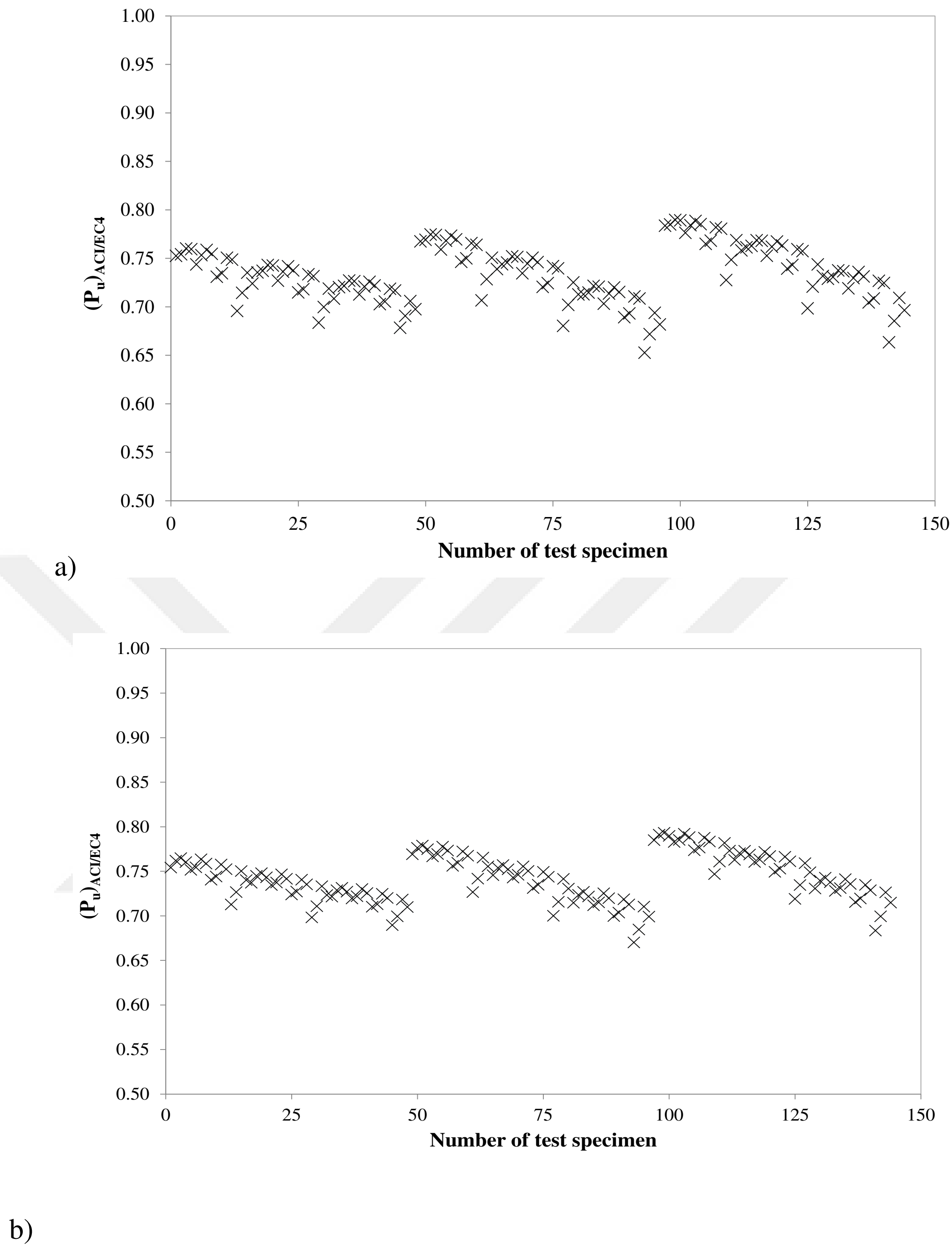
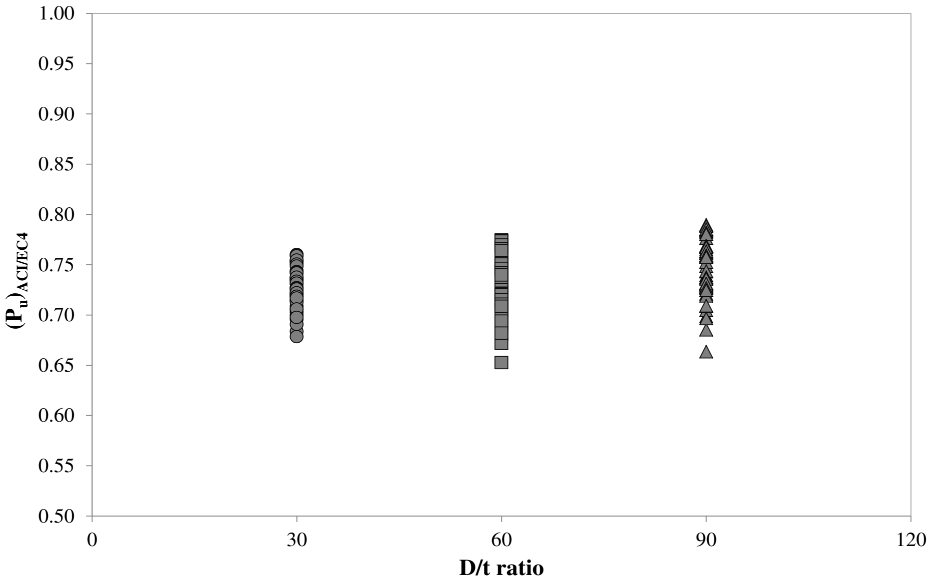
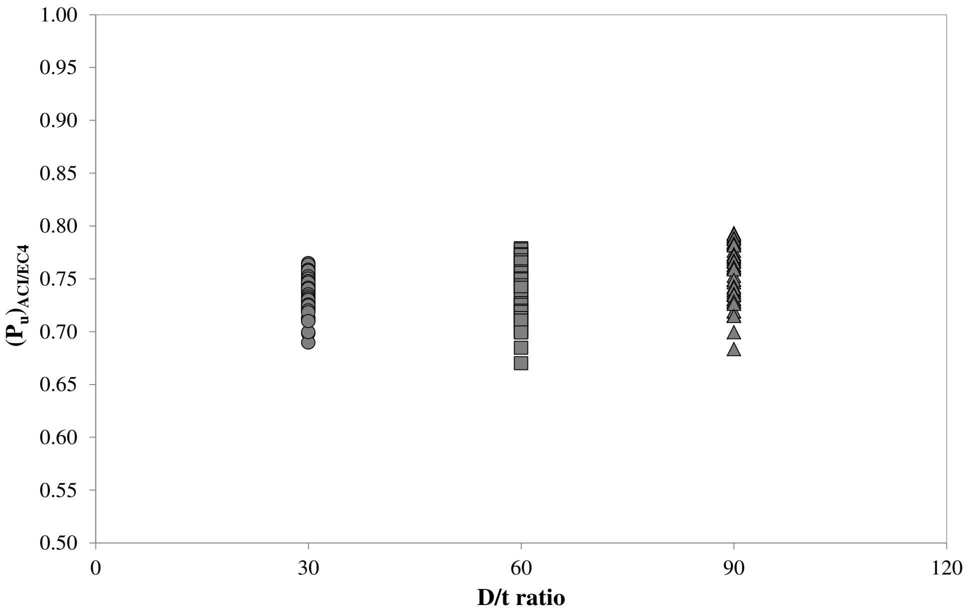


Figure 4.23 Performance of Eurocode 4 and ACI code to predict the capacity of the CFST columns at: a) 28-day and b) 90-day

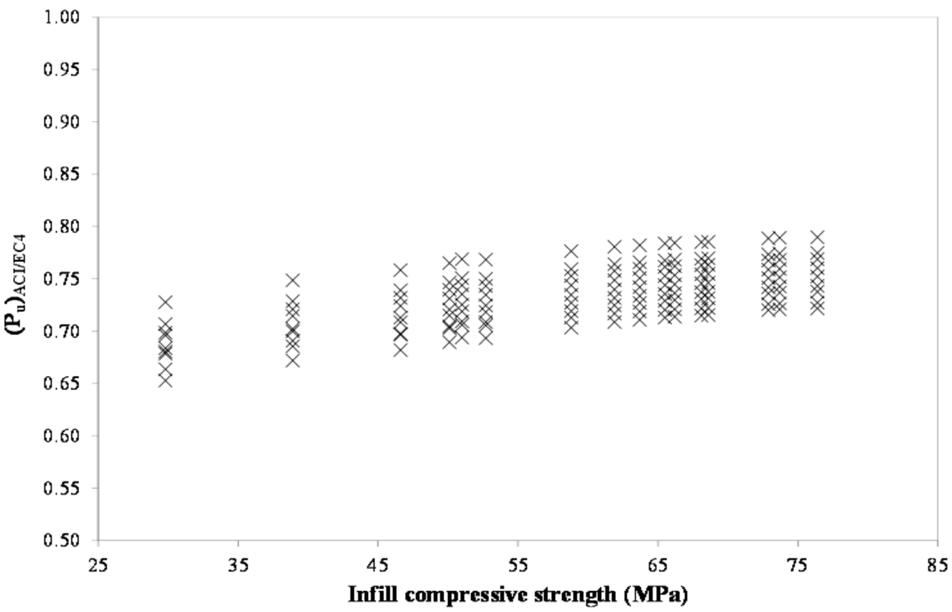


a)

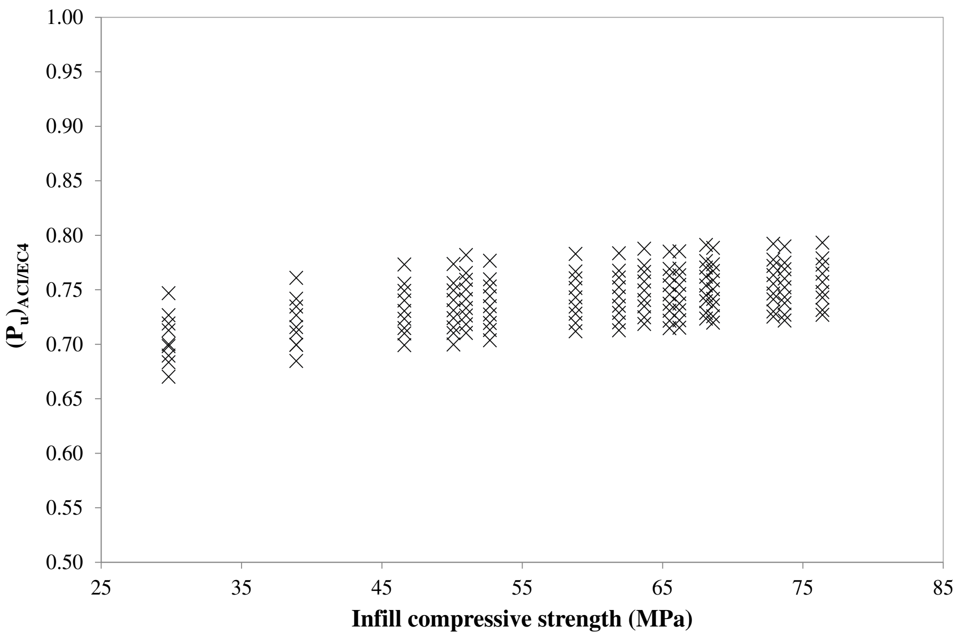


b)

Figure 4.24 Interaction between the normalized axial capacities based on Eurocode 4/ACI code and D/t ratio of section at a) 28 days and b) 90 days

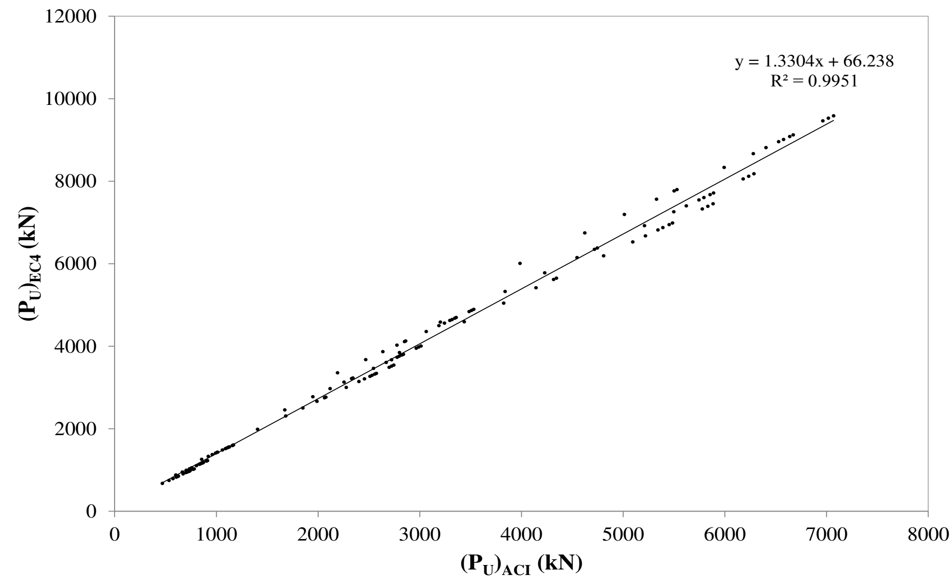


a)

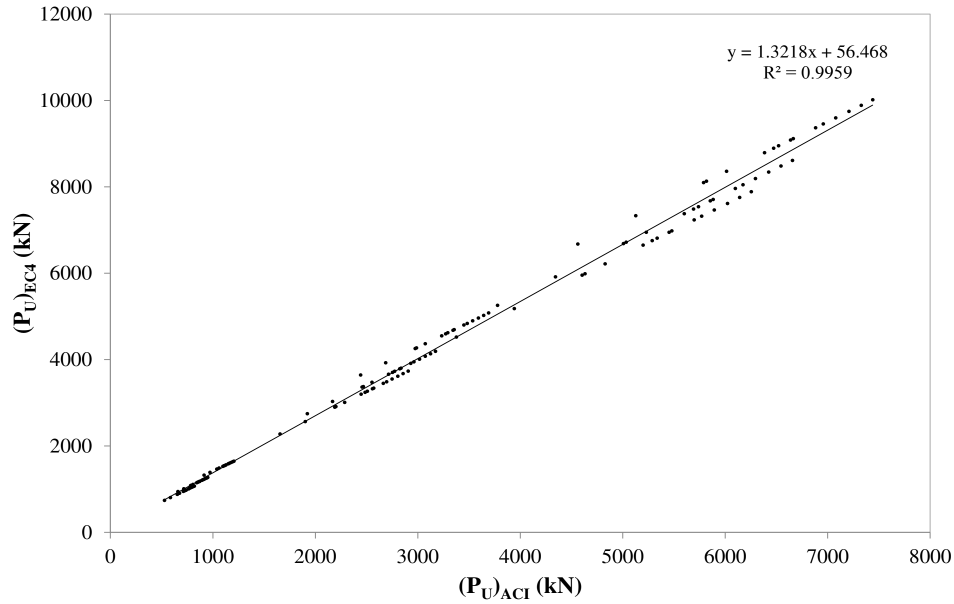


b)

Figure 4.25 Interaction between the normalized axial capacities based on Eurocode 4 /ACI code and infill compressive strength at: a) 28 days and b) 90 days



a)



b)

Figure 4.26 Correlation between the design code provisions for the composite sections having different SCC mixturesat a) 28 days and b) 90 days

CHAPTER 5

CONCLUSIONS

According to the findings achieved from the experimental and numerical study presented above, the following conclusions can be drawn:

- The use of NS in the SCC production decreased the slump flow diameter while the utilization of FA increased it. The SCC mixtures produced without FA were in the SF2 class while the SCC mixtures produced with FA at replacement levels of 50% and 75% were in the SF3 class according to EFNARC limitation. However, the SCC mixtures produced with 25% FA content can be classified as SF3 at 0% NS replacement level, whereas the SCC mixtures produced at 2%, 4%, and 6% NS replacement level can be categorized as SF2.
- The utilization of NS in SCCs increased both slump flow and V-funnel flow times at each replacement level of FA. However, the use of FA in the SCC production decreased the slump flow and V-funnel flow times. NS incorporation made the SCC more cohesive and viscous. The SCC mixtures produced in this study had the acceptable slump flow and V-funnel flow times with regard to EFNARC.
- NS and the FA had also influenced on the L-box height ratio. Increasing NS content decreased L-box height ratio, while increasing FA content resulted in higher L-box height ratio. All SCC mixtures had the L-box height ratio values more than 0.8 which is the lower limit determined by EFNARC. Besides, FA25NS0, FA50NS0, FA75NS0, FA75NS2 had the L-box height ratio value of 1.0 which is the indication of perfect fluid behavior. In addition, T_{20} and T_{40} L-box flow times were affected by both NS and FA. Increasing in the cohesiveness of SCC due to NS utilization increased the T_{20} and T_{40} L-box flow times. However, they decreased by the incorporation of FA.

- The relationship between the torque and the rotational speed gotten from the rheometer showed that increasing NS content resulted in higher torque values while increasing FA content decreased the torque values. Moreover, the SCC mixtures produced in this study indicated shear thickening behavior when both the Herschel-Bulkley and modified Bingham models were considered. The results for rheology revealed that the use of NS increased the shear-thickening of SCC mixtures whereas the utilization of FA decreased it.
- Using NS with FA in SCC increased the compressive strength and also improve the durability related performance.
- It was seen that both NS and FA have a strong effect on the fresh and hardened characteristics of the SCC mixtures. Moreover, the percent contributions of NS and FA contents as well as testing age were found to be varied for each measured property.
- The compressive strength of the core concrete and the yield strength of steel tube have an important influence on the ultimate strength of the circular steel tubular columns filled with concrete.
- The analysis of results indicated that FA and NS contents significantly affect the strength of the CFST columns.
- Variation in diameter to thickness ratio is observed to be remarkable effects on the ultimate strength of the circular steel tubular columns filled with SCC.
- The relationship between 28 and 90 day axial capacity of the column shows that increasing the strength of core concrete in the tube results about up to 1.2 times greater load carrying capacity for the column tested.
- Ultimate column strength calculated by using ACI formula resulted in lower values than that calculated by Eurocode 4. It is found that the percent different between tow codes is about 33%.
- There is a strong relation between ultimate strength values of the composite columns obtained by using ACI and Eurocode 4 formulae. A simple correlation equation is proposed between the design codes to estimate the ultimate strength of the composite columns infilled with such structure SCC produced in this study.

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PERSONAL INFORMATION

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Qualifications:-

- Bachelor of Construction Engineering and Construction (1989).

- Master of Construction Engineering and Construction (2006)

Researches and conferences: -

- Some properties of concrete containing light weight carbon fiber (2009).
- Properties of concrete produced using fine aggregate where the content of salts is higher than the limits of the specification.
- The effect of using glass powder as a filler on the properties of hot asphalt mixes.
- Effect of Pozzolanic materials on the Mechanical Properties of fine Gap - graded Aggregate Concrete.
- Influences of fly ash and nano silica on the compressive strength and permeability properties of self – compacting concrete
- Effect of nano-silica on fresh properties and rheology of self-compacting concrete with various fly ash contents.
- Share the 2nd International Conference on Buildings, Construction and Environmental Engineering- BCEE2 (2015), Beirut, Lebanon, in an article entitled Sorptivity index of self-compacting concretes with nano-silica and fly ash.
- Obtain admission to the 3rd International Conference on Buildings, Construction and Environmental Engineering- BCEE3(October 23 – 25, 2017), Al Menoufia, Egypt, in an article entitled Comparison of ultimate strength results from ACI and Eurocode 4 for steel tubular columns filled with SCC.

Professional Experience:

- Advisory Engineer in the office - University of Technology (contract for the period 1992-1993).

- A laboratory engineer at the Department of Construction Engineering and Construction (1993-2005)

- Lecturer Assistant since 2003-2009.

- Lecturer since 2009 and so far.

Teaching in the following courses: -

* Engineering defects in concrete structures.

* Concrete Technology.

* Engineering drawing.

*Concrete Laboratory.

Academic and practical experience:

- Member of team assigned the task of preparation of a code for waterproofing.

- A lecturer at the Center for Continuing Education for the following courses: -

  - Concrete self-monitoring.
  - Cracks and workarounds.
  - Chemical additives for concrete.
  - The problems of the sand in Iraq
  - The concrete mix design.

- To provide advisory services through the Advisory Office for construction projects

- Design of health workers of many buildings, as well as carry out the guesswork for different construction projects.

- Conduct laboratory testing of chemical and physical properties of all construction materials (cement, sand, gravel, rebar, concrete cubes, bricks, tiles) as well as testing water filters and pipes (PVC) in addition to materials testing reform.

- And posting program attend conferences and scientific seminars in the area of my field of expertise.