STRUCTURAL BEHAVIOUR OF STEEL STUB COLUMN IN-FILLED USING SELF-COMPACTING CONCRETE WITH FLY ASH AND SILICA FUME

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DEDICATION

This thesis is dedicated to:

My mother, Hajja Fati Modu Dalori, whose love and sacrifice;

My Father, Brothers, Sisters, and In-laws, whose support and encouragement;

And My beloved husband, QS Mohammed Hadi Usman, whose love and patience;

Led to attain my doctoral degree

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ABSTRACT

Concrete filled steel tubular (CFST) column is a composite structural member that consists of a hollow steel tube and concrete core. Literature has indicated that the concrete core could carry up to 60% of the applied compressive load. The use of fly ash (FA) in concrete has attracted the attention of many researchers due to the global quest for sustainable and green materials in achieving an economical and low carbon footprint environment. By the same notion, silica fume (SF) is added, to enable the concrete to flow and fill narrow steel tube, which resulted in the use of self-compacting concrete. Notably, the strength of Portland cement concrete would be affected by the FA and SF as cement replacement. Researchers have a mixed understanding of the ductility of CFST columns infilled with mineral admixtures as core concrete. The aim of this research was to investigate the performance and behaviour of CFST stub columns infilled with self-compacting concrete containing FA and SF under axial load. Laboratory investigations were conducted to develop self-compacting high-performance (SCHP) concrete containing FA and SF with a target compressive strength of 60 MPa. Series of SCHP concrete were prepared at water-cement ratio of 0.3 with 0%, 25%, 35%, 50%, 60%, and 75% replacement of Portland cement (PC) by FA and SF while maintaining 10% replacement of SF. The properties of the SCHP concrete were evaluated in terms of fresh, hardened, and microstructural properties, while the properties of structural cold-formed steel were obtained through a coupon tensile test. The performance of the FA-SF self-compacting CFST stub columns were examined through the axial compression capacity, the load shortening response, and the failure mode. The compression capacities of the CFST columns were then compared with the theoretical values obtained using the international design codes. The CFST stub column's behaviour was also simulated through Finite Element (FE) modelling using ABAQUS software. The experimental results showed that concrete with 25%PC, 65%FA and 10%SF sustained a maximum compressive strength of 79.73 MPa at 28 days, and the cement content of this mixture was just 146.88 kg/m^3. The microstructure of FA-SF self-compacting concrete was relatively less porous compared to the ordinary Portland cement concrete. Moreover, the incorporation of FA and SF in the concrete core has resulted in a higher stiffness index and concrete contribution ratio, indicating the enhancement of the CFST stub columns' stiffness. However, the control CFST stub columns demonstrated better ductility. Comparing the FE predictions with test results revealed that the FE models marginally underestimated the circular and square columns' ultimate strengths by an average of 1.3% and 1.43%, respectively. The proposed model forecasted the ultimate strength of the CFST stub columns with good prediction accuracy. The mean was 0.99, with a standard deviation of 0.01 for circular CFST columns, while a mean value of 1.05 was obtained for square CFST stub columns with a standard deviation of 0.12. Although CFST stub columns infilled with FA-SF self-compacting concrete demonstrated higher axial load capacity and concrete contribution ratio, the ductility was lesser. However, this condition may still permit the usage of CFST stub columns with FA-SF self-compacting concrete to the construction in low seismic zones.

ABSTRAK

Tiang tiub keluli terisi konkrit (CFST) adalah anggota struktur komposit yang terdiri daripada tiub keluli geronggang dan teras konkrit. Kajian lepas menunjukkan bahawa teras konkrit dapat membawa hingga 60% dari beban mampatan yang digunakan. Penggunaan abu terbang (FA) dalam konkrit telah menarik perhatian ramai penyelidik kerana usaha sejagat bagi bahan lestari dan hijau dalam mencapai persekitaran jejak karbon yang ekonomik dan rendah. Dengan pengertian yang sama, asap silika (SF) ditambahkan, untuk membolehkan konkrit mengalir dan mengisi tiub keluli sempit, yang mengakibatkan penggunaan konkrit pemadatan diri (SCC). Terutamanya, kekuatan konkrit simen Portland akan dipengaruhi oleh FA dan SF sebagai pengganti simen. Penyelidik mempunyai pemahaman campuran mengenai kemuluran puntung CFST yang diisi dengan campuran bahan tambah galian sebagai teras konkrit. Tujuan penyelidikan ini adalah untuk mengkaji prestasi dan kelakuan tiang puntung CFST yang dipenuhi dengan konkrit pemadatan diri yang mengandungi FA dan SF di bawah beban paksi. Penyelidikan makmal dilakukan untuk membangunkan konkrit pemadatan diri berprestasi tinggi (SCHP) yang mengandungi FA dan SF dengan kekuatan mampatan sasaran 60 MPa. Siri konkrit SCHP disediakan pada kadar nisbah air-simen 0.3 dengan penggantian 0%, 25%, 35%, 50%, 60%, dan 75% simen Portland (PC) oleh FA dan SF, sambil mengekalkan penggantian 10% SF. Sifat-sifat konkrit SCHP dinilai dari segi sifat baru, pengerasan dan mikrostruktur, sementara sifat-sifat struktur keluli berbentuk struktur sejuk diperoleh melalui ujian tegangan kupon. Prestasi tiang puntung CFST pemadatan diri FA-SF diperiksa melalui keupayaan mampatan paksi, tindak balas pemendekan-beban, dan mod kegagalan. Keupayaan mampatan tiang puntung CFST kemudian dibandingkan dengan nilai teoritis yang diperoleh menggunakan kod reka bentuk antarabangsa. Kelakuan tiang punting CFST juga disimulasikan melalui pemodelan Unsur Terhingga (FE) menggunakan perisian ABAQUS. Hasil ujikaji menunjukkan bahawa konkrit dengan 25% PC, 65% FA dan 10% SF menghasilkan kekuatan mampatan maksimum 79.73 MPa pada 28 hari, dan kandungan simen bagi campuran ini hanya 146.88 kg/m3. Mikro struktur konkrit pemadatan diri FA-SF agak kurang berliang berbanding dengan konkrit simen Portland biasa. Dalam pada itu, penggabungan FA dan SF dalam teras konkrit telah menghasilkan indek kekukuhan dan nisbah sumbangan konkrit yang lebih tinggi sekaligus menunjukkan peningkatan kekukuhan tiang puntung CFST. Walau bagaimanapun, tiang puntung CFST kawalan menpamerkan kemuluran yang lebih baik. Perbandingan ramalan FE dengan hasil ujian menunjukkan bahawa model FE telah menganggarkan kekuatan muktamad yang sedikit kurang bagi tiang bulat dan segiempat sama dengan purata masing-masing 1.3% dan 1.43%. Model yang disarankan meramalkan kekuatan tertinggi tiang puntung CFST dengan ketepatan ramalan yang baik. Puratanya adalah 0.99, dengan sisihan piawai 0.01 untuk tiang puntung CFST bulat, sementara nilai purata 1.05 diperoleh untuk tiang puntung CFST segiempat sama dengan sisihan piawai 0.12. Walaupun tiang puntung CFST terisi dengan konkrit pemadatan diri FA-SF menunjukkan keupayaan mampatan paksi dan nisbah sumbangan konkrit yang lebih tinggi, kemulurannya lebih rendah. Walau bagaimanapun, keadaan ini masih membolehkan penggunaan tiang puntung CFST terisi konkrit pemadatan diri FA-SF untuk pembinaan di zon rendah gempa.

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LIST OF ABBREVIATIONS

CCR	-	Concrete contribution ratio
CFST	-	Concrete filled steel tubular column
CFT	-	Concrete filled tubular column
C-S-H	-	Calcium silicate hydrates
DI	-	Ductility index
EDX	-	Energy dispersive X-ray
FA	-	Fly ash
FE	-	Finite element
FESEM	-	Field-emission scanning electron microscopy
FSSC	-	Fly ash-silica fume self-compacting concrete
HPC	-	High-performance concrete
HVFAC	-	High-volume fly ash concrete
ITZ	-	Interfacial transition zone
MOE	-	Modulus of elasticity
PPM	-	Parts per million
SCC	-	Self-compacting concrete
SCHPC	-	Self-compacting high-performance concrete
SCMs	-	Supplementary cementing materials
SF	-	Silica fume
SI	-	Strength index
SP	-	Superplasticizer
XRD	-	X-ray diffraction

LIST OF SYMBOLS

A_c	-	Cross-sectional area of concrete
A_s	-	Cross-sectional area of steel tube
$A_{s,eff}$	-	Effective cross-sectional area of steel tube
B	-	Breadth of steel tube
D	-	External diameter of steel tube
t	-	Thickness of steel tube
E_c	-	Modulus of elasticity of concrete
E_{cc}	-	Initial modulus elasticity of confined concrete
E_s	-	Modulus of elasticity of steel
F	-	Force
η_1	-	Coefficient of confinement for concrete
η_2	-	Coefficient of confinement for steel
ν	-	Poison's ratio
λ	-	Column slenderness
$(EI)_{eff}$	-	Effective moment of inertia of composite section
l	-	Effective length of CFST column
L	-	Length of CFST column
K	-	Confinement effectiveness parameter
K_c	-	Confinement correction factor
K_s	-	Equivalent confining coefficient of steel
β	-	Coefficient of axial stress on steel tube
α	-	Coefficient of radial hoop stress on steel tube
σ_{cc}	-	Axial compressive stress in concrete
σ_{sz}	-	Axial stress on steel tube
$\sigma_{s\theta}$	-	Radial tensile stress in steel
σ_{nom}	-	Nominal stress in steel
ε_{PL}	-	True plastic strain in steel
ε_{nom}	-	Nominal strain in steel
ε_y	-	Yield strain of steel

ε	-	Ultimate strain
ρ	-	Reduction factor for steel tube buckling
δ_h	-	Hoop stress
δ_v	-	Axial stress
f_c'	-	Cylinder compressive strength of concrete
f_c	-	Unconfined concrete compressive strength
f_{cu}	-	Unconfined concrete cube compressive strength
f_{cc}	-	Confined concrete compressive strength
f_y	-	Yield stress of steel
f_U	-	Ultimate stress of steel
f_{cr}'	-	Required compressive strength
F_1	-	Lateral confining pressure
N_{Exp}	-	Experimental ultimate axial load on CFST column
N_{FE}	-	Finite element predicted ultimate axial load on CFST column
N_{EC4}	-	Eurocode 4 predicted ultimate axial load on CFST column
N_{PU}	-	Predicted ultimate axial load on CFST column
N_{cu}	-	Ultimate compressive force

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CHAPTER 1

INTRODUCTION

1.1 General Appraisal

Concrete and steel are the most widely used construction materials in the world. Concrete is characterized by low cost, high compressive strength, and fire resistance. However, it has low tensile strength, brittle failure, high bulk density, and premature cracking. On the other hand, Steel has high tensile strength, high compressive strength, ductile with high modulus of elasticity, but less economical and low fire resistance compared to concrete. To achieve optimum utilization of concrete and steel, a thin-walled hollow structural steel section is filled with concrete to form a composite column. These columns are known as concrete-filled steel tubular (CFST) columns. It is characterized by good seismic performance, high load carrying capacity, small cross-sectional area, speedy construction, improved fire resistance, and a higher strength-to-weight ratio. The rigidity of CFST columns is more significant than reinforced concrete columns (Jegadesh and Jayalekshmi, 2016).

CFST column offers good resistance to fire due to the prevention of the spalling of the confined concrete by steel casing and the heat sink effect of the concrete. The steel tube accommodates and confines the concrete, whereas the concrete strengthens the steel tube and prevent local inward buckling of the section. Moreover, CFST columns can save on the cost of construction material by eliminating the need for formwork and provides reduced column size, thus yielding more useable floor areas (Liew et al., 2016). The steel tube may also act as a permanent formwork and reinforcement, offering a more economical section by minimizing construction costs and time. There are two types of composite columns commonly used in buildings, in-filled steel section with concrete and steel section encased in concrete.

Concrete-filled steel tubes have nearly 50 years of use in China. Since 1966 it has been used as the primary column in Beijing Metro stations and since the 1970s in workshops and power plant buildings. The concrete-filled steel tube was used in buildings during the 1980s to avoid having a column of huge sizes. Several CFST buildings were constructed in Beijing and Fujian province. Many buildings have been erected in different cities in China since the 1990s. The pace of concrete-filled steel tube building has stepped up rapidly in recent decades. The concrete-filled steel tubes are used in bridges, buildings, and other structures as major compressive components. In the construction of bridges, CFST members were used as the piers, main girders, arch ribs, the falsework, pylons, etc. CFST members are commonly used as central arch ribs (Chen et al., 2017). The utilization of CFST members as arches can provide full use of their load-bearing capacity because arches are practically under pure compression when exposed to distributed loading. These bridges are commonly referred to as CFST arch bridges.

Due to improvement in the field of concrete technology, self-compacting concrete (SCC) is used to fill hollow structural steel (HSS) sections thereby, increase the workability and compactness of concrete (Han et al., 2017). SCC can flow and compact under its weight and fill the formwork without vibration (Thirumal and Harish, 2016). Some of the benefits of using SCC include speedy construction, noise elimination, and labour cost reduction. However, SCC often requires a high volume of cementitious material ranging from 400 kg/m^3 to 600 kg/m^3, EFNARC (2002). To overcome the afore-mentioned problem, fly ash (FA) and silica fume (SF) are used as supplementary cementing materials. SF and FA have once been considered industrial by-products, contributing to contamination and secondary emissions. The use of these by-products in Portland cement concrete would offer ecological benefits and help reduce Portland cement consumption while improving the properties of the concrete (Liew et al., 2017).

1.2 Problem Background

The placement of concrete in thin structural hollow steel tubes and its durability require adequate compaction. Concrete tends to get stiffer from pumping or lose slump and entrained air than with other casting methods. This is partially due to friction-induced additional heat as the concrete is forced through the pipe.

Portland cement is a vital ingredient of concrete production at a relatively high cost. One of the key contributors to CO_2 pollution in the air is the cement industry. A metric tonne of cement produced causes the emission of one metric tonne of CO_2. The emissions of carbon dioxide are causing global warming, which leads to climate change. Large-scale cement production is causing environmental issues and the loss of natural resources. Coupled with nations' desire to reduce greenhouse gas emissions, demand for high-quality concrete products, Conservation of natural resources and insufficient landfills have led researchers to use industrial by-products as additional cementation material for the manufacture of concrete.

For several years, extensive research on the CFST column has been carried out worldwide, and a greater perception of the CFST stub column's behaviour has been established. However, very few researches were available on CFST stub columns containing fly ash and silica fume as partial replacement of ordinary Portland cement. Little information is known about incorporating fly ash and silica fume on the behaviour of the CFST stub column. Zhang et al., (2016) investigate the structural behaviour of circular fly ash-concrete filled steel tubular stub column with a fly ash content of 90% and 100%. It was observed that the ultimate load decreases as fly ash content increases because concrete with a very high fly ash content does not include enough cement to maintain a pozzolanic reaction, the axial load performance of CFST column with 25% weight (wt). Fly ash replacement of cement and 0.5, 1.0, and 1.5% polypropylene fibres addition was explored by Jegadesh and Jayalekshmi (2016). The research results showed that the concrete with a 1% addition of fibre and 25% wt. FA gives the peak axial capacity of CFST columns. Moreover, the incorporation of FA and fibres in the concrete core improves the axial capacity of the CFST column.

Furthermore, Vinod Kumar and Rajamane (2017) investigates the axial load behaviour of CFST columns using cold-formed steel and geopolymer concrete. FA and ground granulated blast furnace slag are used as Portland cement replacement materials in the concrete. Results indicated that the geopolymer CFST column's load-carrying capacity was higher than the OPC concrete filled steel tubular column. Besides, the use of FA and SF has been documented by Sadrmomtazi et al., (2018) to improve the transition zone structure by micro-fillers or their deterrence of calcium hydrate crystal production. Apart from that, FA reduces concrete porosity because of micro filler and prohibit the development of calcium hydrate crystals and thus increased the concrete's compressive strength.

Also, the creep performance of plain fly ash concrete (FAC) and fly ash concrete-filled steel tubes (FACFTs) and the effect of fly ash-replacement ratios, 20%, and 40%, was studied by Han et al., (2017) and found that fly ash has un-ignorable effects on the creep of FACFTs. Apart from this, Li et al., (2019) studied the performance of C40 fly ash and silica fume SCC as filled in-line multi-cavity steel tube bundle shear wall. They conclude that the confinement effect improves the deformation resistance of fly ash and silica fume SCC. Likewise, Liu et al., (2017) explored the interaction between steel tubes and reactive powder concrete (RPC) core. Silica fume ground granulated blast-furnace slag or fly ash was incorporated as supplementary cementing materials to prepare the 170 MPa RPC. Their findings indicated that the utilization of RPC as core concrete in CFST stub columns improves the ductility of high strength concrete. Given the preceding, FA concrete filled steel tubular columns have strong potential for load-bearing, but little work is currently underway on FA and SF self-compacting CFST columns.

There is a synergy between FA and SF that can provide an excellent alternative to produce concrete with smaller cement content and improved mechanical properties. FA application in high quantities might influence the early strength of concrete. Nevertheless, the incorporation of SF enhances the pozzolanic activity and early strength (Samhitha et al., 2019). Moderate additions of SF seemed to densify the microstructure of the interfacial transition zone. The blending of plain concrete with 10–20% SF significantly improved the corrosion resistance. Moreover, Dotto et al., (2004) also conclude that the addition of SF can be effectively used in protecting steel reinforcement against corrosion. In addition, Lee et al., (2005) observed that the incorporation of 10% SF in OPC concrete indicates no evidence of spalling and cracking up to about one year of exposure. Furthermore, in concrete mixtures containing FA, the depth of carbonation was slightly higher compared to control concrete. However, the depth of carbonation was lower in concrete containing FA and SF, and this is because SF had little effect on carbonation (Gonen and Yazicioglu, 2007). Therefore, it is essential to study the axial compression behaviour and failure mechanism of steel tubular stub columns filled with fly ash-silica fume self-compacting (FSS) concrete.

1.3 Problem Statement

CFST column may be the best solution, as the reinforced concrete (RC) column may need to be heavily reinforced to fulfil the strength requirement where the structural element is prone to heavy loading. For the concrete to flow and fill unique forms, and heavily reinforced sections, SCC could be used. SCC is the best alternative as compacting concrete in a narrow structure, such as a hollow steel tube, is difficult and could lead to honeycombs.

However, SCC often requires a high volume of cementitious material ranging from 400 kg/m^3 to 600 kg/m^3, EFNARC (2002), which is necessary to keep enough yield stress and viscosity of the fresh concrete. When a large quantity of cement is used in self-compacting concrete, it could increase the heat of hydration and cost, thus increasing the risk of cracking in hardened concrete. Zhu et al., (2016) observed that shrinkage of SCC is higher than normal vibrated concrete due to the high cement consumption of SCC. Therefore, to meet the strength and durability requirement and minimize the cement content, supplementary cementitious materials (SCM) could be used.

Malaysia depends mostly on coal-fired power plants for generating electricity. One of the four coal power plants in Malaysia, known as the Tanjung Bin power plant, produces 42,000 metric tons of FA per month from coal ash burning (Abdullah et al., 2018). It is expected that the production of FA will increase as the demand for coal for electricity generation in Malaysia is projected to increase in 2020 because coal is the most abundantly available and cheapest fossil fuel in the world (Abdullah et al., 2018). Despite the vast FA production, its utilization in concrete is very low (Zhang et al., 2016).

Therefore, replacing cement with industrial by-product materials like FA and SF would reduce the heat of hydration in concrete, improve the rheological and mechanical properties of concrete. Research has pointed out that 25% wt. fly ash replacement of cement yields savings up to 20% on the construction costs due to a reduction in cement consumption and contributes to environmental sustainability by indirectly reducing carbon dioxide emissions in the cement production process. It, therefore, offers a positive and environmentally friendly solution.

In most studies on the composite action of the CFST columns, researchers have mixed understanding about the ductility of CFST columns infilled with high-strength concrete (Liu et al., 2017; Xu et al., 2018). To some of these, the utilization of concrete with mineral admixtures as core concrete in CFST columns improves the ductility. In contrast, for others, there is no apparent improvement in the post-peak ductility due to the high brittleness of core concrete. Furthermore, In the existing design codes, only one loading condition in the column members is considered, i.e. the load is applied simultaneously to the steel tube and the concrete core. On the contrary, in engineering practice, tube structures can be exposed to different loading conditions (Huang et al., 2012).

What is more, Eurocode 4 design equations for the axial load capacity of CFST stub columns are relatively complex. The simplified design method described in ENV1994-1-1 accurately predicts resistance obtained in laboratory tests. Nonetheless, it only applies to isolated non-swaying columns. Initial imperfections are considered without explicitly defining their values (R P Johnson et al., 2005).

Moreover, the local buckling of the steel section of CFST columns is also omitted in EC4 by limiting the section slenderness ratio D/t to 90(235/fy) for circular sections and B/t to $52\sqrt{234/f_y}$ for rectangular sections (H. Thai and Thai, 2020).

Although, CFST column is one of the best alternatives to fulfil strength requirement and SCC can be used adequately to fill and compact the narrow steel tubes. The utilization of a large quantity of cement in SCC can pose problems. However, to minimize the cement content in SCC, FA and SF can be used as partial replacement of Portland cement, the axial load performance of CFST columns with mineral admixtures as core concrete needs to be investigated.

Experiment models in laboratory tests could only indicate the location of the deformation and damages. The precise conditions of load distribution and stress concentration across the CFST column could not be measured by the experiment model. Finite element models (FEM) might be helpful to validate the results obtained from experiments as sometimes it is difficult to simulate and control parameters in experiments. Both the FEM simulations and experiments depend on many parameters: material properties, boundary conditions (B.C.), etc. The advantage of FEM is this very possibility to model even bad experiments. Moreover, the FEM model can be used to "measure" what cannot be measured in the actual experiment for the benefit of knowledge. The FEA of the fly ash-silica fume CFST stub column model is yet to be established. Such simulation requires lots of parameters to be predefined carefully to achieve more identical conditions with physical testing. Hence, the FEM is needed to fully understand the structural behaviour of fly ash-silica fume CFST stub columns.

1.4 Research Goal

This research aims to investigate the axial load behaviour of fly ash-silica fume concrete-filled steel tubular stub column. The study will examine the aspect of composite capacity, axial load-deformation curve, failure modes and the improvement of analytical design equations and the FE modelling.

1.4.1 Research Objectives

This research aims to investigate the axial load performance of CFST stub columns with mineral admixtures as core concrete with the following objectives:

i. To develop self-compacting high-performance concrete (SCHPC) mixes containing fly ash-silica fume and evaluate the fresh, hardened, and microstructural properties of the SCHPC, with a target compressive strength of 60 MPa
ii. To investigate the axial load behaviour of fly ash-silica fume CFST stub column experimentally
iii. To simulate the behaviour of fly ash-silica fume CFST stub column under axial loading through Finite Element (FE) Model via ABAQUS software and evaluate the FE predictions with experimental results
iv. To formulate an equation to predict the ultimate axial load capacity of the fly ash-silica fume CFST stub column based on the findings of experimental studies.

1.5 Scope of the study

The scope of this study is limited to experimental investigation and numerical analysis to provide a better assessment of the behaviour of cold-formed concrete-filled tubular stub column under axial loading. The use of cold-formed steel sections in residential construction has grown extensively over the past 20 years. Cold-formed steel sections could be alternative economic structural components and frame systems for both residential and commercial construction due to its rapid and robust manufacture, ease of handling and transport, cost and material efficiency, high strength-to-weight ratio, fully recyclable, fast erection, and durability (BAMAGA, 2013). The increased use of cold-formed steel as a building material necessitates more research in this area (Ghersi et al., 2002).

Circular and square steel hollow sections were studied. Self-compacting concrete incorporating fly ash-silica fume with target concrete compressive strength of 60 MPa were developed and evaluated based on fresh, hardened, and microstructural properties. The CFST columns are three times the diameter to reduce the end effects and ensure that it would be stub columns with minimum impact from slenderness. A three-dimensional nonlinear finite element (FE) model using ABAQUS software was developed to predict the fly ash-silica fume CFST stub column's axial load behaviour. The proposed ABAQUS model was verified against the experimental results.

1.6 Significance of the study

The introduction of self-compacting concrete initiated the development of construction technologies. The most important achievement is saving construction time due to the improved speed of casting and eliminating vibration. The benefit of using high strength concrete in thin steel casings is that the structural steel cost is minimized and provides more excellent resistance to compressive load. However, plain steel or reinforced concrete columns are still used more extensively than CFSTs due to the lack of knowledge and skill that engineers have with CFST structural systems.

The utilization of waste materials from the construction industry in structural engineering applications reduces plants' technical and environmental problems. It minimizes electricity costs besides reducing solid waste, greenhouse gas emissions associated with Portland clinker production and conserves existing natural resources.

From the background study of CFST columns, it is obvious that CFST column is a better and convenient system to fulfil the strength requirement where the structural element is prone to heavy loading as compared to the RC column. Due to the benefit of composite action of the steel tube and the core concrete, the CFST column possesses a large energy absorption capacity, excellent seismic resistance, high ductility, and high strength. Therefore, it is vital to improve the productivity and quality of the core concrete by the incorporation of silica fume and a large volume of fly ash as partial replacement of ordinary Portland cement. The addition of silica fume and fly ash in Portland cement concrete reduces the concrete porosity and improves the compressive strength of concrete. Besides, the utilization of a high volume of fly ash in concrete as cement replacement will reduce Portland cement consumption and offer an ecological benefit. Hence, this research is essential and can implement a new way of construction of CFST column that is economical and environmentally friendly.

1.7 Organization of the Thesis

This thesis is organized into seven chapters.

Chapter 1: This chapter provides a general appraisal and overview of the background problem. It also identified the goals, scope of the study, and significance of the research

Chapter 2: Presents a review of the accessible, relevant, and related literature.

Chapter 3: The chapter outlines the detailed description of the materials and the suitable procedures adapted for conducting the laboratory experiment and numerical program for the purpose of achieving the stated objectives.

Chapter 4: The chapter analyses and discusses the developed mix design method. The results of fresh properties of SCHPC in terms of slump flow, L-box passing ratio and V-funnel time were examined. The results of the hardened properties of the SCHPC focused on the compressive strength, the splitting tensile strength and the modulus of elasticity of the SCHPC. Likewise, the results of the microstructural analysis such as field emission scanning electron micrograph (FESEM), and X-ray diffraction analysis (XRD) were analysed and discussed

Chapter 5: This chapter reports the results and discussions arising from the axial load test conducted on 24 concrete filled steel tubular stub columns. The failure modes, axial load capacity, and axial deformation of the columns were discussed. The performance indexes, in terms of strength index, concrete contribution ratio, and ductility index were determined to analyse the performance of fly ash and silica fume SCHP CFST stub column. Similarly, the ultimate axial load capacities of the specimens examined were compared with predictions of Eurocode 4

Chapter 6: The numerical models' precision, and effectiveness in simulating the response of fly ash and silica fume CFST columns were analysed and discussed in this chapter. Comparisons were made between the main experimental results and those obtained by FE models. A simple analytical formula is proposed to predict the axial load capacity of CFST stub columns made with self-compacting high-performance concrete. The prediction accuracy of the proposed model is compared with the Eurocode 4 prediction and test results.

Chapter 7: This chapter deals with the conclusion of the study and highlights the contribution of the research. It also presents recommendations based on the research findings.

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LIST OF PUBLICATIONS

The following are the list of publication by the author which are relevant to this study

Journal Papers

A. M. Falmata, A. Sulaiman, R. N. Mohamed & A.U. Shettima (2020), "Mechanical properties of self-compacting high-performance concrete with fly ash and silica fume" Research Article, 2, Article number: 33 (2020), Publisher, SN Applied Sciences **(*ISI Index*)**

F. A. Mustapha, A. Sulaiman, R. N. Mohamed, S. A. Umara (2020), "The effect of fly ash and silica fume on self-compacting high-performance concrete" Research Article, Publisher, Materials Today Proceedings (***Scopus Index***)

Conference Papers

Falmata Audu Mustapha, Arizu Sulaiman and Roslli Noor Mohamed, ISCEE 2020**,** "Performance of Fly ash and Silica fume Self-compacting Concrete-filled Steel Tubular Stub Columns under Axial Compression." International Conference on Sustainable Construction and Structures, Paper ID: ISuCOS 2020: 041-019, Virtual Conference, 1st - 2nd December 2020.

Arizu Sulaiman, **Falmata Audu Mustapha,** and Roslli Noor Mohamed, ISCEE 2020**,** "Performance of Square Steel Tubular Stub Columns in-filled with Fly ash and Silica fume Self-compacting Concrete under Concentric Loading," International Conference on Sustainable Construction and Structures, Paper ID: ISuCOS 2020: 041-046, Virtual Conference, 1st - 2nd December 2020.