PROPERTIES OF GLASS FIBER REINFORCED SELF COMPACTING CONCRETE

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To my beloved family

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ABSTRACT

Self Compacting Concrete (SCC) is able to flow under its own weight and completely fill the formwork, even in the presence of congested reinforcement, without any compaction, while maintaining homogeneity of the concrete. Majority of concrete cast rely on compaction to produce good quality concrete. However, compaction is difficult to be done in conditions where there are dense reinforcement and large casting area. Usage of SCC will overcome the difficult casting conditions and reduce manpower required. Addition of fibers will enhance the tensile and ductile behaviour of concrete with brittle nature. SCC was added with relatively short, discrete, and discontinuous glass fibers to produce Glass Fiber Reinforced Self Compacting Concrete (GFRSCC). The purpose of this study is to investigate the workability and mechanical properties of plain SCC and GFRSCC. Control concrete (NC), plain SCC, and GFRSCC samples were prepared. Water-cement ratio of 0.40 was used for all concrete mixes. The fiber and brand of superplasticizer used were alkaline-resistance glass fiber and *Rheobuild 1100*, respectively. Three fiber contents of 0.5%, 1.0%, and 1.5% by volume of concrete were utilised in this study. The laboratory testing included slump flow test, L-Box test, sieve segregation resistance test, density test, ultrasonic pulse velocity (UPV) test, compressive strength test, splitting tensile strength test, and flexural strength test. The dosage of superplasticizer required increased as fiber content increased. Plain SCC and GFRSCC were highly workable than NC. The experimental results show that plain SCC exhibited higher compressive strength than NC and GFRSCC. The splitting tensile strength of NC was higher than plain SCC and GFRSCC due to negative effect of superplasticizer added. The flexural strength of NC was slightly higher than plain SCC. All GFRSCC exhibited higher flexural strength than plain SCC. The optimum fiber content was 1.0% by volume of concrete. GFRSCC with 1.0% fiber content developed higher load at first crack and ultimate load than NC and plain SCC slabs.

ABSTRAK

Konkrit Tanpa Pemadatan (SCC) berupaya untuk mengalir di bawah berat sendiri, mengisi ruang acuan dan mengekalkan keseragaman dalam konkrit walaupun terdapat susunan tetulang yang padat. Majoriti konkrit bergantung kepada pemadatan untuk menghasilkan konkrit yang berkualiti. Tetapi, kerja pemadatan sukar untuk dijalankan dalam keadaan yang terdapat susunan tetulang yang padat dan kawasan penuangan yang besar. Penggunaan SCC akan mengatasi keadaan penuangan yang sukar dan mengurangkan tenaga buruh yang diperlukan. Penambahan gentian akan meningkatkan sifat-sifat tegangan dan kemuluran konkrit yang asalnya bersifat rapuh. SCC ditambah dengan gentian kaca yang pendek, diskret, dan tidak selanjar untuk menghasilkan Konkrit Tanpa Pemadatan diperkuat dengan Gentian Kaca (GFRSCC). Objektif kajian ini adalah untuk mengkaji kebolehkerjaan dan sifat-sifat mekanikal SCC biasa dan GFRSCC. Sampel konkrit yang disediakan termasuklah konkrit kawalan biasa (NC), SCC biasa, dan GFRSCC. Nisbah air-simen 0.40 digunakan untuk semua campuran konkrit. Gentian kaca ketahanan-alkali dan *superplasticizer* berjenama *Rheobuild 1100* digunakan dalam kajian ini. Tiga jenis peratus kandungan gentian sebanyak 0.5%, 1.0%, dan 1.5% daripada isipadu konkrit digunakan dalam kajian ini. Kajian makmal yang dijalankan termasuklah ujian runtuhan kon, L-Box, rintangan pengasingan konkrit, ketumpatan, halaju gelombang ultrasonik (UPV), kekuatan mampatan, kekuatan tegangan pembelahan, dan kekuatan lenturan. Kandungan *superplasticizer* yang diperlukan meningkat apabila peratus kandungan gentian bertambah. Kebolehkerjaan SCC biasa dan GFRSCC adalah sangat tinggi berbanding dengan NC. Hasil ujikaji menunjukkan sampel SCC biasa mempunyai kekuatan mampatan yang lebih tinggi daripada NC dan GFRSCC. Kekuatan tegangan pembelahan NC adalah lebih tinggi daripada SCC biasa dan GFRSCC. Penambahan superplasticizer memberikan kesan negatif terhadap kekuatan tegangan pembelahan konkrit. Kekuatan lenturan NC adalah lebih tinggi sedikit daripada SCC biasa. Semua sampel GFRSCC mempunyai kekuatan lenturan yang lebih tinggi daripada SCC yang biasa. Peratus kandungan gentian optimum ialah 1.0% daripada isipadu konkrit. Papak GFRSCC dengan kandungan gentian 1.0% mencapai beban pada retakan pertama dan beban muktamad yang lebih tinggi daripada papak NC dan SCC biasa.

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LIST OF ABBREVIATIONS

AR-glass fiber	-	Alkaline Resistance glass fiber
BS	-	British Standard
DOE	-	Department of Environment
EN	-	European Standard
EFNARC	-	European Federation of Specialist Construction Chemicals and Concrete Systems
FRC	-	Fiber Reinforced Concrete
FR-LLSCC	-	Fiber Reinforced LECA Lightweight Self Compacting Concrete
FRSCC	-	Fiber Reinforced Self Compacting Concrete
FRSCHPC	-	Fiber Reinforced Self Compacting High Performance Concrete
GFRSCC	-	Glass Fiber Reinforced Self Compacting Concrete
GGBFS	-	Ground Granulated Blast Furnace Slag
HPC	-	High Performance Concrete
ITZ	-	Interfacial Transition Zone
LECA	-	Lightweight Expanded Clay Aggregates
LVDT	-	Linear Variable Differential Transducer
NC	-	Conventional Concrete or Control Concrete

OPC	-	Ordinary Portland Cement
PP	-	Polypropylene
SAJ	-	Syarikat Air Johor
SCC	-	Self Compacting Concrete
SCHPC	-	Self Compacting High Performance Concrete
SP	-	Superplasticizer
UPV	-	Ultrasonic Pulse Velocity

LIST OF SYMBOLS

A_c	-	Cross-sectional area of the specimen in which the compressive force acts
a	-	Average distance between the point of fracture and the nearest support
D, ϕ_{final}	-	Mean diameter of slump spread
d	-	Cross-sectional diameter of concrete cylinder
d_1	-	Width of the concrete prism
d_2	-	Height of the concrete prism
F	-	Maximum load at failure
f_c	-	Compressive strength
f_{cf}	-	Flexural strength
f_{ct}	-	Tensile splitting strength
$H1$	-	Vertical distance from the base to the surface of concrete at the position of reinforcing bars of L-box
$H2$	-	Vertical distance from base to concrete surface at the end of the channel of L-box
I	-	Distance between the supporting rollers
J_{sf}	-	Slump flow spread of J-Ring test
L	-	Length of the line of contact of the concrete cylinder

L_F	-	Maximum flow distance of L-Box test
L_J	-	Difference in height of the mixtures inside and outside the J-Ring
L_L	-	Difference in height inside and outside the steel bars of L-Box test
L_S	-	Elevation difference before and after opening the sliding shutter of L-Box test
M_a	-	Mass of concrete sample poured on the sieve
M_b	-	Mass of cement paste or mortar passing the sieve
P	-	Maximum load
S_{f0}	-	Slump flow spread measured immediately after mixing
S_{f45}	-	Slump flow spread measured 45 minutes after mixing
T_{500}	-	Time to achieve 500 mm spread diameter
$T_{5MINUTES}$	-	Time for discharge to complete for V-Funnel test
t_{final}	-	Time to achieve final spread diameter
ΔH_{final}	-	Difference in concrete level between the beginning and end of the L-box

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Self Compacting Concrete (SCC) was originating in Japan and well established in some countries such as Sweden and United State [1]. Apart from individual symposium papers, several publications have been produced by some committees, such as "EFNARC Specifications and Guidelines for Self Compacting Concrete" and "The European Guidelines for Self Compacting Concrete" [2, 3, 4]. EFNARC stands for The European Federation of Specialist Construction Chemicals and Concrete Systems. SCC can be defined as a concrete that is able to flow under its own weight and completely fill the formwork, even in the presence of dense reinforcement without any compaction, while maintaining the homogeneity of the concrete [1 – 4]. SCC can also be known as Super-Workable Concrete [5]. The high workability is one of the crucial properties for SCC and can be controlled by appropriate dosage of superplasticizer [6]. Fiber Reinforced Concrete (FRC) is defined as a concrete incorporating relatively short, discrete, and discontinuous fibers. The fibers used are steel fiber, polypropylene fiber, carbon fiber, glass fiber, asbestos fiber, and natural organic fiber. The role of fibers is to improve the tensile properties of concrete due to its brittle nature [7, 8].

Both SCC and FRC can be categorized as High Performance Concrete (HPC) due to its special proportions and properties. HPC is a specialized concrete designed to provide several benefits in the construction of concrete structures that cannot always be achieved routinely using conventional ingredients, normal mixing and curing practices [5]. Besides, HPC can be termed as concrete in which its ingredients and proportions are specifically chosen and developed for particularly appropriate properties for the expected use of the structure [6].

Inclusion of fibers into SCC will produce Fiber Reinforced Self Compacting Concrete (FRSCC) with superior properties in fresh and hardened state. The reinforced fibers in concrete may improve the tensile strength, flexural strength, impact strength, toughness, drying shrinkage, and failure pattern of the concrete [9, 10]. Generally, the raw materials required for production of FRSCC are cement, coarse and fine aggregates, water, superplasticizer, and fibers. Modification to the FRSCC mixtures has been done by using different types of fibers and lightweight material such as Light Expanded Clay Aggregate (LECA). LECA is a type of lightweight aggregate and being used to reduce the self-weight of the structures as well as the cross-sectional area of members [11, 12]. The investigations on the influences of fibers on properties of FRSCC have been presented by many researchers. This study was conducted to investigate the properties of FRSCC with glass fiber, namely Glass Fiber Reinforced Self Compacting Concrete (GFRSCC).

1.2 Problem Statement

The majority of concrete cast required compaction to ensure that the development of adequate strength and durability. Generally, the purpose of compaction of concrete is to achieve the highest possible density of the concrete [6]. Dense microstructure of concrete will results in low permeability, high strength, high resistance to chloride and sulfate attacks, low carbonation, and improved durability. Insufficient compaction will lead to the formation of voids, which results in negative impact on the physical and mechanical properties of concrete. Inclusion of voids will also influence the protection of the embedded steel reinforcement [1]. Compaction of concrete is done manually by using vibrators in construction site. However, compaction will be difficult to be carried out at conditions as follows:

i) Large concrete casting areas.
ii) Presence of congested reinforcement
iii) Inaccessible areas and spaces, etc.

The concrete floor slabs in factories and commercial buildings are of large areas and often subjected to continuous static and dynamic loadings. Self-weight is considered as static loading; while vibrations and impact loadings can be categorized as dynamic loadings. The loadings are usually induced by storages, containers, machineries, and heavy vehicles that present in the factories and commercial buildings. Hence, the concrete slabs have to exhibit good fatigue and impact strength to prevent failure in fatigue [6].

FRSCC will be suitable in the construction of industrial concrete floor slabs due to the combined features of both SCC and FRC. The elimination of compaction enables the casting of large area of concrete slab to be completed in shorter time with reduced cost and manpower required. Besides, the fibers within FRSCC will improve the tensile properties, flexural strength, impact strength, toughness, and post-cracking behaviour of concrete. Therefore, FRSCC is an ideal solution for the construction of concrete slabs to maintain the serviceability of slab throughout their service lifespan. Figure 1.1 and Figure 1.2 show the casting of a large area of concrete slab with congested reinforcement in commercial centre in Italy.

Figure 1.1: The casting of large area of concrete slab [4]

Figure 1.2: Concrete slab with dense reinforcement [4]

1.3 Objectives of Study

The purpose of this study is to evaluate the properties of the plain Self Compacting Concrete (SCC) and Glass Fiber Reinforced Self Compacting Concrete

(GFRSCC). Comparisons will be made among the properties of normal concrete (NC), plain SCC, and GFRSCC. The concrete specimens are subjected to appropriate tests to determine the fresh and hardened properties of the concrete. Observations will be made to evaluate the fiber conditions after cracking occurred and failure mode of the concrete specimens. The objectives of this study are as follows:

i) To design and produce mix proportions for GFRSCC.
ii) To evaluate the physical and mechanical properties of GFRSCC.
iii) To obtain and compare the physical and mechanical properties of conventional concrete (NC), plain SCC, and GFRSCC

1.4 Scope of Study

The scope of this study is focused on the properties of FRSCC with glass fiber. Three volume percentages of fibers are utilized to investigate the influence of volume percentage of fibers to properties of concrete. The scope and limitations of this study are:

i) The type of cement used is *Holcim* brand Ordinary Portland Cement (OPC).
ii) The type of fiber used is alkaline-resistance glass fiber.
iii) The size of crushed aggregate used is 10mm.
iv) All the concrete specimens are subjected to wet curing.
v) The appropriate tests and evaluations of concrete specimens are done in laboratory scaled sample.
vi) The testing and evaluation of concrete mainly on workability, compressive strength, splitting tensile strength, flexural strength, and failure mode of concrete specimens.

1.5 Significance of Study

FRSCC has great potential and wider applications in construction industry due to the combined benefits of both SCC and FRC. FRSCC with elimination of compaction and improved toughness of hardened concrete make it more suitable for use in construction of structures with dense reinforcements and subjected to impact and earthquake loads.

The results of this study will present the physical and mechanical properties of the plain SCC and GFRSCC. For GFRSCC, the optimum fiber content will be determined from the test results and applied to the mix proportions of the reinforced concrete slabs. The fiber conditions and failure patterns of the concrete specimens will also be observed.