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SHEAR CAPACITY OF STEEL FIBRE REINFORCED
CONCRETE COMPOSITE SLAB

MOHD BASRI BIN CHE BAKAR

A project report submitted in partial fulfillment of the
requirement for the award of the degree of
Master of Engineering (Civil – Structure)

Faculty of Civil Engineering
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December, 2010

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Especially dedicated to my beloved mom, dad, sister and younger brother

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ABSTRACT

This thesis present the results of combined bending and shear test on composite slabs with steel fibres (SFs) in-situ concrete topping. Mechanical properties of steel fibre reinforced concrete (SFRC) were first determined by varying the fibres dosage from 0.50% to 1.25%. The test results show that there was not much improvement of the SFRC properties for steel fibres dosage of 1.0% and 1.25%. Apart from that, strong correlations were found between the concrete splitting tensile strength, compressive cube strength and flexural strength of SFRC. Following this, SFRC with 1.0% dosage was cast onto precast slab with different surface roughness. The SFRC replaced the conventional method using cast in-situ reinforced concrete topping. The experimental results on its ultimate shear capacity were further compared with previous research, and a parametric equation was proposed in predicting the interface shear strength using SFRC as concrete topping. The results shows that the ultimate shear capacity were 16.69% and 13.47% higher than the calculated value for the exposed aggregate and longitudinal roughened surface roughness, respectively. However, they were 15.23% and 17.56% lower than the smooth as-cast surface specimen with conventional reinforced concrete topping, respectively. As for the interface shear strength, the surface roughened in the longitudinal direction was the highest with 2.17 N/mm^2. Further comparison was made with BS 8110 and Eurocode 2 and the results show that they were higher than the minimum value provided in both codes. The finding also suggested that surface roughened in the longitudinal direction was better than the other specimens with SFRC topping in terms of interface bonding.

ABSTRAK

Tesis ini membincangkan mengenai keputusan gabungan ujian lenturan dan ricih ke atas papak komposit yang mengaplikasikan konkrit bertetulang besi gentian tuang di-situ sebagai penutup konkrit. Sifat-sifat mekanikal konkrit bertetulang besi gentian ditentukan dahulu dengan menpelbagaikan peratus dos besi gentian bermula dari 0.50% sehingga 1.25%. Keputusan ujian yang dijalankan menunjukkan peratus dos besi gentian di antara 1.0% hingga 1.25% tidak menunjukkan peningkatan yang ketara pada sifat-sifat mekanikal konkrit bertetulang besi gentian itu sendiri. Selain itu, kajian ini telah mendapati konkrit bertetulang besi gentian mempunyai hubungan yang kuat di antara kekuatan tegangan konkrit, kekuatan mampatan konkrit dan juga kekuatan lenturan konkrit. Berikutan itu, konkrit yang ditambah dengan peratus dos besi gentian sebanyak 1.0% dituang di atas papak pratuang yang mempunyai jenis kekasaran permukaan yang berbeza-beza. Keputusan ujian makmal ke atas kapasiti ricih muktamad dibandingkan dengan kajian yang terdahulu dan persamaan parametrik juga diusulkan untuk meramalkan kekuatan ricih permukaan yang mengaplikasikan konkrit bertetulang besi gentian sebagai penutup konkrit. Keputusan ujian menunjukkan permukaan dedahan dengan batuan adalah 16.69% lebih tinggi daripada nilai teori kapasiti ricih muktamad manakala permukaan kekasaran dalam arah pemanjangan adalah 13.47% lebih tinggi daripada nilai teori. Walau bagaimanapun, permukaan dedahan dengan batuan dan permukaan kekasaran dalam arah pemanjangan adalah 15.23% dan 17.56% lebih rendah berbanding spesimen yang dilapisi penutup konkrit bertetulang besi dengan permukaan licin seperti dituang. Dari segi kekuatan ricih permukaan, permukaan kekasaran panjang mempunyai nilai tertinggi sebanyak 2.17 N/mm^2. Perbandingan nilai kekuatan ricih permukaan dengan BS 8110 dan Eurocode 2 menunjukkan semua spesimen papak komposit mempunyai nilai yang lebih tinggi daripada nilai minimum yang dicadangkan oleh kedua-dua kod latihan tersebut. Kajian ini juga mencadangkan permukaan kekasaran dalam arah pemanjangan adalah yang terbaik dari segi ikatan permukaan bersentuhan berbanding semua spesimen papak komposit yang mengaplikasikan konkrit bertetulang besi gentian sebagai penutup konkrit.

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A_s	-	area of the tension reinforcement
A_i	-	area of the joint
b	-	full breadth of the precast unit
b_i	-	width of the interface
b_v	-	width of the contact interface
d/l	-	inverse of fibre aspect ratio
$E_{precast}$	-	Elastic Modulus of precast unit
$E_{topping}$	-	Elastic Modulus of concrete topping
E_{steel}	-	Elastic Modulus of steel reinforcement
F	-	maximum load
F_v	-	horizontal shear force
f_{cu}	-	concrete cube compressive strength
f_{ct}	-	concrete splitting tensile strength
f_t	-	flexural concrete strength
f_{ctk}	-	characteristic axial tensile strength of concrete
h_p	-	precast slab depth
I_{comp}	-	second moment of area
I_g	-	gross moment of inertia
L_z	-	distance between the points of min. and max. bending moment

l	-	span length
l/d	-	aspect ratio
n_1	-	transformation factor for precast unit width to be transformed
n_2	-	transformation factor for area of tension reinforcement to be transformed
PWc_{crit}	-	critical percentage of fibres (by weight of mix)
R_z	-	surface roughness
SG_f	-	specific gravity of fibres
SG_c	-	specific gravity of concrete matrix
V	-	minimum shear force
V_{Ed}	-	transverse shear force
V_f	-	volume percentage of steel fibres
V_v	-	vertical magnification of the profile record
v	-	strength reduction factor
v_{ave}	-	average shear strength at the cross-section of the interface considered at ultimate limit state
v_{Edi}	-	design value of the shear strength in the interface
v_{Rdi}	-	design shear resistance at the interface
w	-	uniform distributed load
W_a	-	weight of aggregate fraction (particle size >5 mm)
W_m	-	weight of mortar fraction (particle size < 5 mm)
X	-	depth of neutral axis
y_p	-	distance from the neutral axis of composite section to the centroid of precast slab

y_s - distance from the neutral axis of composite section to the steel centroid in the precast slab

z - lever arm of composite se

β - ratio of longitudinal force in the new concrete area and the total longitudinal force either in the compression zone or tension zone, both calculated for the section considered

ε_{fs} - free shrinkage of the SFRC

ε_{os} - free shrinkage of plain concrete

τ_{EC2} - Eurocode 2 interface shear strength

$\tau_{exp\ shear}$ - Experimental interface shear strength

μ is the coefficient of friction between the fibres and the concrete (range from 0.04 for plain steel fibres to 0.12 for deformed fibres)

γ_c is the partial safety factor for concrete

CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is one of the most important material in the constructions nowadays that promises a lot of advantages. The ability of concrete itself can be cast in any shape, excellent resistant to water and high temperature, required less maintenance are among the obvious advantages. Concrete is also known as an economical material which can reduce the overall project cost. Combination with steel as reinforcement in producing reinforced concrete ends up with other excellent properties to concrete in resisting the compressive and tensile forces. Reinforced concrete can be classified into precast or cast in-situ concrete. Precast concrete is cast and cured with high quality control in the factory before transported to construction site and lifted into position with the aid of lifting equipment controlled by highly skilled worker.

Example of construction that uses the precast concrete structure are bridge deck, tunnel lining and building elements including beam, column, slab and wall as shown in the Figure 1.1. Application of precast concrete structures in the construction stage contribute many advantages which include shorten the construction period, less labour required and at the same time keep the construction site clean with less formwork. However, only slab structure among the other building elements will be emphasized in this study.

In order to enhance the structural performance of precast concrete slab, it will be levelled with in-situ concrete acting as concrete topping that has specific purpose to create horizontal shear strength between the two contact surfaces i.e. precast unit and concrete topping. This is known as composite slab and will be designed monolithically. Interface shear links are usually provided in which projected from the precast slab into concrete topping to resist the horizontal shear.

Nowadays, some modifications can be made by varying the materials used in the casting of concrete topping. This include an application of steel fibre reinforced concrete (SFRC) as structural topping that is possible in resulting better horizontal shear strength between the precast slab and concrete topping without providing any interface shear links. Hence, by understanding the material properties of SFRC including its overall effect to the strength of composite slab and the development of the horizontal shear strength is the main finding in conducting this study.

Figure 1.1: Applications of precast concrete structures in a building construction

1.2 Problem Statement

Composite slab is designed to act monolithically. Essentially, precast slab will bend together with the concrete topping when flexural load is applied onto the composite slab. The flexural behaviour will automatically generate the sliding movement between the precast slab and concrete topping as illustrated in Figure 1.2. Horizontal shear strength developed between these two types concrete will resist the sliding movement of the contact surfaces. In the code of practice e.g. British Standard and Eurocode 2, it states the minimum value of horizontal shear stress that should be fulfilled when designing a composite slab depending on the certain cases i.e. surface texture of precast slab and grade of concrete topping. Otherwise, all the horizontal force should be carried by additional reinforcement e.g. interface shear reinforcement.

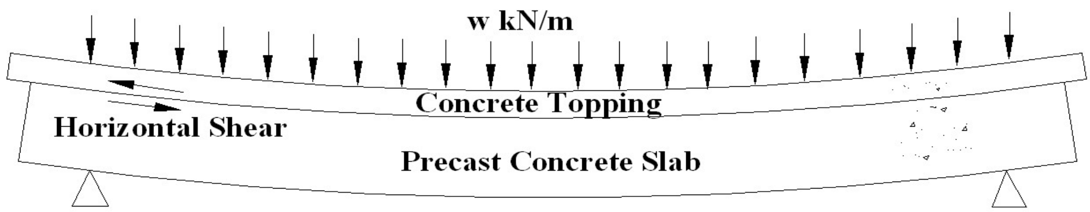


Figure 1.2: Horizontal shear along the interface of a composite slab bends under flexural load

Most precast composite slab structure is designed without providing any shear reinforcement at the interface because it is believed that horizontal shear strength can be carried up by the bonding force between precast slab and in-situ concrete by treating the surface to a certain texture and roughness. The top surface of the precast slab will be brushed either in longitudinal or transverse direction, and exposed aggregate to create the required surface texture. However, most designers prefer the surface to be remained smooth as-cast and according to the FIP [14], they believe smooth surface has better bonding strength compared with the rough ones. Therefore, in this study, it is also important to find out the effect of SFRC application as concrete topping to the horizontal shear strength based on different surface texture of the precast slab.

Two main parameters will be examined in this study i.e. mechanical properties of SFRC itself as concrete topping and the different types of surface texture of the precast concrete slab that affect the interface shear strength. These two parameters can affect the bonding strength at the interface and thus, affect the flexural behaviour of the precast composite slab.

1.3 Objectives

This study conducted to achieve the following objectives:

i. To study the mechanical properties of SFRC.
ii. To determine the ultimate shear capacity of composite slab with different surface texture under wet curing condition.
iii. To compare the ultimate horizontal shear capacity of composite slab using SFRC and conventional reinforced concrete as concrete topping.
iv. To propose a parametric equation in predicting the ultimate horizontal shear capacity using SFRC as concrete topping.

1.4 Scope of Study

This study is intended to study the mechanical properties of SFRC prior to the application as concrete topping on existing precast slab. The material properties of SFRC which consists of compressive, splitting tensile and flexural strengths and

Modulus of Elasticity were determined with five different volumetric percentages of 0% (as control specimens), 0.50%, 0.75%, 1.00% and 1.25% by absolute concrete weight of grade C25 (f_{cu} = 25 N/mm^2 at 28 days). The strength developments of the SFRC specimens were observed for 7, 14 and 28 days depending on the tests conducted. SFRC with particular volumetric percentage selected from five different volumetric percentages of SFRC specimens whichever give the best results in those mechanical properties was cast as structural concrete topping of composite slab.

Later on, the ultimate shear capacity of SFRC composite slab was determined by carrying out combined bending and shear test. The slab was designed to have 1100 mm length, 500 mm width and 175 mm overall depth i.e. 100 mm depth precast slab with 75 mm concrete topping. The experimental result was compared with the previous study [1] using the same dimensions and concrete properties so that the significant result at the end of this study can be obviously represented.

The surface of precast slabs were treated in four different ways; smooth as-cast, roughened in longitudinal and transverse direction and roughened by exposed aggregate. Therefore, four specimens of SFRC composite slabs were prepared and wet cured until the test day by covering them using wet gunny sacks to avoid the specimens from being exposed to the surrounding environment. Since the previous study [1] claimed that wet cured sample has better interface bond, this was used as the preferred choice to cure the specimens.

A pair of point load was applied until failure of the specimen. The point load was located at 1.5H from the support where H is the overall depth of the SFRC composite slab. During the test conducted, end-span interface slip, mid-span deflection and concrete strains were recorded simultaneously. Following the full scale test, a parametrical equation was proposed in this study to determine the interface shear strength using SFRC as concrete topping.

1.5 Importance of Study

This study conducted to determine the suitability of SFRC as a replacement to the conventional reinforced concrete as concrete topping. An appropriate bonding and interface shear strength can reduce maximum deflection and at the same time increase the loading capacity of SFRC composite slab. The success of this research can reduce labour cost and time in the construction of precast building structure.

1.6 Thesis Structure

The thesis structure presents an outline of all contents as listed below:

a) Chapter 1 described an introduction throughout the study conducted.
b) Chapter 2 described a review of the literature convincing the objectives of the study.
c) Chapter 3 clarifies the samples of SFRC specimens and composite slabs preparation as well as experimental setup for testing combined bending and shear test.
d) Chapter 4 interprets the experimental results.
e) Chapter 5 presents analysis and discussion of the results.
f) Chapter 6 concludes the thesis contents with several conclusions and recommendation for further investigation in the future.

CHAPTER 2

LITERATURE REVIEW

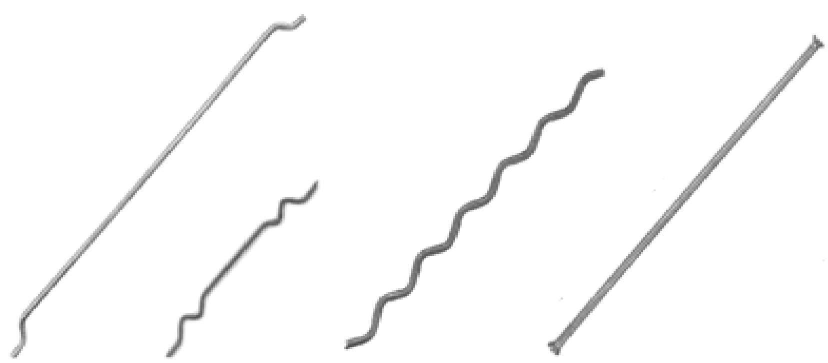
2.1 Introduction

Applications of steel fibre reinforced concrete (SFRC) in building construction are growing rapidly nowadays. There are numerous reasons why SFRC is chosen; it promise improvements in the engineering properties of concrete including flexural strength, flexural toughness index, impact resistance and fatigue resistance. Apart from that, SFRC can increase tensile strength by delaying the growth of cracks, increase toughness and energy absorption by transmitting stress, improves the impact and fatigue strength and also can reduces concrete shrinkage. Based on these potentials, investigations have been done on applications of SFRC as concrete topping to the precast slab with various parameters investigated that produced new theories and relationships between shear, surface roughness and bonding strength at the interfaces between precast unit and concrete topping. Section 2.2 onwards will be further discussed on this matter from the previous studies.

2.2 Steel Fibres (SFs)

SFs are generally made up from carbon steels or alloy steels which recently are used primarily for corrosion resistance fibres especially in marine structures and commonly used in the refractory industry to reinforce high temperature concretes. Generally, there are two types of steel fibres recently available in the market; round steel fibres are produced by cutting or chopping round wires into short lengths which have typical diameter around 0.25 mm to 0.75 mm and the second one is rectangular steel fibres which produced either by shearing sheets or flattening wire. Commonly cross sectional dimensions of rectangular steel fibres are in the range of 0.15 to 0.41 mm thickness and 0.25 to 0.90 mm wide. Steel fibres have tensile strength in the range between 345 MPa to 2100 MPa depending on the type of steel and type of production process [2].

The shape of SFs can be designed either with hooked ends or completely corrugated with end cones in order to improve anchorage and adhesion with cement matrix. The various shapes of SFs are illustrated in the Figure 2.1. Most of SFs are produced as single fibre, however, some are produced magnetically aligned or glued together in bundles.



(a) (b) (c) (d)

Figure 2.1: Different shapes of steel fibres; (a) Hooked-end steel fibre, (b) Crimped-end steel fibre, (c) Crimped steel fibre, and (d) Straight steel fibre

2.3 Steel Fibre Reinforced Concrete (SFRC)

SFRC is concrete made with hydraulic cement containing fine or fine and coarse aggregate and discontinuous discrete fibres. Basically, SFRC contain higher cements contents and higher ratio of fine aggregate to coarse aggregate rather than ordinary concrete mixes. However, cement contents in SFRC can be reduced by replacing them with admixtures i.e. pozzolanic materials like fly ash, palm oil fuel ash, etc. In order to improve the workability of SFRC, water reducing admixtures and in particular superplasticizers are usually used in conjunction with air entrainment.

The mix proportions design of SFRC depend upon the requirements of a particular job in terms of strength, toughness, workability; affected by fibre aspect ratio (*l/d*), steel fibre volumetric percentage, steel fibre size and specific fibre surface. As claimed in the previous study [2] for a certain fibre type and orientation, the workability of the design mix decreased as the size and quantity of aggregate particles increases by more than 5 mm. However, the presence of aggregate particles less than 5 mm had little effect on the compacting characteristics of SFRC. Equation (2.1) was proposed to estimate the critical percentage of fibres which can make the SFRC unworkable [2]:

$$PWc_{crit} = 75\frac{\pi.SG_f}{SG_c}.\frac{d}{l}.K \tag{2.1}$$

where;

PWc_{crit}	is the critical percentage of fibres (by weight of mix);
SG_f	is the specific gravity of fibres;
SG_c	is the specific gravity of concrete matrix;
d/l	is the inverse of fibre aspect ratio;
K	is $W_m/(W_m + W_a)$;
W_m	is the weight of mortar fraction (particle size < 5 mm);
W_a	is the weight of aggregate fraction (particle size >5 mm).

It is recommended that fibre content should not exceed 0.75 PWc_{crit} in order to permit proper compaction, meanwhile the second factor which is the aspect ratio (*l/d*) of steel fibres had major effect on workability. The relationship between workability of SFRC and aspect ratio shows that workability will decrease as the aspect ratio increases.

One of main problem faced in obtaining a uniform steel fibre distribution in concrete mix is the tendency for steel fibres to clump together. Clumping maybe caused by several factors such as:

i. Steel fibres may be added too quickly to allow them to disperse in the mixer.
ii. Too high volume of steel fibres added.
iii. The mixer itself may be inefficient to disperse the steel fibres.
iv. The steel fibres may be already clumped together before added to the mix; normal mixing action unable to disperse them.

2.3.1 Mechanical Properties of Steel Fibre Reinforced Concrete (SFRC)

There are three main parameters influence the mechanical properties of SFRC [4]:

i. Steel fibres: By considering type, geometry, aspect ratio, volume fraction, surface, orientation and distribution of steel fibres.
ii. Matrix: By considering strength and maximum aggregate size used, type of cement and supplementary cementitious material and water/binder ratio.
iii. Specimen: By considering the size, geometry and method preparation of specimen.