BOND STRESS BETWEEN STEEL DEFORMED BARS CONFINED WITH STEEL FIBER REINFORCED CONCRETE

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Dedicated to;

My parents,
ZAKARIA BIN YUSOF
NOR SIAH BINTI OTHMAN

My supervisor,
PROF. DR. AHMAD BAHARUDDIN ABD. RAHMAN

Family and Friends

thank you very much and a special love for your prays and supports, physically and spiritually.

may ALLAH S.W.T. bless you always.

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ABSTRACT

Bond interaction between steel bars and concrete plays important role in providing good performance of reinforced concrete structures. Bond stress-slip relationship was used to evaluate the performance of Steel Fibre Reinforced Concrete (SFRC) with respect to steel bar diameter and concrete strength. Although the relationship between deformed steel bars and SFRC has been studied, the bond-stress slip relationship between deformed steel bars and SFRC considering the effect of bar diameter and concrete strength is still lacking. The objective of this research was to explore the effects of SFRC with different concrete strength in controlling the bond stress behaviour. The deformed steel bars with herringbone ribs were used to investigate the mechanical interlocking and friction between the steel bar and SFRC. Series of pull-out test were conducted to investigate the behaviour of bond stress between deformed steel bars and confined with SFRC. The pull-out test was used to determine the ultimate load and bond stress-slip of steel-concrete specimens. The effects of steel bar diameters and concrete strengths were investigated by means of 24 pull-out tests comprising plain and confined concrete specimens. Concrete in grades of 30 MPa and 60 MPa and steel bar diameters of 12, 16 and 20 mm were considered for this investigation. Hooked-end steel fibres with optimum volume fraction of 1.5% from the cement proportion were used as the confinement concrete. Specimens comprising 100 mm x 100 mm cubes were tested for compressive strength and 110 mm x 220 mm cylinders were tested for pull-out specimens at 14 days. The highest bond strength values were observed in SFRC specimens in grade 60 (C60-F-12). The results showed that there were significant strength improvement in SFRC. The bond strength between deformed steel bars and confined SFRC concrete increases with smaller bar diameters. The addition of steel fiber leads to reduction of crack width in reinforced concrete specimens.

ABSTRAK

Hubungan interaksi antara batang keluli dan konkrit memainkan peranan penting dalam menunjukkan prestasi konkrit bertetulang yang baik. Hubungan di antara ketegangan dan kegelinciran digunakan untuk menilai prestasi konkrit bertetulang serat keluli ataupun SFRC berkaitan dengan variasi saiz batang keluli dan kekuatan gred konkrit. Walaupun hubungan di antara batang keluli dan SFRC pernah dikaji tetapi kajian terhadap hubungan dalam ketegangan dan kegelinciran batang keluli and SFRC berkaitan saiz batang keluli dan kekuatan gred konkrit masih berkurangan. Objektif penyelidikan ini adalah untuk meneroka kesan SFRC terhadap pelbagai kekuatan gred konkrit dalam mengawal tingkah laku tekanan bon. Batang keluli yang mempunyai sejenis tulang rusuk herringbone digunakan untuk mengkaji ikatan mekanikal dan geseran di antara batang keluli dan SFRC. Ujian tarik dilakukan untuk menyiasat kelakuan tegasan ikatan antara batang keluli dan SFRC. Ujian tersebut dijalankan adalah untuk menentukan beban muktamad dan ikatan antara ketegangan dan kegelinciran terhadap spesimen batang keluli dan konkrit. Sebanyak 24 spesimen telah dijalankan dan spesimen tersebut terdiri daripada konkrit biasa dan konkrit terkurung. Spesimen konkrit bergred 30 MPa dan 60 MPa dengan pelbagai saiz batang keluli 12, 16 dan 20 mm telah digunakan dalam penyiasatan ini. Gentian keluli bercangkuk dengan isipadu sebanyak 1.5% daripada bahagian simen diaplikasi untuk spesimen konkrit terkurung. Konkrit kiub bersaiz 100 mm x 100 mm diuji untuk melihat kekuatan mampatan manakala spesimen silinder bersaiz 110 mm x 220 mm pula diuji dalam ujian tarik di mana spesimen-spesimen ini mempunyai kekuatan konkrit berkadar 14 hari. Nilai kekuatan ikatan yang tertinggi dicapai oleh spesimen SFRC bergred 60 (C60-F-12). Keputusan menunjukkan terdapat peningkatan kekuatan konkrit untuk spesimen SFRC. Kekuatan ikatan antara batang keluli dan konkrit terkurung SFRC meningkat apabila menggunakan saiz batang keluli yang lebih kecil. Penambahan gentian keluli menyebabkan pengurangan retakan dalam spesimen konkrit bertetulang.

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f_{ck} = Characteristics strength of concrete

f_{yk} = Characteristics strength of steel

E_{cm} = Concrete Young Modulus

E_s = Steel Young Modulus

τ_b = Bond stress

τ_{max} = Bond Strength

V_f = Volume fraction of steel fibre in concrete

G = Concrete grade

l = Embedded length

d = Diameter bar size

w/c = Water-to-cement ratio

l/d = Length-to-diameter aspect ratio

c/d = Concrete cover-to-diameter ratio

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In structural applications, fibres acts as role supplementary to the reinforced bar by restrain cracking and give contribution to the improvement of resistance to material deterioration due to impact load, fatigue, shrinkage and thermal stresses. During structural members in flexural and tensile loads occurs such as beams, columns and slabs, reinforcement bars perform to support total tensile load. Steel fibres help to improve performance in flexural strength, improve resistance and fatigue performance to the structural members and also contributed to reduction of section thickness (Mohod, 2012). Fibre reinforcement can convert the concrete physical properties from brittle to ductile mode. The mechanism of steel fibres and concrete can be elaborate based on fiber-matrix interactions. Pull-out behaviour on hooked-end fibres can be characterized into 5 modes: (1) elastic bond, (2) fiber-matrix debonding, (3) plastic deformation of the hook; (4) coulomb friction on the hook; (5) fiber-matrix frictional bond (Abbas and Khan, 2016).

Fiber-matrix interaction represents the response of fibre strength in concrete matrix by bridging the tensile force across the microcracks. Combination of fibre content (V_f) and fibre aspect ratio (l/d) of steel fibres in the concrete influenced the strength contribution of fibre to the concrete. Another perspective in term fibre reinforcing index (RI) and concrete strength, this situation also can affect to the strength contribution of concrete (Thomas and Ramaswamy, 2007). Short discrete fibers functions to slow down the propogation of microcracks by bridging the crack using fibres and prevent from continuing increase cracks width. Due to capability of energy absorption, usage of steel fibres by confining the concrete in structures such as precast products, shotcrete, seismic structures, hydraulic structures, repairs and others civil engineering applications. Fibres contributes to increase in compression specific toughness of concrete. Toughness is determined using stress-strain curve where the usage of fibres in concrete tend to increase strain at peak load and produced high energy absorption at post-peak region in stress-strain curve (Marar *et al.*, 2011).

High Strength Concrete (HSC) has economic advantages compared to conventional concrete since the usage of HSC in large variety in civil construction applications. For high rise buildings, HSC creates reduction on oversized column at lower floors, buildings can have larger floor space due to allowing large column spacing between them and also allowing additional number of stories. In bridge structures, application of HSC in long span bridge can reduce dead load of bridge girder and bridge piers, as results the bridge can have larger underpass clearance widths. In addition, saving on bridge maintenance expenditure and extension of serviceable life of the bridge (Parghi and Modhera, 2008). Normal Strength Concrete (NSC) and High Strength Concrete (HSC) are considered the range of compressive strength values to be 40 MPa or less and 40 MPa or greater respectively (Almeida Filho, 2008).

HSC has higher cementitious materials content which increase the early heat of hydration of concrete and produces high shrinkage in which lead to potential cracks. High strength concrete contributes to low of water-to-cement ratio and the concrete strength can be achievable by addition of superplasticizers (SP). The content of Portland cement (Type 1) for high performance concrete in range 450 – 550 kg/m^3 (Parghi and Modhera, 2008). HSC can be characterized as low water-to-cement ratio, low porosity, well-graded aggregates, good compaction, proper curing and containing Superplasticizers for workability purposes. The bond behaviour of fibres in high strength concrete mechanical properties can be observe by compressive strength, tensile strength, flexural strength, impact strength, ductility and flexural toughness which the concrete strength dominated by the dimension, type, volume fraction, aspect ratio of fibres (Marar *et al*., 2011).

At early age of concrete, shrinkage mechanisms generated deformation to the concrete structures. If the deformation is inhibited, tensile stress promoted in the structures. The concrete produced cracking due to tensile stresses higher than tensile strength of hardening concrete. Reinforcement is one of the effective way of prevention to the deformation of concrete (Sule and Breugel, 2001). Usually deformed steel bar at short concrete corbels play important roles since this region related to three mechanism of bond stress-slip behaviour. There are three factors to define bond strength: chemical adhesion, friction and bearing of bar deformation. Chemical adhesion only resist small stress and can be lost quickly. Friction is mechanical interlock between ribs bar and concrete matrix and it occurred as the losses of adhesion strength and also there is movement or slip between steel and concrete. As no more friction, tension from force applied transferred by bearing of bar deformation. The strength of deformed bar take place on the ribs when no adhesion strength left. The tension force has been transferred to concrete by ribs bar. The radial components of rib force on concrete surrounding increase bond stress between surface steel and concrete matrix (Barbosa and Filho, 2013).

Amount of reinforcement required need to be consider in modern building codes when dealing with seismic design of buildings in order joint region such as exterior beam-joint. In reinforced concrete structures, standard hooks with 90-degree is commonly use where sufficient embedment depth is not available for straight bars. The bends and tails of the hooked bars create reinforcing congestion at part where all beams and columns main bar pass through. The congestion at joint region inhibit placement of concrete and vibration during casting and production of honeycombs at that part. Thus, the problem can be solve by using corrugated steel bar in the joint region instead of hooked bars. Additional high performance of steel fibres to the concrete mixture and acts as confined concrete can reduce the amount of joint transverse reinforcement (Hameed *et al.*, 2013).

Compressive and tension strength of concrete are parameters that effected the anchorage length and transmission of the tension force on the bar ribs. In addition, factors influence the bond stress during pull out test are surface of bar roughness, diameter or bar sizes and arrangement of bar ribs (Barbosa and Filho, 2013). The behaviour of high strength concrete in pull out test also resulted on splitting concrete cover due to internal cracking produced by stress transference from steel bar ribs to concrete matrix. The longitudinal cracking seems to be appeared cause by compressive strength discharge from inclination of rib surface. Bond stress-slip relationship model is used to identify the cracking of pattern and width. The bond stress-slip behaviour influenced the behaviour of reinforced elements in cracked stage. Distribution of bond stresses along steel bars and slip between steel and concrete matrix which is lead to cracking in term of widths and deflections. The results of bond test conducted using pull out specimens and the failure of bond achieved by pull out. Tension bar with ribs tested in pull out test with splice length, $5d_b$ where d_b is the diameter of bar used for all specimens in the experiment to create local bond failure condition (Harajli, 2002).

1.2 Problem Statement

Bond interaction between steel surface and concrete play very important role in reinforced concrete structures since failure in steel-concrete bond can be deterioration to the civil infrastructures. Adhesive joint contributes to the enhancement of steel-concrete bond. There are two mechanisms for steel-concrete behaviour, adhesive strength and frictional force. For plain and deformed steel bar, both has frictional force but the difference in mechanical interlocking since deformed bar giving better interlocking due to ribs bar but different diameter bar sizes has different rib spacing and rib inclination.

Cracks in fresh concrete structures can lead to restrained thermal deformations. High strength concrete increase these deformations which creates the material more prone to early-age cracking. Due to concrete strength increase at early age as the cement hydration process develops, bond behaviour also affects between reinforcing steels bars and concrete matrix. The behaviour of reinforced concrete on normal and high strength concrete can be analyse based on stress development and cracking response. Addition of steel fibres can improve both deformations and crack width on confined concrete. Percentage volume fraction from previous researcher which give good impact on bond strength will use for further study either concrete strength influence the bond stress slip behaviour with addition of steel fibres.

The selection of steel diameter bar size to the structures are very important since it also effect the concrete cover thickness which lead to the bond failure. As the bond stress increase due to tension force from ribs bar to the concrete, longitudinal propagation of cracks to the bar axis occur. Effect on slip corresponding to the bond strength between the variation diameter bar sizes to the thickness concrete cover and also effect on slip due to utilization of steel fibre to the concrete strength need to be further investigation for better understand on bond behaviour.

Common application of civil structures that can be relate to this research is region of beam-column joints for longitudinal reinforcement. Bond-slip model is conduct to determine the behaviour of embedded reinforced bars to the thickness of concrete cover and spacing between bars. This investigation gives the estimation of bond stress between steel and concrete surroundings to achieve adequate concrete cover and spacing between bars.

1.3 Aim of Study

The aim of this study was to investigate the bond stress between steel deformed bars on plain reinforced concrete and steel fibre reinforced concrete (SFRC) with different of concrete strengths and variation on diameter of bar sizes.

1.4 Objectives of Study

The objectives of this study are as follows:

1. To evaluate the bond stress-slip behaviour of steel bar diameter, concrete grades and steel fibre and plain reinforced concrete.
2. To explore the effects of SFRC with different concrete strength in controlling the bond stress behaviour.
3. To investigate the failure modes of the pull-out specimens as a result of different steel bar diameter, concrete grades and steel fiber reinforced concrete.

1.5 Scope of Study

Previous existing journal papers were reviewed to study the pull out test and fundamental bond stress-slip behaviour between steel surface and concrete matrix for the purpose of this study. There are two types of concrete in grades 30 MPa and 60 MPa and each grade has plain reinforced concrete and SFRC. Plain reinforced concretes is acts as control specimens. SFRC specimens contains hooked-end steel fibres with optimum volume fraction of 1.5% from the cement proportion. Three diameter of bar sizes of 12, 16 and 20 mm were used in this research. A total of 24 cylinders reinforced concrete specimens are cast with dimension of 110 mm diameter and 220 mm length. The ratio of dimension is 1:2. All deformed steel bars in reinforced concrete specimens have the length of 570 mm.

1.6 Significance of Study

This project report provides the experimental data on bond stress-slip behaviour in predicting the performance of steel-concrete bond between plain and steel fibre reinforced concrete. In previous research, the bond strength is considered only at slip values of 0.01 mm, 0.1 mm and 1.0 mm. The data produced from this study were generated by considering variables such as variation diameter bar sizes and different concrete strength in order to observe the performance of confined concrete with various parameters.

1.7 Outline of Thesis

This project report is divided into five chapters. Chapter 1 presents the background of study, problem statements, the objectives of the research, the scope of study and the significance of the project report.

Chapter 2 presents the literature review that is related to the purpose of the project report. This part introduces the effects of steel fibres from researchers on the concrete strength and steel bar diameter.

Chapter 3 presents the research methodology. The methodology was designed to identify the performance of bond stress-slip behaviour of plain reinforced concrete and SFRC on concrete strength and steel bar diameter. The preparation of specimens, testing and procedures are discussed in detail in this chapter.

Chapter 4 presents the results, analysis and discussions of the pull-out test. This chapter discusses the results of material test, compressive test of control cube concretes, tensile test of control steel bars and pull-out tests.

Chapter 5 presents the conclusions and recommendation. The contribution in this project report is highlighted.

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