ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Member Size and Coarse Aggregate Size Effect on Bond Strength of a Reinforced Concrete Member

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A Thesis in Structural Engineering

By

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UNDERTAKING

I certify that research work titled “Member Size and Coarse Aggregate Size Effect on Bond Strength of a Reinforced Concrete Member” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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ABSTRACT

The utilization of reinforced concrete as a structural material is derived from the combination of concrete that is strong and relatively durable in compression with reinforcing steel that is strong and ductile in tension. Maintaining composite action requires transfer of load between the concrete and steel. This load transfer is referred to as bond and is idealized as a continuous stress field that develops in the vicinity of the steel-concrete interface. The effectiveness of this bond strength between concrete and reinforcing steel is the most important and influenced by a wide range of parameters. From such parameters this study focuses on the effect of coarse aggregate and specimen size.

The aggregate and specimen size effect on bond strength of concrete and deformed bar is investigated using tensile test method. The parameter includes; concrete of compressive strength of 25MPa with varying maximum aggregate sizes of 9.5mm, 25mm, and 37.5mm, reinforced concrete member sizes of 10cm*10cm*30cm, 12cm*12cm*40cm, 14cm*14cm*50cm with centrally embedded bars of diameters of 10mm,12mm and 14mm respectively are considered.

By varying the aggregate size for each specimen the tensile test experiment was done by using Universal Testing Machine (UTM). From the experiment result increasing of specimen size decreases the average bond strength, this shows that by controlling of all other variables and only increasing of specimen size decreases bond strength of the member due to its brittleness behavior.

In the study by increasing of aggregate size the bond strength for a given elongation is constant but the maximum bond strength and elongation decreases as the aggregate size increases, this is due to decreasing of number of aggregate and volume of paste in a given section.

Keywords: average bond, development length, brittleness, reinforced concrete member, elongation, specimen size, aggregate size

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f_{ct}=tensile strength of concrete

p_{app}=applied tensile load

M_{cr}=cracking moment

M_a=applied moment

I_{cr}=moment of inertia of the cracked concrete section and

I_g=moment of inertia of the uncracked concrete section

β_1=coefficient dependent on bond properties

β_2=coefficient dependent on loading

M_{cr}=cracking moment

E= modulus of elasticity

I_e= effective moment of inertia

ε_{suc}=strain in steel in uncracked phase and

ε_{sc}=strain in steel in cracked phase

$\emptyset_1$= the curvature at the uncracked phase

$\emptyset_2$=the curvature at the cracked phase

U_m=maximum bond stress

S_1=maximum slip distance

C_o=clear distance between lugs

L_d=embedment length

f_c'= cylindrical compressive strength of concrete

f_c = cubic compressive strength of concrete

ACHRONYMS

PVC conduit= Polyvinyl Chloride conduit

AG110= 9.5mm of maximum aggregate size with concrete cross-section of 10cm*10cm

AG112= 9.5mm of maximum aggregate size with concrete cross-section of 12cm*12cm

AG114= 9.5mm of maximum aggregate size with concrete cross-section of 14cm*14cm

AG210= 25mm of maximum aggregate size with concrete cross-section of 10cm*10cm

AG212= 25mm of maximum aggregate size with concrete cross-section of 12cm*12cm

AG214= 25mm of maximum aggregate size with concrete cross-section of 14cm*14cm

AG310= 37.5mm of maximum aggregate size with concrete cross-section of 10cm*10cm

AG312= 37.5mm of maximum aggregate size with concrete cross-section of 12cm*12cm

AG314= 37.5mm of maximum aggregate size with concrete cross-section of 14cm*14cm

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Reinforced concrete is one of the most widely used composite materials in civil engineering.
In reinforced concrete members, concrete forms the body of the member and provides stiffness and resistance to compression loads. The steel reinforcing bars are placed where tensile loads are expected, so that once the concrete cracks, the steel is present to resist the tension.

In most composite members, including reinforced concrete, composite action requires that loads be transferred from one material to another through a bond. This interface where bond occurs has the potential to be the weakest part of the member.

There is a current interest in using large bars as reinforcement in seismically resistant structures to both reduce congestion and maintain enough clear spacing between the bars. While a large amount of experimental and analytical work has been performed to study the size effect on the shear strength and textural strength of reinforced concrete members, less attention has been devoted to the size effect on the bond strength of reinforcement, on tension stiffening, including the size effect on tension lap splice strength.

Tension stiffening refers to the tension carrying ability of concrete between cracks, contributing to the stiffness of a reinforced concrete member before the reinforcement yields. If concrete is assumed to carry a tension between the cracks only, the reinforcement carries the entire axial load at the crack location. The rigidity of the reinforced member affects the performance of a reinforced member in terms of deflection and crack control.

Concrete cracks when the tensile stress limit is exceeded. Cracking causes a softening behavior in plain concrete. As cracking progresses, concrete loses its stiffness at a relatively high rate. However, this softening behavior is counteracted by the steel reinforcing bars in the tension zone of concrete. The tensile stress in concrete gradually decreases as cracking develops.

The propagation of cracks is a complicated phenomenon that depends on the interaction between concrete and reinforcement and plays an important role in the analysis of concrete structures. This thesis investigates the effect of a specimen and aggregate size on bond strength of concrete based on bond stress-slip relationships by using standard bond test methods.

1.2 Standard Bond Tests

Bond test methods can be classified in to two categories according to their form, namely transfer type, and anchorage or development type. Pull-out and beam-end forms of test lies in the anchorage type and clearly express the idea of anchoring a bar. One end of the bar is in tension and the other end is unstressed and the equilibrate reaction is supplied through surrounding concrete. In the transfer test, both the ends of the bar are stressed in tension and force is not applied directly to the concrete. In this research transfer test type are used, pulling two ends of the bar by a 1000kN tensile load capacity of Universal Testing Machine (UTM).

Figure 1-1 Universal Testing Machine (AAiT construction material testing laboratory)

1.3 Objectives of Research

1.3.1 General objective

The main objective of this research is to study whether or not specimen and coarse aggregate size affect the bond strength of reinforced concrete member.

1.3.2 Specific objective

. The specific objective of this research is summarized as follows;

- Determine size effect on stiffness of reinforced concrete member.
- Design a test set up to examine the bond behavior
- Analyze the output of the test result, define the load-strain, bond stress-elongation curve and evaluate the effect of individual parameters(specimen and aggregate size)

1.4 Scope of the study

This research will study the bond behavior of specimen until the bar yields whether the concrete cracks or not. The stress transferred between steel and concrete by bond action will be analyze by varying aggregate and specimen size.

1.5 Significance of the study

There are different studies done on behavior and factors affecting bond strength of concrete and deformed bar. Different codes also recommend development or splice length of reinforcing bar to act bond force, but there is shortage of data on how this bond strength is affected by size. This paper has an objective to answer how bond strength is affected by aggregate and specimen size.

1.6 Methodology

- Literature review of different studies on bond and bond-slip behavior reinforced concrete member.
- Experimental investigation which considers bond stress behavior of concrete.
- Discussion on the experimental result.
- Conclude and give recommendation on behavior of bond stress for variation of aggregate and specimen size

1.7 Overview of the Report

This report follows the development of the experimental test researching bond stress behavior of concrete. Chapter 2 details previous work conducted on the behavior of bond and bond slip behavior of concrete. Chapter 3 describes the test specimens developed for this study, including specimen design, specific parameters of interest, the test matrix, test setups and procedures. Chapter 4 contains result and discussions of tests. Chapter 5 presents the conclusion and recommendation of the report.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

Bond failure as a result of tensile cracking is one of the most common modes of failure for reinforced concrete structures. Understanding the bond-slip behavior at the interface between the steel reinforcement and the concrete helps to understand this bond failure. The width, spacing and direction of cracks greatly depend on the bond-slip characteristics of the system (American Society of Civil Engineers, 1982).

The composite behavior of steel and concrete in reinforced concrete structures is dependent on the bond between the two materials. The bond between steel and concrete as shown in the figure 2.1 has three main components: chemical adhesion, friction and mechanical interlock (Wang and Liu 2003).

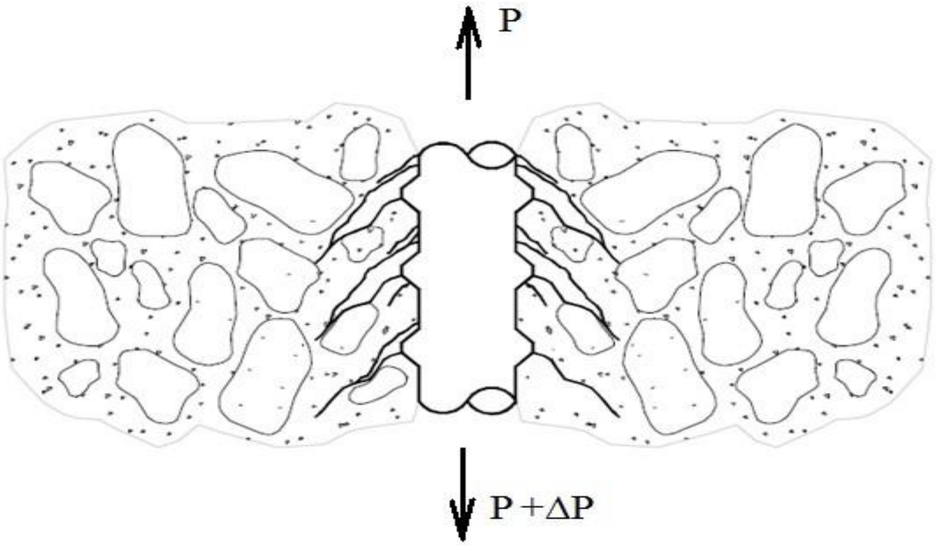

Figure 2-1 Steel-concrete bond (Wang and Liu 2003)

2.2 Bond-Slip Mechanisms

The bond-slip mechanism comprises three components, i.e. chemical adhesion, friction and mechanical interlock between the bar ribs and the concrete. Chemical adhesion depends on the chemical reaction between the concrete and the reinforcing steel bars, friction depends on the surface roughness and the magnitude of friction is related to the normal force to the movement direction, and mechanical interlock depends on the reinforcement geometry and surface deformation (Hanus et. al., 2000). The first two components play a more important and primary role in the bond of plain bars, even though some mechanical interlocking takes place due to the roughness of the bar surface. For deformed bars, mechanical interlock is thought to be the primarily mechanism with the others only being secondary effects (Cox and Herrmann, 1999).

However, in spite of acknowledging the three bond components as individual mechanisms, they are not independent. They interact with each other and cannot be analyzed as separated issues. The combined effect of these components leads to different behaviors. The general types of bond failure are bar failure, bar pullout, concrete pullout, concrete failure by splitting and concrete failure by transverse crack. Many researchers have contributed to the investigation of bond mechanisms. It is generally accepted that there are different stages of the interaction between steel and concrete when a tensile force is applied to a Steel reinforced specimen.

According to the federation internationale du beton (*fib*), 2000, the bond stress is low at the beginning of the loading process while the concrete remains uncracked and no bar slip is taken place. Chemical adhesion dominates the resistance for very low levels of bond (up to about 1.5MPa (Lutz and Gergely, 1967 and Gambarova and Karakoc, 1982)) and mainly localized at the tips of the ribs. The strength of the cohesion greatly depends on the concrete and its chemical reaction with the surface layers of the steel reinforcement. At the same time, the micro-mechanical interaction between the microscopic rough steel surface and concrete surface also contributes to the bond strength, nevertheless it is considered as a minor role comparing to the chemical adhesion.

When the load further increases, slip occurs after the chemical adhesion is broken down and the mechanical interlock, provided by the wedging action of the ribs, is responsible for the resistance to the pulling apart of the two materials (Chinn et al. 1955, Eligehausen et al. 1983). Secondary internal transverse cracks (radial cracks) are firstly developed at the tips of the ribs to allow slip (as shown in Figure 2.2).

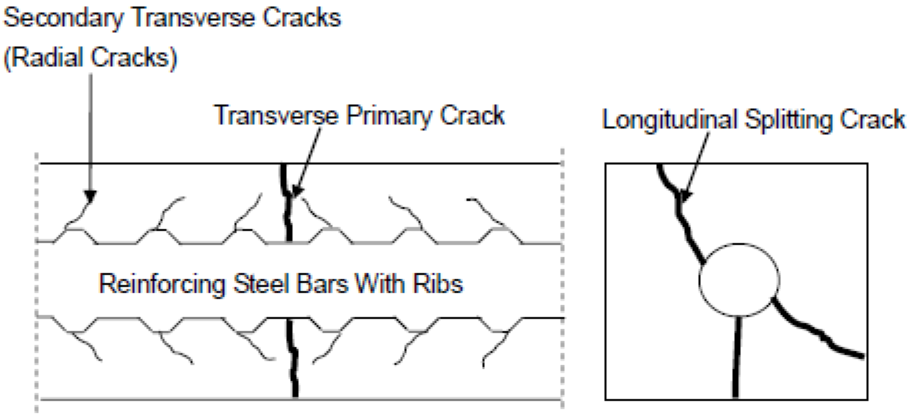

Figure 2-2 Cracks formed in reinforced concrete beams (Tassios, 1979; CEB Bulletin No. 151, 1982)

Longitudinal cracks (Goto, 1967 and Gerstle and Ingraffea, 1990) are developed and spread, and when further load is applied, the wedging action is enhanced by crushing of the concrete in front of the ribs. Therefore the component of the wedging action parallel to the reinforcing steel bar depends on the rib pattern of the reinforcement and the outward component depends on the hoop stress provided by the surrounding confinement. According to Tepfers (1979), as long as there is an undamaged outer concrete ring around the reinforcement, the concrete is capable of exerting a hoop stress around the bar, so that bond strength and stiffness are mostly determined by mechanical interlock.

In the case of a low level amount of or even no transverse reinforcement (named as stirrups or links), the specimen would fail in splitting after the splitting cracks propagate through the concrete cover and reach the outer concrete surface. When there is a medium level amount of transverse reinforcement and therefore relatively long bond lengths, pullout failures and splitting failure could be both observed since various stages of bond damage along the bond length are taking place at the same moment. In the case of high level amount of transverse reinforcement or large concrete cover, the splitting cracks are confined around the bar and the splitting is limited to the cracked core around the reinforcement.

In the cases with medium and high level amount of transverse reinforcement, the bar and the bar ribs are essential to ensure that the bond stress can reach what is considered to be an ultimate value of approximately ${f_c}/{3}$ (Gambarova and Karakoc, 1982). Splitting failure does not occur but pull-out failure and the bond stress is dominated, instead of rib bearing, by the friction at the interface. Once after most of the concrete in front of the ribs is sheared off or crushed, the bond stress would be further reduced when the friction interface is smoothened by wearing and compaction.

Due to the non-linear material properties of concrete, it is not surprising that the bond strength contributed by mechanical interlock which is provided by the wedging action of the ribs also increases ascending non-linearly. When enough concrete is crushed in front of the ribs, a wedge with a low incident angle, of about 30 to 40 degrees, exists and produces the inclined transverse cracks, and longitudinal cracks (Malvar, 1992).

2.3 The Comité Euro-International du Béton (CEB) Code Bond-Slip Model (1990)

This model was proposed by Ciampi et al. (1981). The following equations were developed to describe the ascending and descending branches of bond model which is shown in Figure 2.3.

$$\tau = \tau_{max}\left(\frac{s}{s_1}\right)^{\alpha} \quad \text{for} \quad 0 \le S \le S_1 \ldots\ldots(2.1)$$

$$\tau = \tau_{max} \quad \text{for} \quad S_1 \le S \le S_2 \ldots\ldots(2.2)$$

$$\tau = \tau_{max} - \left[\tau_{max} - \tau_f\right]\left(\frac{s-s_2}{s_3-s_2}\right) \quad \text{for} \quad S_2 \le S \le S_3 \ldots\ldots(2.3)$$

$$\tau = \tau_f \quad \text{for} \quad S > S_3 \ldots\ldots(2.4)$$

Where;

S_1= slip where bond stress become maximum

S_2= slip where maximum bond stress starts to descend

S_3= slip where the bond strength become frictional stress

τ_{max} = maximum bond stress

τ_f = frictional bond resistance

α is an empirical constant ($0 < \alpha < 1$) that describes the shape of the bond stress- slip curve.

The CEB Model Code states that the ascending branch refers to the stage where the ribs on the reinforcement penetrate into the mortar matrix, characterized by the local crushing and micro-cracking. Hence, in the ascending branch, the bond stress increases nonlinearly up to a point where the slip S is equal to S_1 (equation 2.1). The horizontal level between S_1 and S_2 occurs only for confined concrete, referring to advanced crushing and shearing off the concrete between the ribs (equation 2.2). During this stage, the bond stress is a constant maximum. The descending branch refers to the reduction of bond stress due to the splitting cracks along the bars (equation 2.3). The last horizontal part represents a residual bond capacity, which is maintained by minimum transverse reinforcement, keeping a certain degree of integrity intact (equation 2.4)

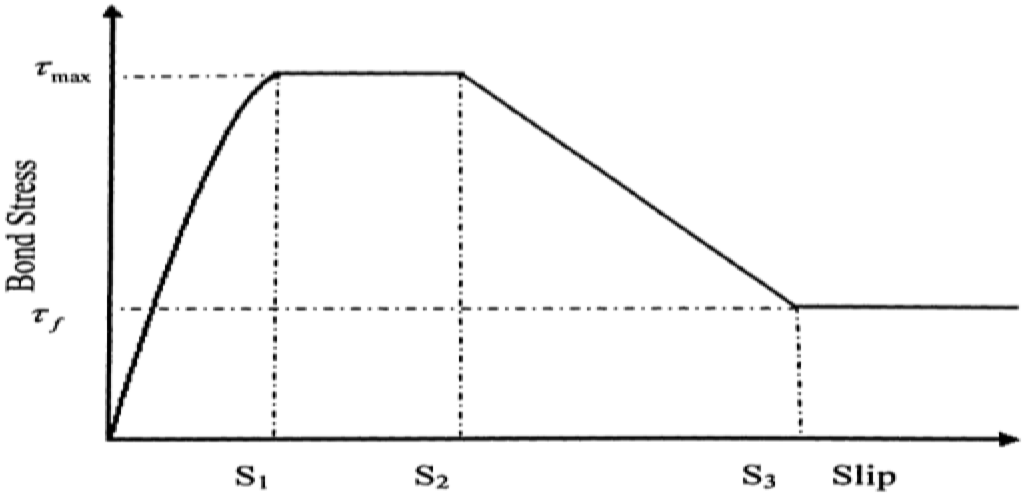

Figure 2-3 CEB bond model (The Comité Euro-International du Béton, 1990)

According to CEB Model Code MC90, the parameters in Equations 2.1 to 2.4 are given in table 2.1

Table 2-1 Parameters for defining the mean bond stress-slip relationship

Parameters	Unconfined concrete		Confined concrete	
	Good bond condition	All other bond condition	Good bond condition	All other bond condition
S_1	0.6mm	0.6mm	1.0mm	1.0mm
S_2	0.6mm	0.6mm	3.0mm	3.0mm
S_3	1.0mm	2.5mm	Clear rib spacing	Clear rib spacing
α	0.4	0.4	0.4	0.4
τ_{max}	$2.0(f_{ck})^{1/2}$	$1.0(f_{ck})^{1/2}$	$2.5(f_{ck})^{1/2}$	$1.25(f_{ck})^{1/2}$
τ_f	$0.15\tau_{max}$	$0.15\tau_{max}$	$0.4\tau_{max}$	$0.4\tau_{max}$

2.4 Harajli's bond stress-slip model

Harajli (2002) generated a monotonic envelope bond stress-slip relationship using regression analysis of test data. Using both the analytical model and experimental results, he proposed an equation for maximum bond stress and the corresponding slippage. Figure 2.4 shows the local bond stress and slip relationship for axially loaded concrete prisms reinforced with steel bars. The vertical axis U is the local bond stress and the horizontal axis is local slip distance. Local bond stress U is increasing in a descending rate instead of linear relationship with slip distance. Equation 2.5 shows the relationship between local bond stress and slip distance. The maximum bond stress U_{max} and the corresponding slip distance s_1 are defined in equation 2.6 and 2.7. The bond stress-slip relationship used are as follows

$U = U_{max}(\frac{s}{s_1})^{\alpha}$…………………………………………………………………….. (2.5)

$U_{max} = 31\sqrt{f_c'}(psi)$…………………………………………….…………..... (2.6)

$s_1 = 0.15c_o$…………………………………………….……………........ (2.7)

Where;

U_{max}=maximum bond stress

S_1=maximum slip distance

C_o=clear distance between concrete lugs

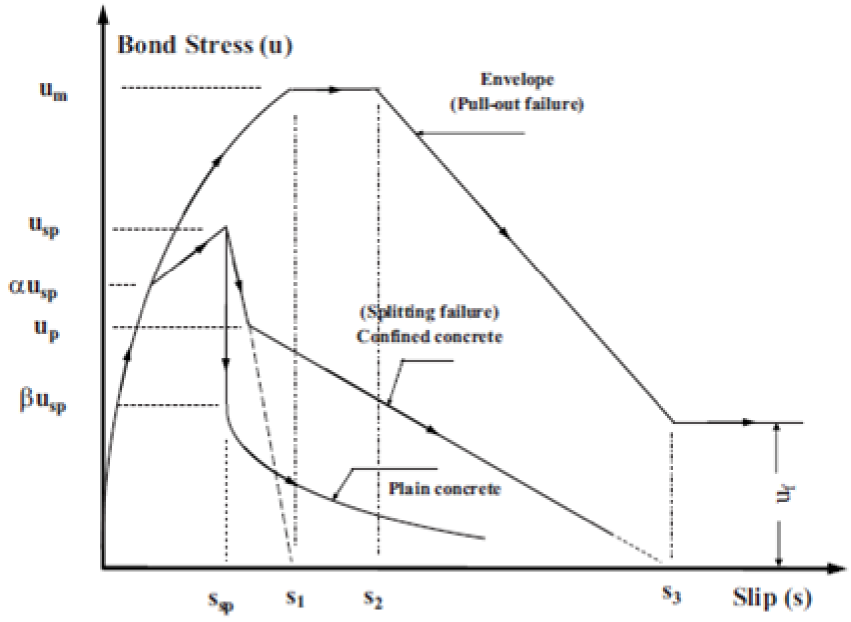

Figure 2-4 Monotonic envelope model (Harajli 2002)

2.5 Factors affecting bond strength

It has been well established in research studies that factors affecting the bond strength of deformed or ribbed bars includes the bar size and surface conditions, the depth of concrete cover, the spacing between embedded bars, the bonded length of the bar, the concrete strength, the confinement of the concrete (due to transverse reinforcement or FRP surrounding the bars), and the position of the bars when the concrete is cast (Rania Al-Hammoud 2012, ACI Committee 408, 2003).

2.5.1 Bonded length of the bar

The bond capacity increases with an increase in the bonded length. This increase is not proportional to the length due to the non-uniform nature of bond forces. For splice and pullout specimens, the loaded end of the bonded length transfers most of the bond forces to the concrete. The non-loaded or free end has little effect on the transfer of the bond force. When a splitting failure occurs, a crack develops at the surface of the concrete. The energy needed to initiate the crack increases with an increase of the bonded length but at a slower rate (ACI Committee 408, 2003).

2.5.2 Concrete cover and bar spacing

The larger the bar cover and spacing the better the bond strength until another failure mode is incited. If the bar cover and spacing is very large a pull-out failure or a failure by yielding of the bar can be expected, instead of the splitting failure that occurs when the cover and/or the bar spacing is small. Splitting cracks usually develop through the smallest cover. In most structures, if a bond failure develops, it would be due to splitting (ACI Committee 408, 2003).

2.5.3 Bar Size

The relationship between bar size and bond strength is not always valued. The reason is that, (1) a longer development or splice length is required as the size increases and (2) for a given development length larger bars achieve higher total bond force than smaller bars for the same degree of confinement. Addressing the second point first, for a given bonded length larger bars requires larger force to cause either a splitting or pullout failure. The result is that the total force developed at bond failure is not only an increasing function of concrete cover, bar spacing and bonded length, but also bar area (Orangum, Jirsa and Breen 1977; Darwin et al. 1992, 1996a). The bond force at failure however, increases more slowly than the bar area, which means that a longer embedment length is needed for a larger bar to fully develop a given bar stress (the first point). When evaluated in terms of bond stress smaller bars appear to have a greater advantage ; thus conventional wisdom suggest that it is desirable to use a larger number of small bar rather than small number of large bars; this is true until bar spacing are reduced to the point that bond strength are decreased(Ferguson 1977;Rehm and Eligehausen 1979). Therefore, it is preferable to use smaller size bars than larger bars having the same area (ACI Committee 408, 2003).

2.5.4 Concrete strength

The bond force between the steel bars and the concrete is dependent on the concrete tensile properties. The bond strength traditionally has been related to $(f'_c)^{1/2}$, where f'_c is the compressive strength of the concrete. This is due to the fact that the tensile strength of concrete is directly proportional to the square root of the concrete compressive strength. However, recent studies on bond strength have shown that relating the bond strength to $(f'_c)^{1/4}$ would give a better representation. This is because of the fact that the bond strength is dependent on the concrete fracture energy in addition to the concrete tensile strength (ACI Committee 408, 2003). Concrete cracks develop when the loading energy is greater than the concrete fracture energy. Those cracks would decrease the bond between the steel bars and the concrete. Therefore, the higher the fracture energy is, the higher the bond strength. In general, it has been found that as the concrete strength increases, the bond strength increases but at a lower rate (ACI Committee 408, 2003).

2.5.5 Amount of transverse confinement

Confinement in the form of transverse reinforcement, steel stirrups or fiber reinforced polymer (FRP) confines the concrete over the bonded length and hence obstructs the propagation of splitting cracks (ACI Committee 408, 2003; Hamad & Rteil, 2006). This causes an increase in the bond force between the steel bars and the concrete. As the area of transverse confinement increases, the confining force increases which may result in a pullout failure rather than splitting failure (ACI Committee 408, 2003).

2.6 Previous Investigations on Size Effect on Bond Strength

2.6.1 K. Ahmed et al.

From K. Ahmed et al. (2008) investigation Composite behavior of reinforced concrete require adequate bond between concrete and steel reinforcement that can transfer stresses between them. The bond strength is influenced by the cover to the reinforcement and development length. An experimental investigation was carried out and twisted steel bars conforming to BS 4461 were used in high strength concrete to study bond strength characteristics. The post-peak bond behavior was studied by using a displacement controlled universal testing machine. The results of this experimentation confirmed that by increasing the cover/bar diameter ratio, bond strength increased and slip decreased for both small and large diameter twisted steel bars. This increased confinement reduced the uneven bond stress distribution along the development length. Stress concentration on the front key (concrete between two ribs) was reduced due to its continuity along the twisted steel bar. Hence it offered maximum possible resistance to bond failure and the bond strength increased. Similarly, by increasing the development length, bond strength and corresponding slip both increased. Another fact visible from all figures and observed in all samples is that as the first concrete key failed there was a sudden drop in bond strength due to the formation of longitudinal splitting cracks. These cracks are visible from the surface of the cylinder. Once a key is failed, failure propagated immediately this immediate crack propagation is due to a brittle property of high strength concrete.

2.6.2 Ahmed M.Diab et al.

From Ahmed M.Diab et al. (2014) studies on Bond behavior and assessment of design ultimate bond stress of normal and high strength concrete, they done there study in two phases. The first phase included the studied bond behavior using two different models. In the first model, single pull-out test (SPOT), the concrete section of specimen was subjected to compressive stresses. In the second model, double pull-out test (DPOT), the concrete section of specimen was subjected to tensile stresses. So this phase of study aimed to make a comparison between the single pull-out test and the double pull-out test. To compare the behavior of these models, different levels of compressive strength were considered through the use of different coarse aggregate types, different water-cement ratios and different cement contents. The second phase focused on the study of bond strength of high strength concrete using double pull-out test to assess design ultimate bond stress. In this phase, the effect of concrete compressive strength, bar diameter, concrete cover, embedded length, and pre-flexural crack length was studied. Based on this test result the following factors affects the bond strength.

2.6.2.1 Effect of concrete cover

Results on effect of the concrete cover on ultimate tensile bond strength and ultimate slip shows that as the concrete cover decreases, the ultimate bond strength decreases, and the corresponding slip increases. As an example, when the concrete cover decreases from 67 to 42 mm the ultimate bond strength decreases by 4%, 8%, 12.5% and 19% for compressive strength of 30, 50, 70 and 90 MPa, respectively. This is in an agreement with Darwin et al. [20], and Zuo and Darwin [21]. This can be explained on the basis of the increase in confinement that offers more resistance to longitudinal cracks and reduces the uneven bond stress distribution along the embedded lengths. High strength concrete may require higher concrete cover.

2.6.2.2 Effect of bar diameter

From the result of effect of bar diameter on ultimate tensile bond strength and ultimate slip, It is shown that as the bar diameter increases, the bond strength decreases, and the corresponding slip increases. As an example, the ultimate tensile bond strength decreases by 10%, 6%, 6% and 5% when the bar diameter increases from 16 to 18 mm for concrete compressive strength 30, 50, 70 and 90 MPa, respectively. This is in an agreement with Kazim Turk and Alavi-Fard and Marzouk.

2.6.2.3 Effect of embedded length

The result of effect of embedded length on both ultimate tensile bond strength, and ultimate slip is shows that as the used embedded length increases, the ultimate bond strength increases, and the corresponding slip increase. When the development length increases from 5 bar diameter to 7.5 and 10 bar diameter the bond strength increases by 4.3% and 10.0%, respectively. This is in an agreement with Ahmed et al.

2.6.2.4 Effect of pre-flexural crack length

The effect of crack length on both ultimate tensile bond strength, and ultimate slip is that, as the crack length increases the ultimate tensile bond strength decreases, and the corresponding slip increases. The fully cracked specimen loses about 30% of its bond strength. The presence of cracks decreases the stiffness of concrete section, and makes the distribution of the bond stress non-uniform along the bar. This result may be due to the decrease in the bearing which leads to a reduction in bond strength.

2.6.3 T. Ichinose et al.

T. Ichinose et al. (2004) investigate the size-effect on bond strength between deformed bars and concrete by using a pullout and lap splice tests. The specimen parameters include bar diameter (up to 52 mm), rib shape, cover thickness, and the presence/absence of confining reinforcement. The experimental results show that: (a) pullout specimens with the smallest cover thickness exhibit the largest size-effect; (b) larger confinement by either cover concrete or steel reinforcement results in smaller size-effect, and; (c) the size-effect is mainly attributable to brittle splitting cracks, and not to local crushing of concrete in front of the bar ribs. Prevailing design equations for lap splice strength are modified to better account for the size-effects observed in the experiments. The equations yield a large size- effect for splices with small cover and short splice length, where brittle failure is expected. On the other hand, the equations yield a small size-effect for splices with low rib-height bars and many stirrups, where ductile failure is expected. The proposed equations agree with both the experimental results presented in this study and the bulk of the experimental data reported in the literature.

From the above-reviewed literature, we can see the effect of concrete cover, embedment length, bar size separately on bond strength of reinforced concrete. As a research gap, this paper addresses how bond strength is affected by the size of specimen by increasing the above parameters by constant scaling factor. Also this paper studies on effect aggregate size on bond strength of concrete

CHAPTER THREE

3. EXPERMENTAL PROGRAM

3.1 Introduction

The main goal of this study is to find out the effect of the specimen and aggregate size on bond strength of concrete. During the experimental study, different concrete specimens with different aggregate size were tested by using transfer bond test method by applying tension force on both sides of the bar.

3.2 Specimens design

A total of nine test specimens were tested on concrete prism with embedded steel bar.

The specimen embedment length design for bond test is based on the requirement of ACI 408-03 recommendation. Recommendation of ACI 408-03 for embedment length is

$$L_d = 0.019\frac{A_b f_y}{\sqrt{f_c{}'}} \qquad (3.1)$$

And minimum unbonded edge distance to resist the end effect of $6d_b$. this partial debonding was achieved by cutting a PVC tube, slightly larger in diameter than the rebar, to a specified length and either taping or gluing it to the rebar prior to casting as shown in the Figure 3.1.

So total length (height) of the specimen is

$$h_d = l_d + 2 * 6d_b \qquad (3.2)$$

Where $2 * 6d_b$ is for debonding at the two ends by PVC

By using this equation the length of specimens for bar diameter 10mm, 12mm and 14mm are h_{10}=31cm, h_{12}=40cm and h_{14}=50cm respectively. The detail of specimen matrix is shown on Table 3.4.

The specimen cross-section design is as per the recommendation of CEP-FIP (1978), the effective concrete surrounding the embedded reinforcement should be a minimum diameter of 7.5D_{bar}. By using this recommendation the following concrete section are used to embed the bar

For bar diameter of 10mm

10cm by 10cm of concrete to embed the bar

For bar diameter of 12mm

12cm by 12cm of concrete to embed the bar

For bar diameter of 14mm

14cm by 14cm of concrete to embed the bar

Figure 3-1 Unbonded length of bar by PVC

3.3 Specification of aggregate size

Three types of aggregate size (maximum aggregate size of 9.5, 25, and 37.5mm) were used to analyze the effect of aggregate size on bond strength. For casting concrete specimens, ordinary Portland cement (OPC), Course aggregate, fine aggregate and fresh water were used. Before the beginning of casting, sieve analysis was done.

3.4 Specification of concrete

The mechanical properties of the concrete are shown in table 3.2. It's compressive and tensile strength is obtained by making trail mix as ACI 211.1-91 and Abebe Dinku 2002 recommendation.

Testing of hardened concrete, in order to determine its compressive and tensile strength is one of the most important and necessary experiments performed widely nowadays. One of the usual methods of the experiments is casting concrete samples and crushing them in the laboratory, by using the relevant testing machine.

Three types of trial specimens are utilized for cube and tensile test of hardened concrete with 9.5, 25 and 37.5 maximum aggregate size. Six cylinders of diameter 150mm and depth of 300mm for splitting tensile strength test and six cubes of 150mmx150mm fore compressive strength test were casted with the specimen for each category of aggregate sizes. Three of them were tested at 7th day and three of them were tested at test date. The mix design for producing target C-25 concrete were performed with a great concern and the detail is just attached on the annex of this document.

Figure 3-2 cubes for trial mix

Figure 3-3 slump test

Figure 3-4 Compressive and tensile strength testing machine for concrete

Table 3-1 Trial-1 mix design

Material	Aggregate size 1 (AG1)	Aggregate size 2 (AG2)	Aggregate size 3 (AG3)
Max aggregate size	9.5mm	25mm	37.5mm
Free water(kg/m^3)	217.184	180.734	168.71
Cement content(kg/m^3)	472.13	316.39	296.72
Coarse aggregate (kg/m^3)	904.5	1122.92	1189.71
fine aggregate (kg/m^3)	675.37	747.687	743.03
Water cement ratio	0.462	0.57	0.56

Table 3-2 cubic compressive and tensile strength of concrete on test date

Trial No	Aggregate size 1 (AG1)		Aggregate size 2 (AG2)		Aggregate size 3 (AG3)	
	Compressive strength(MPa)	Tensile strength(MPa)	Compressive strength(MPa)	Tensile strength(MPa)	Compressive strength(MPa)	Tensile strength(MPa)
Trial 1	24.5	2.00	25.15	2.08	25.0	2.05
Trial 2	24.15	1.87	24.9	2.00	23.9	1.89
Trial 3	25.3	2.05	24.3	1.89	24.8	2.02
Average	24.65	1.97	24.78	1.99	24.56	1.98

3.5 Specification of rebar

Bars with a nominal diameter of 10, 12 and 14mm are used in this study. Table 3.3 shows the sizes and mechanical properties of rebar.

Table 3-3 mechanical properties of rebar

Diameter (mm)	Yield strength(f_y) (MPa)	Ultimate strength(f_u) (MPa)	Elongation (%)
Φ_{10}	524.7	718.52	18.67
Φ_{12}	518.03	681.2	19.33
Φ_{14}	508.4	664.33	22.16

3.6 Description of specimens

From specimen size design on section 3.2, the following table (table 3.4) shows the specimen geometry matrix of the specimen

Table 3-4 Specimen geometry matrix

	Φ_{10}	Φ_{12}	Φ_{14}
Aggregate size of 9.5 mm	Cross-section of 10*10cm with H=31cm	Cross-section of 12*12cm with H=40cm	Cross-section of 14*14cm with H=50cm
Aggregate size of 25mm	Cross-section of 10*10cm with H=31cm	Cross-section of 12*12cm with H=40cm	Cross-section of 14*14cm with H=50cm
Aggregate size of 37.5mm	Cross-section of 10*10cm with H=31cm	Cross-section of 12*12cm with H=40cm	Cross-section of 14*14cm with H=50cm

3.7 Test setup

This section describes the types of testing equipment and instrumentation used with each series.

3.7.1 Axial tensile test set-up and procedure

As mentioned earlier, the purpose of this study is to investigate the effect of specimen and aggregate size on bond strength of reinforced concrete structure by applying a monotonic axial tensile load on bar that is embedded by concrete. The prism specimen is prepared as shown in the above table 3.4 and Specimen details are presented in Fig. 3.5.

Steel bars were placed in a horizontal position within the molds before casting and each bar normally extended on both sides of the mold as shown in Fig 3.6. Before the experiment, specimens were painted in white to make any micro crack, slip behavior or crack propagation visible to the naked eye as shown in Fig 3.7.

The test setup and specimen details are given in Fig. 3.8. Axial elongation was measured by transducers which are positioned at the right and left sides of the specimen, the average displacement from the two transducers were taken as specimen elongation. When the axial tension load is applied by the machine, displacements were collected by a data-logger from the two transducers and the axial load is taken from the machine screen.

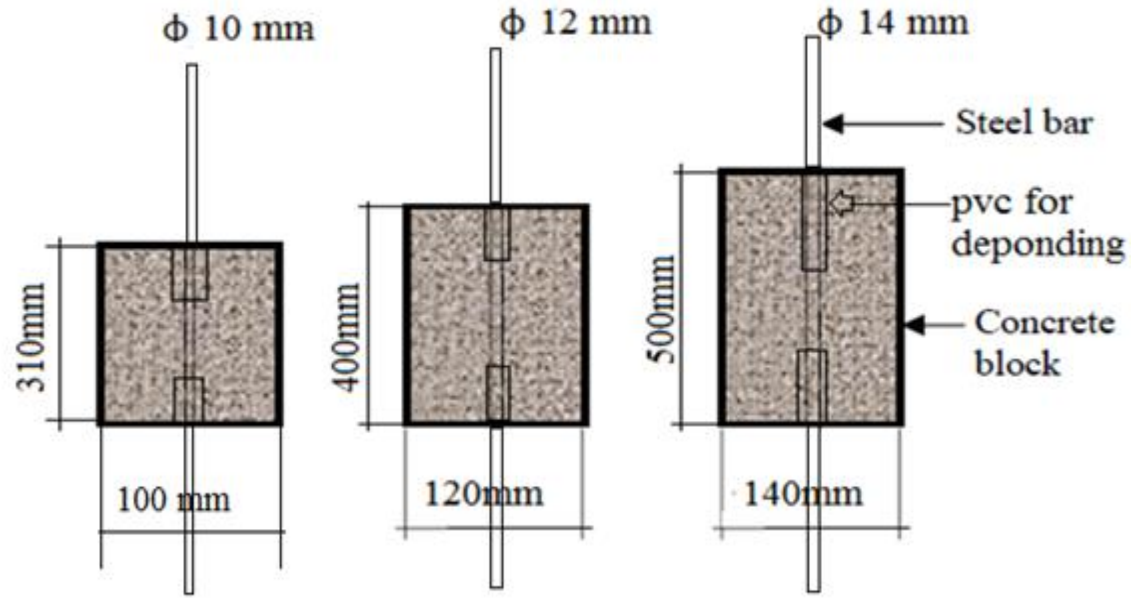

Figure 3-5 specimens detail

Figure 3-6 prepared mold for casting concrete

Figure 3-7 painted specimens that are ready for a test

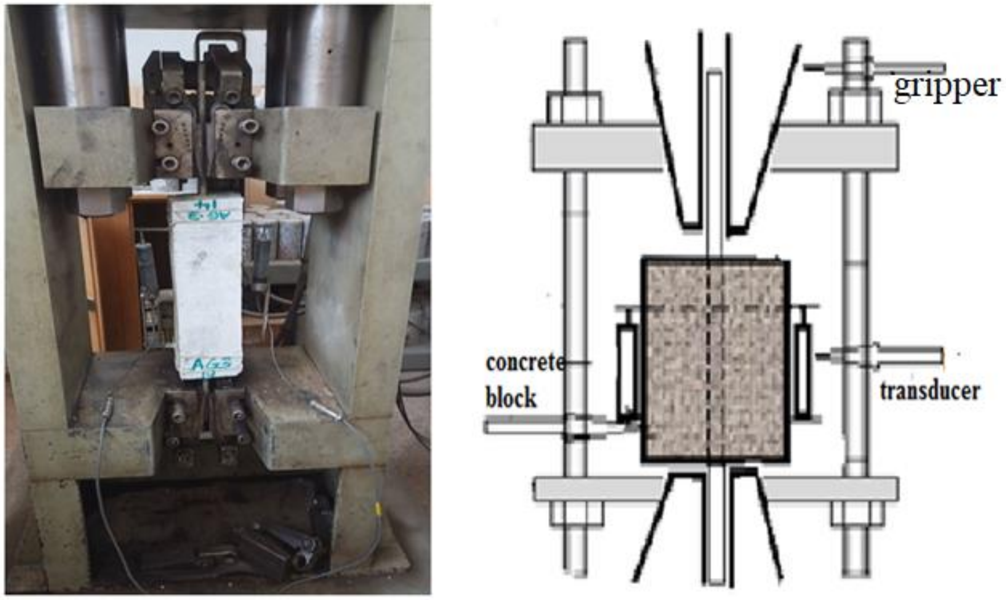

Figure 3-8 test setup and specimen detail

CHAPTER FOUR

4. TEST RESULT AND DISCUSSION

4.1 Test Result

The test was conducted by a 1000kN tensile load capacity of Universal Testing Machine (UTM) which applies a tensile axial load to the embedded bar by gripping the two end of the bar. The magnitude of load applied was displayed on the machine screen. In this study, an increasing tensile stress was applied to the prism until the steel yield because this paper was done by using the elastic analysis method. For the case of maximum stress in the concrete reaches the tensile stress limit before the steel yields, crack was happened on the prisms and equivalent stiffness of the prism was decreased.

The prism is initially assumed to be uncracked and under a uniform strain ε_{comp} corresponding to a total axial force P_T causing a stress f_c in the concrete and f_s in the steel. A uniform strain is considered to be under plane stress with area of concrete A_c and area of steel A_s.

As the load P is increased, the tensile stress in the concrete transferred from the steel due to bond action increases until the maximum tensile stress of the concrete is reached f_t, if it reaches its tensile stress limit f_t the concrete will start to crack. The composite prism strain(ε_{comp})at any cross section is uniform until the first crack was happened (Yun Lin 2010). While increasing the applied load, the tensile stress in the steel will reach its yield strength and the tensile stress of concrete will eventually reach the tensile stress limit f_t.

The total applied load carried by the concrete plus the steel is;

$$P_T = P_c + P_s = \sigma_c A_c + \sigma_s A_s = E_c \varepsilon_c A_c + E_s \varepsilon_s A_s \qquad (4.1)$$

Since we have uniform average strain before the concrete cracks, we can assume that $\varepsilon_{comp} = \varepsilon_c = \varepsilon_s$ until the first crack on the concrete was happened.

The average elongation from the transducers is changed to the average strain of the prism (ε_{comp}) by the formula

$$\varepsilon_{comp} = \frac{average\ elongation\ from\ transducer}{embedmentlenght} = \frac{\Delta}{L_d} \text{..................................} \quad (4.2)$$

Since we get strain by the above method, using the modulus of elasticity of concrete and steel we can get individual load carried by concrete (P_c) and steel (P_s).

Test result shows that the stiffness of the bare bar was increased by the embedded concrete as shown on the figure 4.1 to figure 4.8 by decreasing the strain for a given load capacity. But for the case of specimen AG314 since the concrete is cracked before the steel yields, the stiffness of specimen from the concrete decreases to its bare bar stiffness as shown in the figure 4.10.

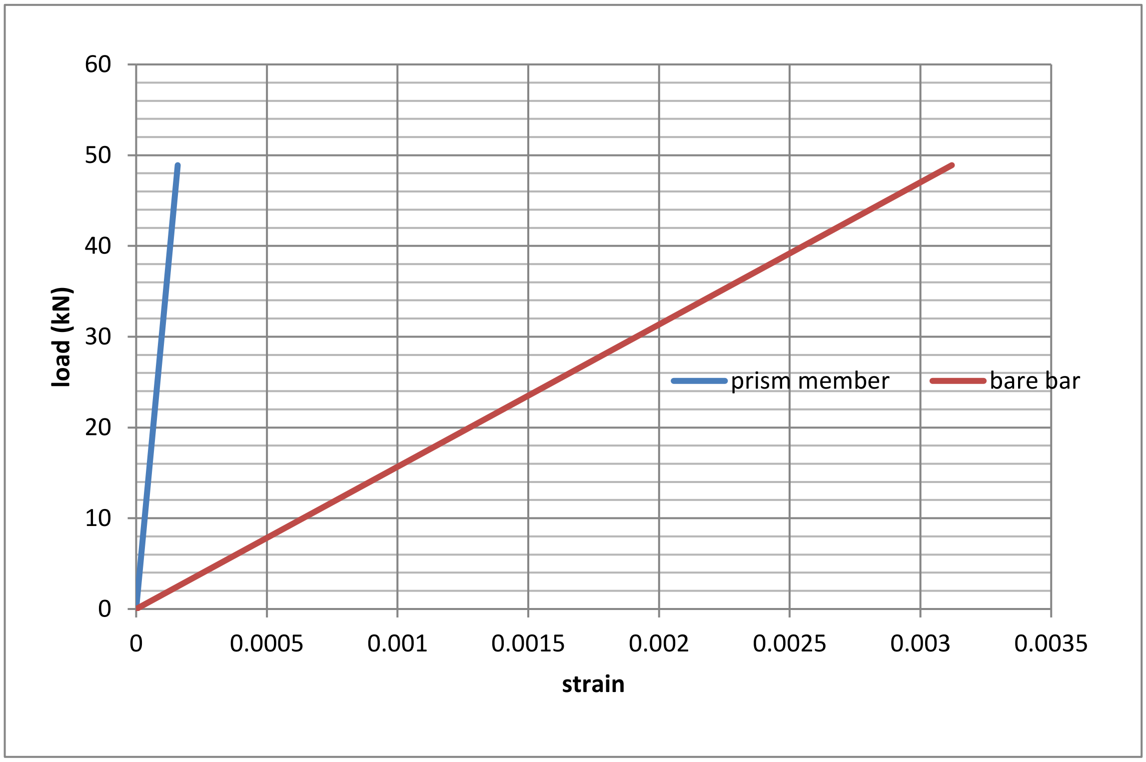

Figure 4-1 Total loads vs strain chart of bare bar and prism member of specimen-1 (AG1 10)

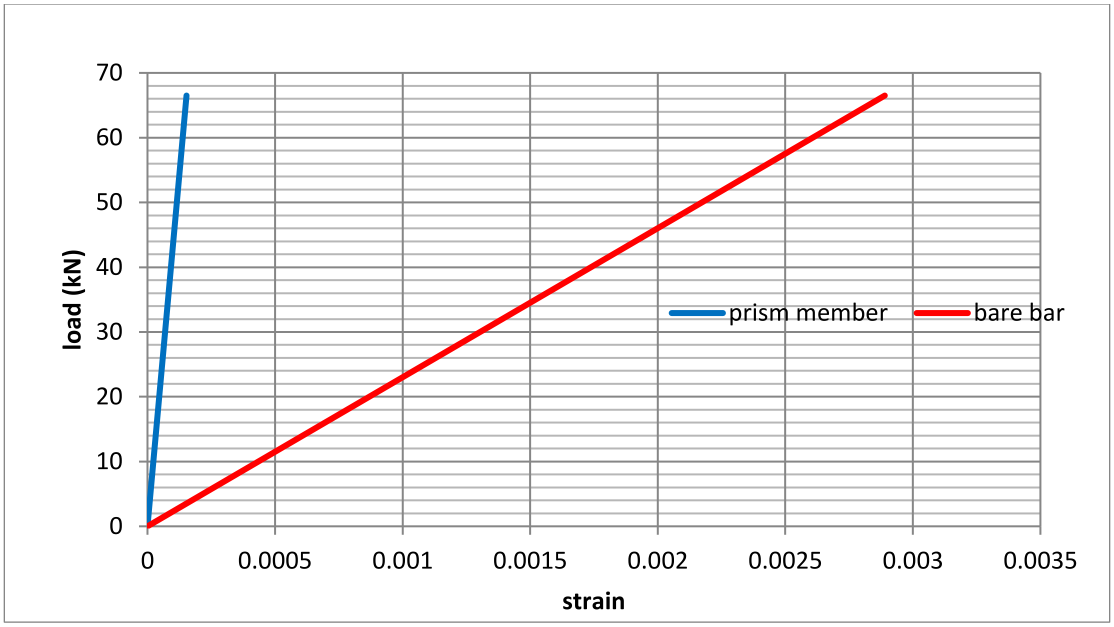

Figure 4-2 Total loads vs strain chart of bare bar and prism member of specimen-2 (AG1 12)

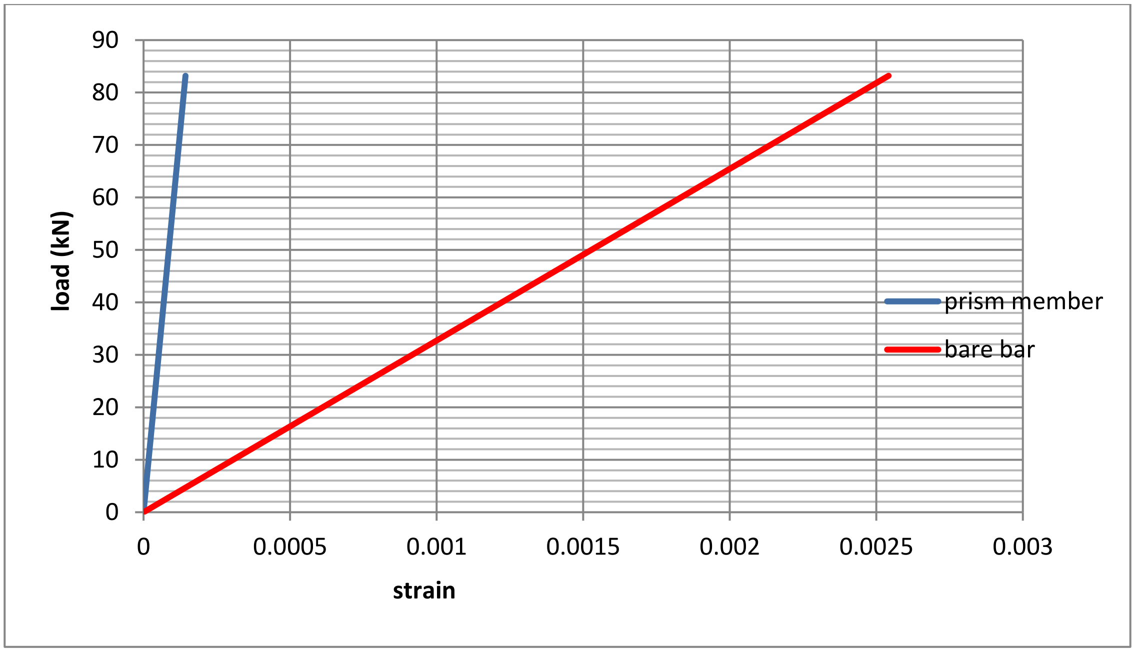

Figure 4-3 Total loads vs strain chart of bare bar and prism member of specimen-3 (AG1 14)

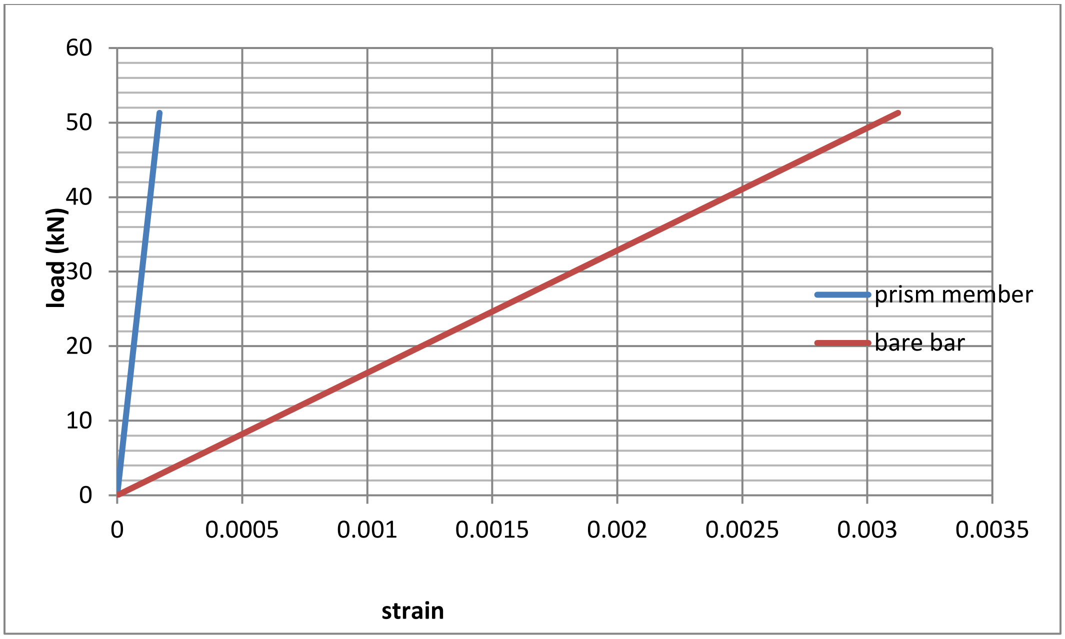

Figure 4-4 Total loads vs strain chart of bare bar and prism member of specimen-4 (AG2 10)

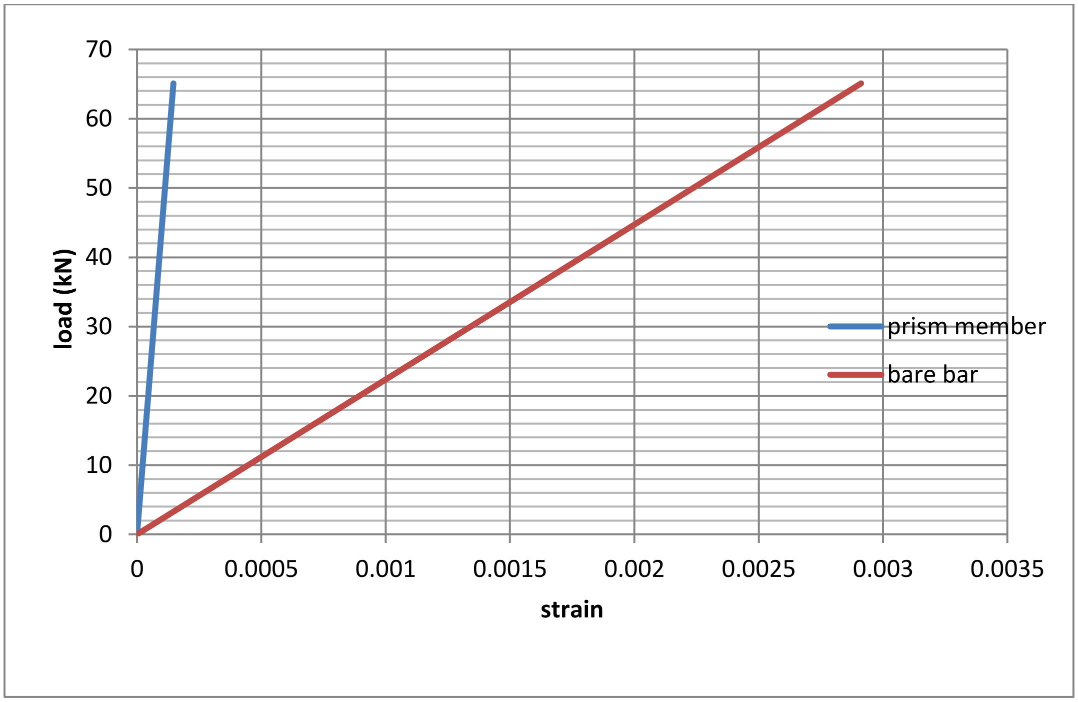

Figure 4-5 Total loads vs strain chart of bare bar and prism member of specimen-5 (AG2 12)

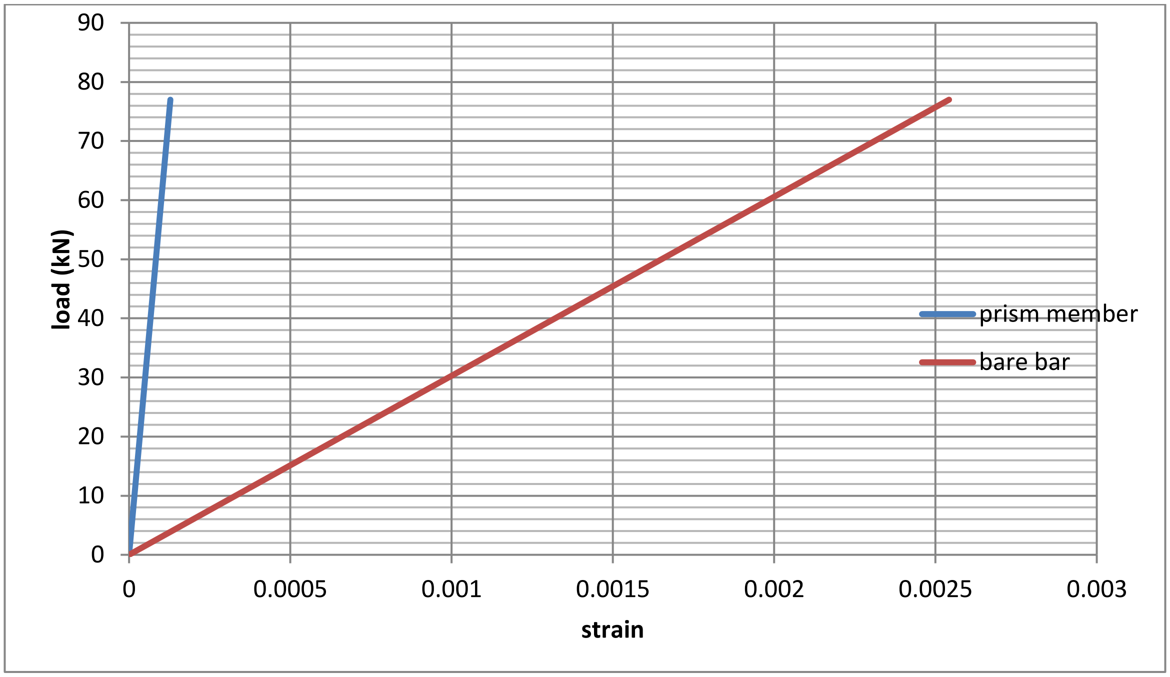

Figure 4-6 Total loads vs strain chart of bare bar and prism member of specimen-6 (AG2 14)

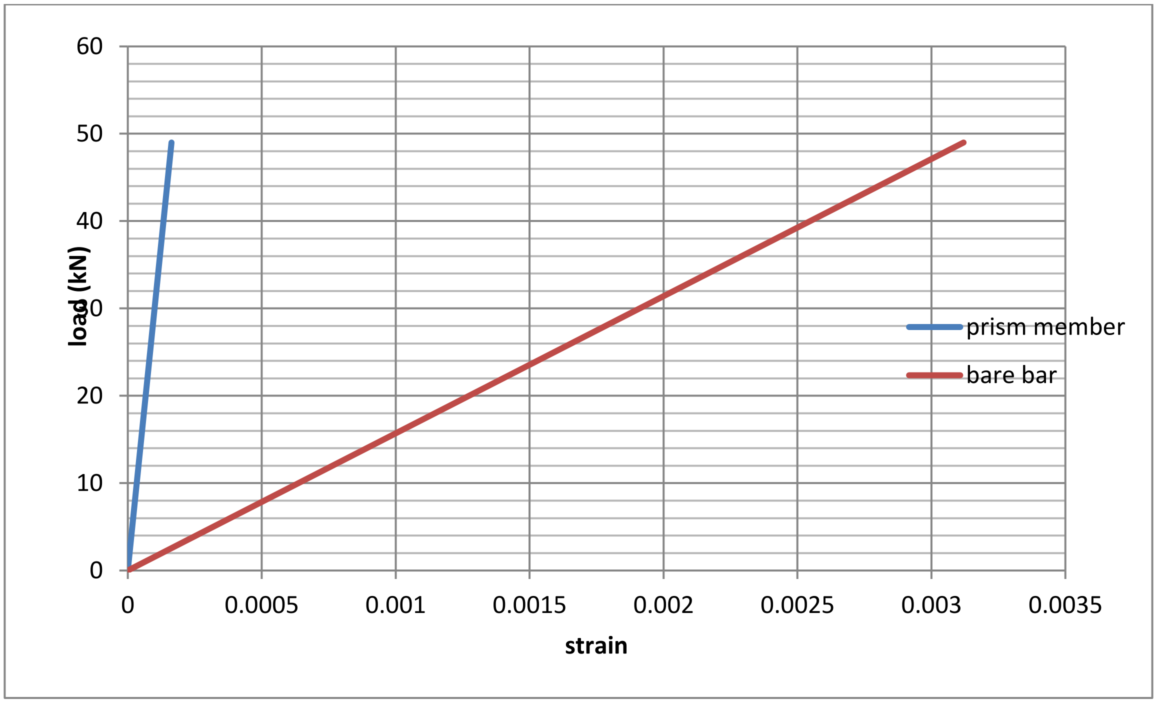

Figure 4-7 Total loads vs strain chart of bare bar and prism member of specimen-7 (AG3 10)

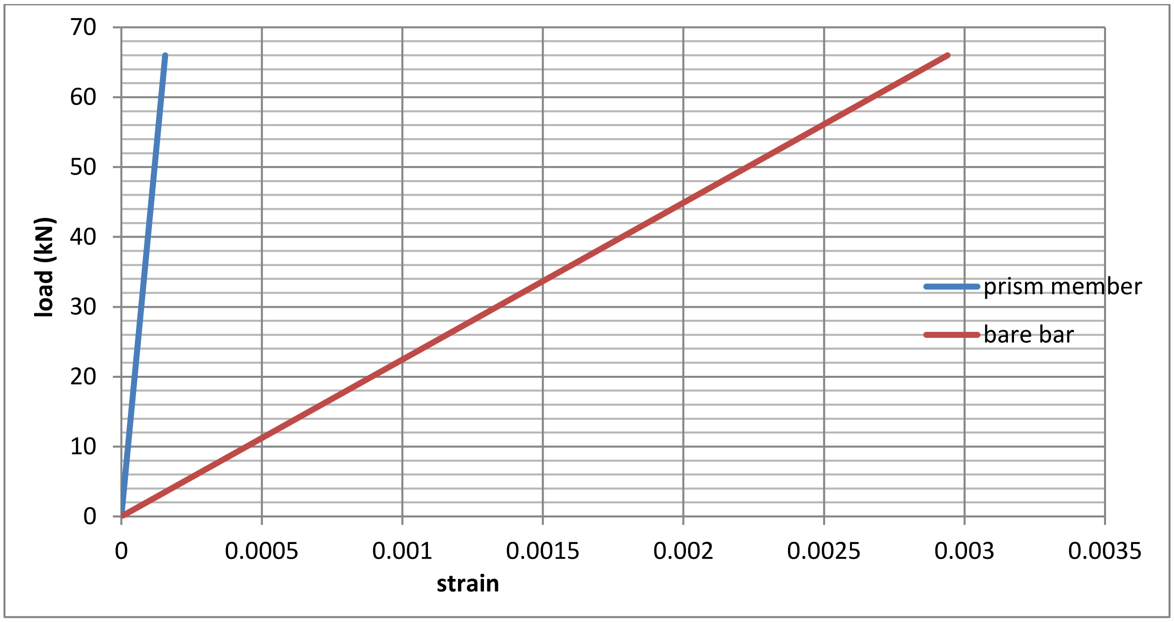

Figure 4-8 Total loads vs strain chart of bare bar and prism member of specimen-8 (AG3 12)

The only specimen which the concrete crack before the steel yields is specimen 9 (AG314). Since this paper analyzes until the steel yields and in case of this specimen the concrete is cracked before the steel yields so concrete modulus of elasticity is decreased after crack that means its tensile strength was decreased. For modeling of such type of post-cracking member response it is to account for the tensile contribution of concrete between cracks with an average stress-strain response for the cracked concrete (refer Figure 4.9).

This gives a concrete tensile response with a descending branch after cracking and is equivalent to assuming the concrete has a reduced effective modulus of elasticity (Ec) that depends on the level of strain in the member. Results from tests of (Bischoff and Paixao, 2004) show that the post-cracking tensile strength of concrete is modeled reasonably as follows

$$f_c = \beta_c f_{cr} \ldots\ldots (4.3)$$

$$\beta_c = e^{-1100(\varepsilon_{cm}-\varepsilon_{cr})(\frac{E_b}{200})} \ldots\ldots (4.4)$$

Where;

f_c=post-crack tensile strength of concrete

f_{cr}=pre-crack tensile strength of concrete

ε_{cm}=post-crack strain of concrete

ε_{cr}=pre-crack strain of concrete

E_b=Elastic modulus of bar in GPa

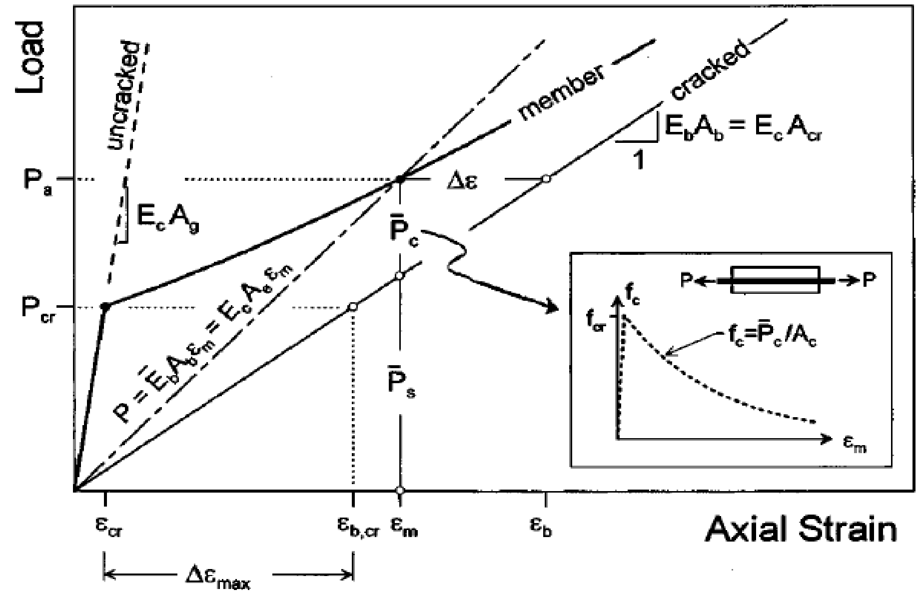

Figure 4-9 tensile member response (15)

By using Bischoff and Paixao model we can find the tensile strength of the concrete after crack but due to decrease in the tensile strength of the embedded concrete the total load carrying capacity of the specimen was decreased. The tensile strength and stiffness is diminished at the cracked sections. However, at the section between successive cracks, some tensile stress is restrained in the concrete around steel bar due to the action bond, contributing to axial stiffness of the member and this additional tensile strength is from tension stiffening effect of the concrete. This is the only specimen that we see the tension stiffening effect.

The load versus strain chart of this specimen is compared with the load versus strain chart of the bare bar on Figure 4.10 and it shows that the concrete that embeds the bar increases the stiffness until concrete cracks and then the tensile response of concrete is descending from prism member stiffness approaching to bare bar stiffness.

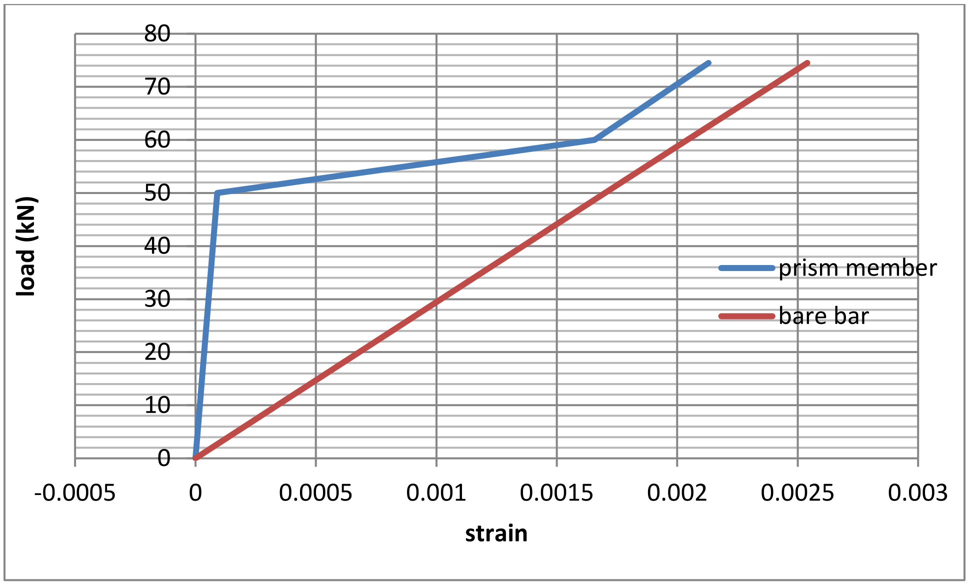

Figure 4-10 Total loads vs strain chart for bare bar and prism member of specimen-9 (AG3 14)

4.2 Discussion on the results

When we embed the bar by concrete the member becomes stiffer than a bare bar and this stiffness is comes from the embedded concrete. The above test results of the specimens show that the stiffness of the bare bar was increased by the embedded concrete above 90%.

The following charts (Figure 4.11 to Figure 4.13) shows that as specimen size increases the stiffness of the member from the embedded concrete also increases. That means as the size of concrete that embed the bar increases it makes the bar stiffer. As the specimen size increases the maximum strain of the member decreases and the maximum load carried by the concrete increase.

This decrease in maximum strain for a given load makes the member stiffer and has brittle behavior that is why the test shows transvers/horizontal cracks as the specimen size increases see table 4.1. Increasing of specimen size makes the member to fail by the horizontal crack formation around mid-height of the member as shown in Figure 4.14. But as the specimen size decreases the failure type become bar failure, concrete never cracks but the steel fails outside of the embedment length as shown in Figure 4.15.

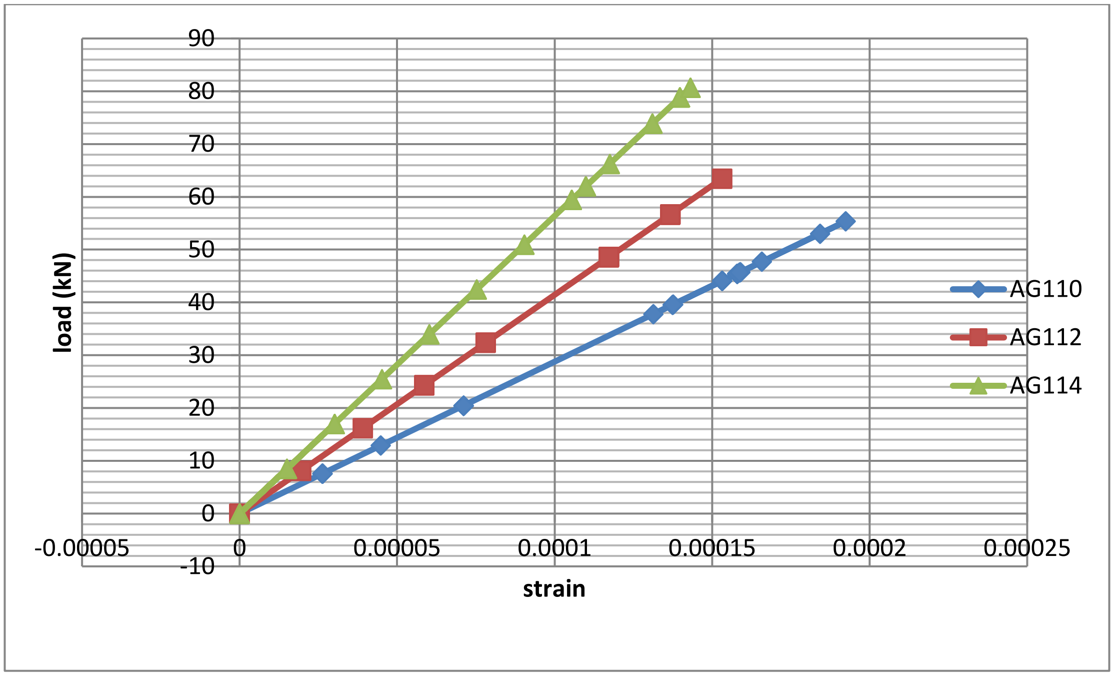

Figure 4-11 concrete load vs strain for fixed aggregate size (AG1) by varying specimen size 10cm*10cm, 12cm*12cm, 14cm*14cm

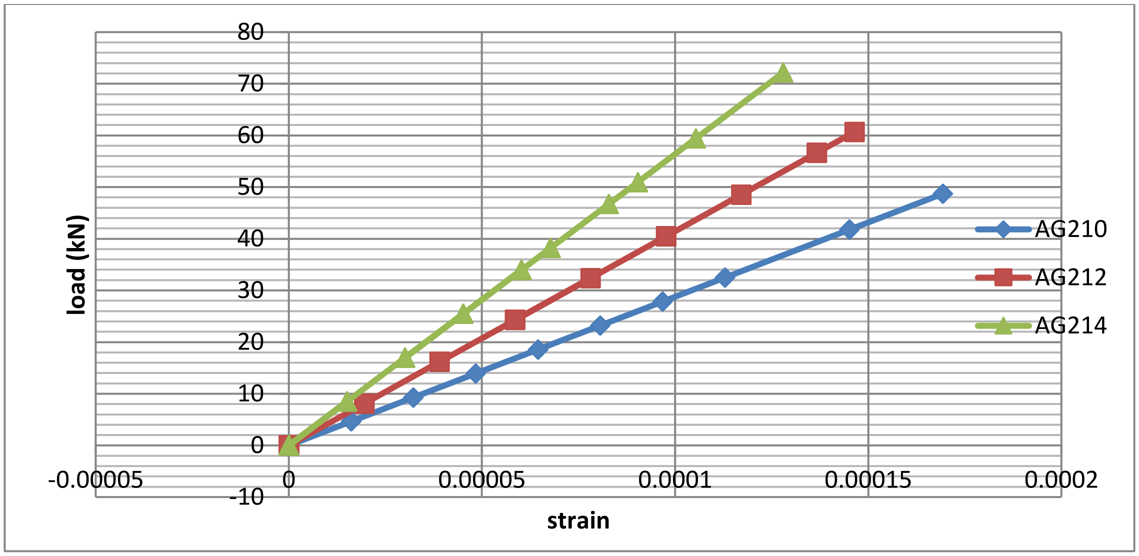

Figure 4-12 concrete load vs strain for fixed aggregate size (AG2) by varying specimen size 10cm*10cm, 12cm*12cm, 14cm*14cm

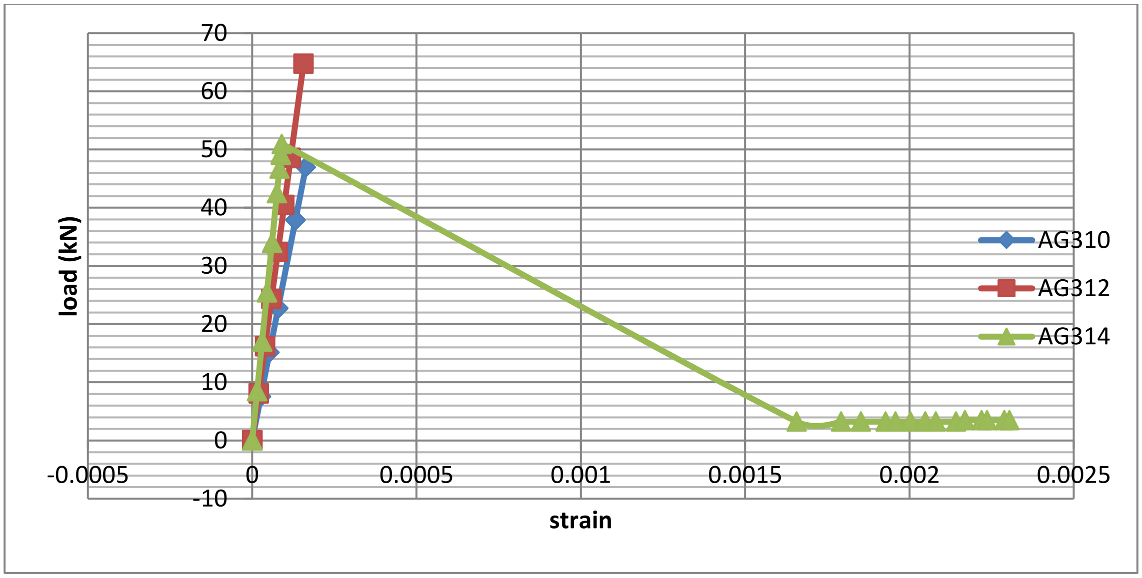

Figure 4-13 concrete load vs strain for fixed aggregate size (AG3) by varying specimen size 10cm*10cm, 12cm*12cm, 14cm*14cm

Table 4-1 Failure load for each type of specimen

	Φ_{10}	Φ_{12}	Φ_{14}
AG1(aggregate size of 9.5mm)	Steel yield by 40.9kN but concrete not cracked	Steel yield by 57.5kN but concrete not cracked	Steel yield by 79.2kN but concrete not cracked
AG2(aggregate size of 25mm)	Steel yield by 41.1kN but concrete not cracked	Steel yield and concrete cracked at the same time by 58.1kN	Steel yield and concrete cracked at the same time by 77kN
AG3(aggregate size of 37.5mm)	Steel yield by 40kN but concrete not cracked	Steel yield and concrete cracked at the same time by 58.6kN	Concrete cracked first by 50kN and then steel yields by 78.5kN

Figure 4-14 failure type for high specimen sizes

Figure 4-15 failure type for small specimen sizes

4.2.1 Effect of specimen size on average bond strength

Since the main objective of this paper is to know how bond strength between steel and concrete is affected by specimen and aggregate size. Tensile forces applied to the reinforcement are transferred into concrete by bond action therefore, cracking of concrete around the reinforcement significantly dependent on the bond properties of the applied reinforcement. Thus, stiffness and deformation behavior of reinforced concrete members are directly influenced by the bond properties. This paper investigates the effect of specimen and aggregate size on average bond strength between steel and concrete. Experimental average bond stress (τ) is calculated as follows by driving the formula for half-length of embedded bar.

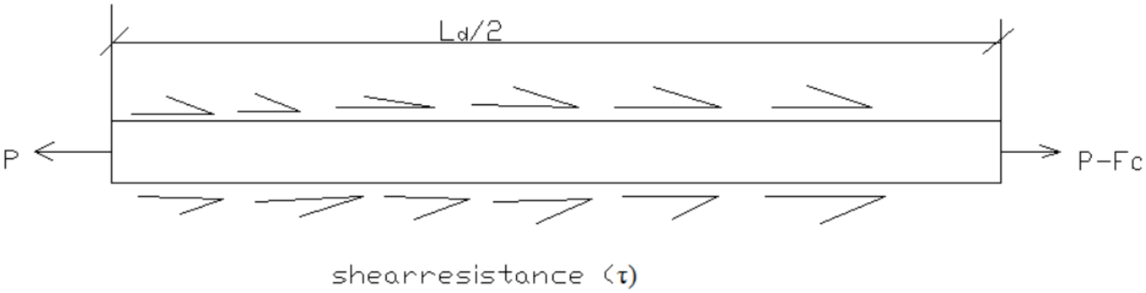

Figure 4-16 free body diagram of embedded bar up to half length

$$p_t = (p_{t-}p_c) + \tau A_s \ldots\ldots \quad (4.5)$$

From this above equation $p_c = \tau A_s \quad \leftrightarrow \quad \tau = \frac{p_c}{A_s}$

Where; A_s Is surface area of reinforcement i.e $A_s = \frac{\pi d l_s}{2}$, from this average bond stress becomes

$$\tau = \frac{2p_c}{\pi d_b L_s} \ldots\ldots \quad (4.6)$$

Where;

τ = average bond stress (MPa)

Pc = tensile concrete load (kN)

P_t = specimen total load (kN)

d_b= bar diameter (mm)

L_s= embedment length (mm)

Figure 4.17 to Figure 4.19 shows that as the specimen size increases the average bond strength between steel and concrete decreases, since increasing of specimen size in this study means scaling up of all dimensions of the member including bar diameter, concrete cover and embedment length by constant scaling factor by controlling all other variables. The result shows that increasing of specimen size decreases average bond stress and increases elongation which means the steel yields or concrete cracks by low bond force with higher elongation behavior as the specimen size increases. Since the yield strength of all bars are almost the same, decreasing of specimen size makes the bar to yield before the concrete cracks. The scope of this study is up to the steel yield so, the reading are taken up to this point. Increasing of specimen size decrease the average bond strength and increase maximum elongation but this maximum elongation for small size specimens are not their peak value because the concrete is not cracked they can elongate more than this but the steel yields before.

This attainment of maximum elongation and cracking of concrete early as the size increase is due to brittleness behavior of the specimen when it comes bigger and this agrees with size effect law of Z. P. Bazant. But there is special case for AG314 due to concrete cracks before the steel yields, it shows decreasing of maximum elongation and this is due to brittleness effect which is shown in figure 4.19.

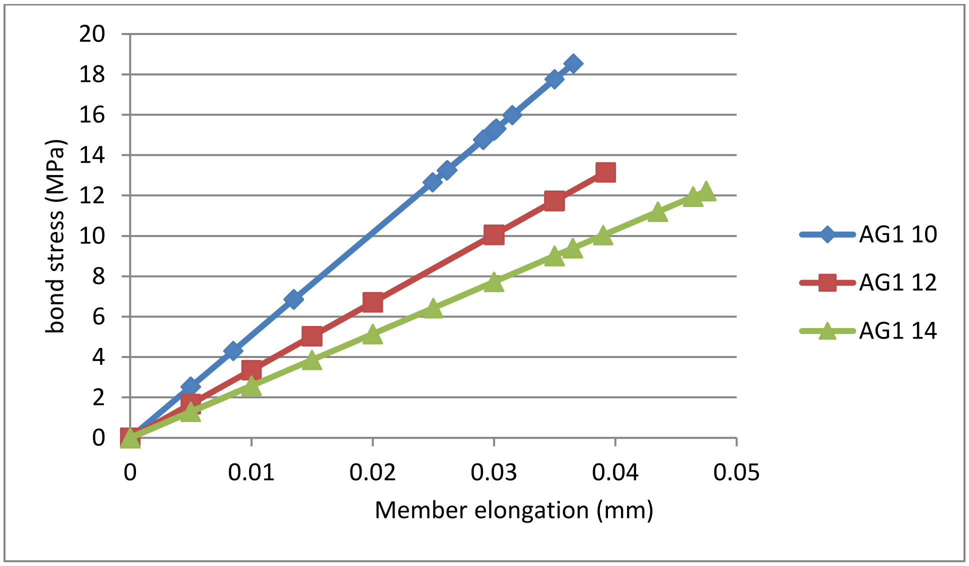

Figure 4-17 average bond stress vs elongation for 9.5mm aggregate size by varying specimen size 10cm*10cm, 12cm*12cm, 14cm*14cm

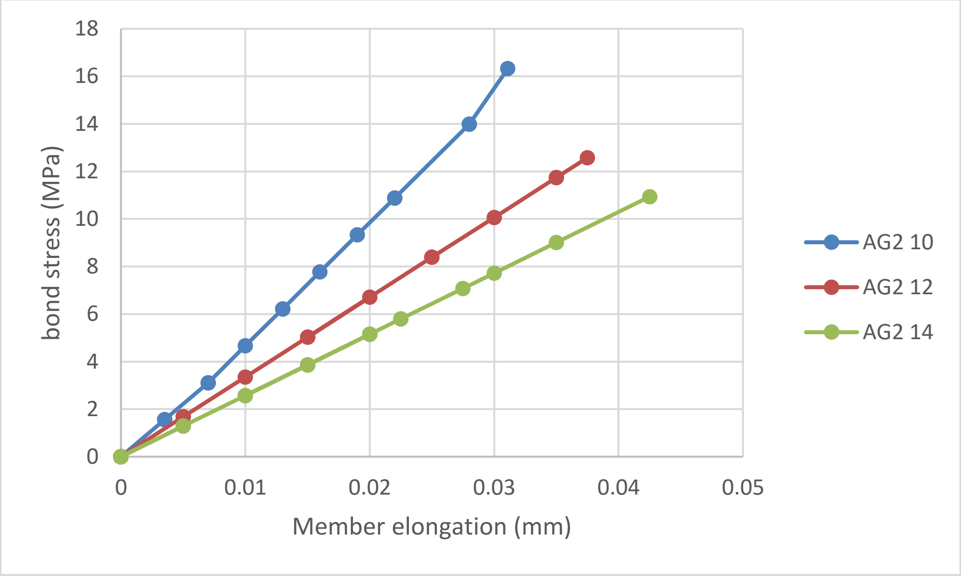

Figure 4-18 average bond stress vs elongation for 25mm aggregate size by varying specimen size 10cm*10cm, 12cm*12cm, 14cm*14cm

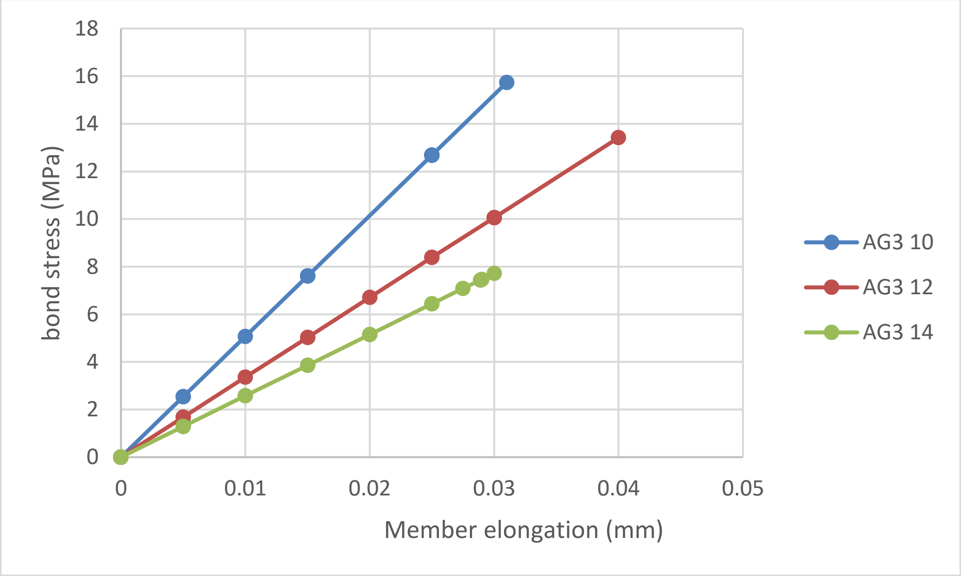

Figure 4-19 average bond stress vs elongation for 37.5mm aggregate size by varying specimen size 10cm*10cm, 12cm*12cm, 14cm*14cm

4.2.2 Effect of aggregate size

The effect of aggregate size on average bond strength are shown on the following charts (Figure 4.20 to Figure 4.22), for each fixed cross-section of 10cm*10cm, 12cm*12cm and 14cm*14cm with varying aggregate from AG1(aggregate size of 9.5mm) to AG3(aggregate size of 37.5mm). The average bond strength for a given elongation is constant but the maximum average bond strength and elongation decreases as the aggregate size increases, this is due to decreasing of number of aggregate and volume of paste for a given cross-section by increasing the aggregate size only. As the volume of paste decreases the bond between aggregates itself and aggregate with steel will decreases and this makes to decrease the maximum average bond strength of concrete. Increasing of aggregate size also makes that the crack line short to reach the outer surface of the specimen so, the specimen cracks early as the aggregate size increases which means the maximum average bond strength will decreases.

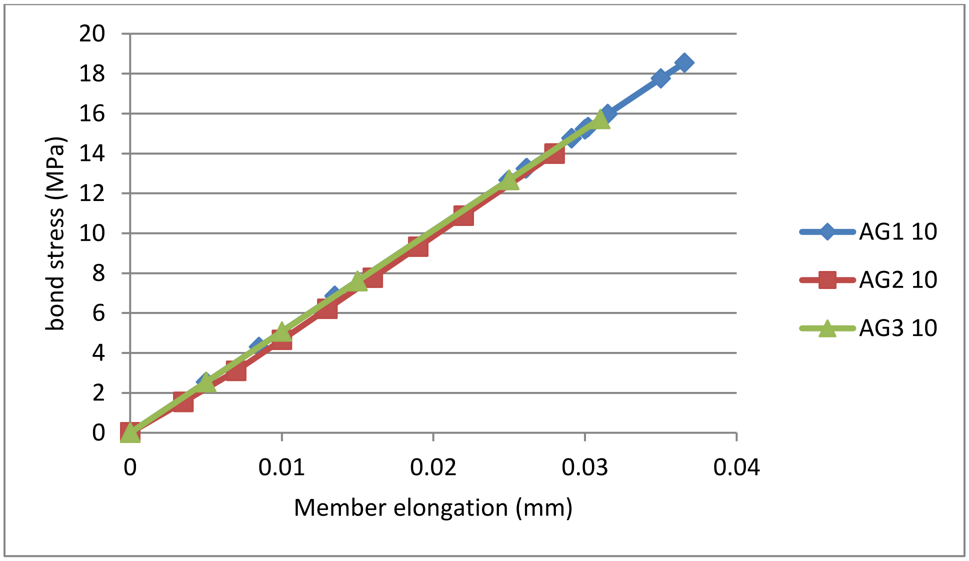

Figure 4-20 average bond stress vs elongation for a cross-section of 10cm*10cm with varying aggregate size from AG1 (9.5mm) to AG3 (37.5mm)

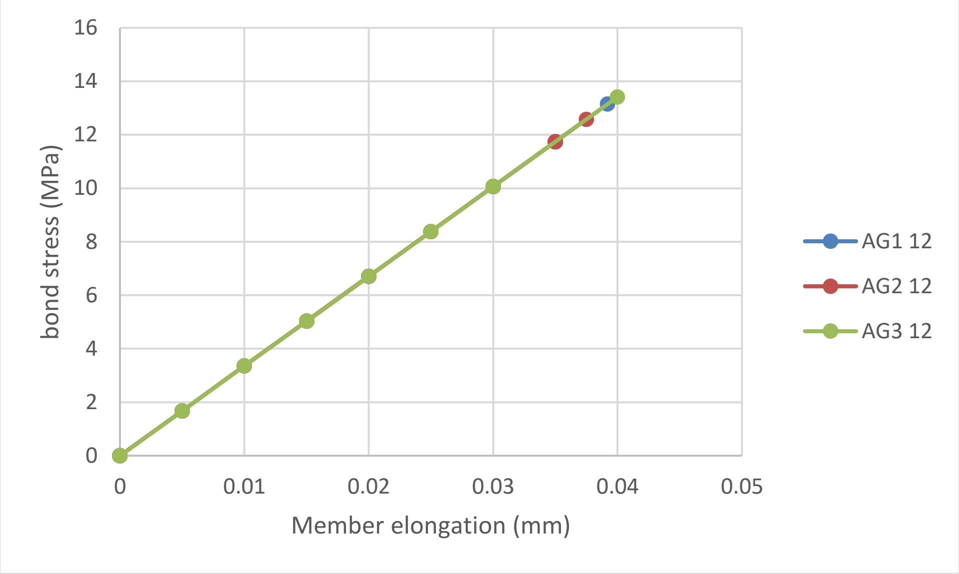

Figure 4-21 average bond stress vs elongation for a cross-section of 12cm*12cm with varying aggregate size from AG1 (9.5mm) to AG3 (37.5mm)

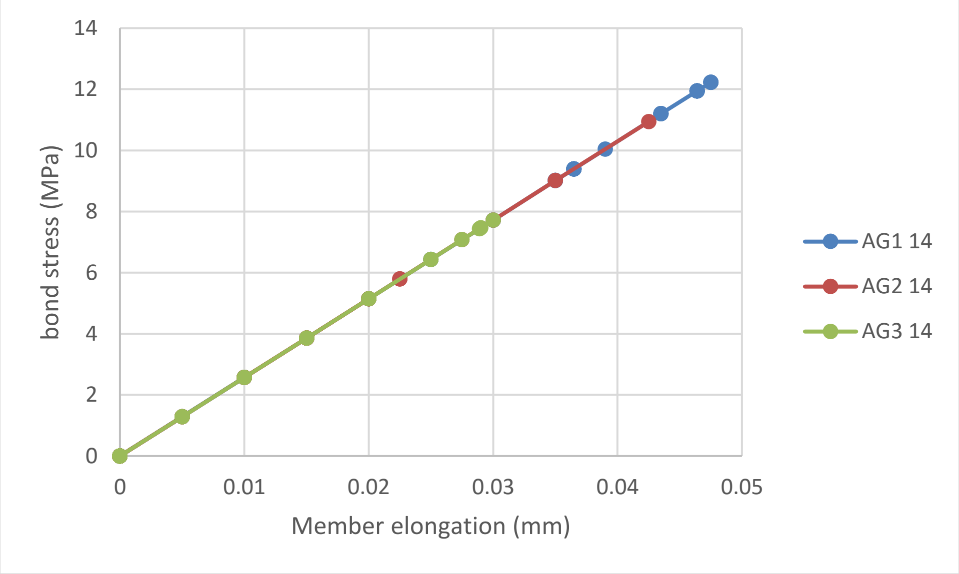

Figure 4-22 average bond stress vs elongation for a cross-section of 14cm*14cm with varying aggregate size from AG1 (9.5mm) to AG3 (37.5mm)

4.2.3 Effect of increasing both aggregate and specimen size

When we increase both aggregate and specimen size at the same time average bond strength decreases and elongation increases as shown in Figure 4.23. Decreasing of average bond stress is from the two parameters effect but when we see the elongation case the specimen size has more influence than aggregate size,that is why the elongation increases. But the special case of AG314 also seen here.

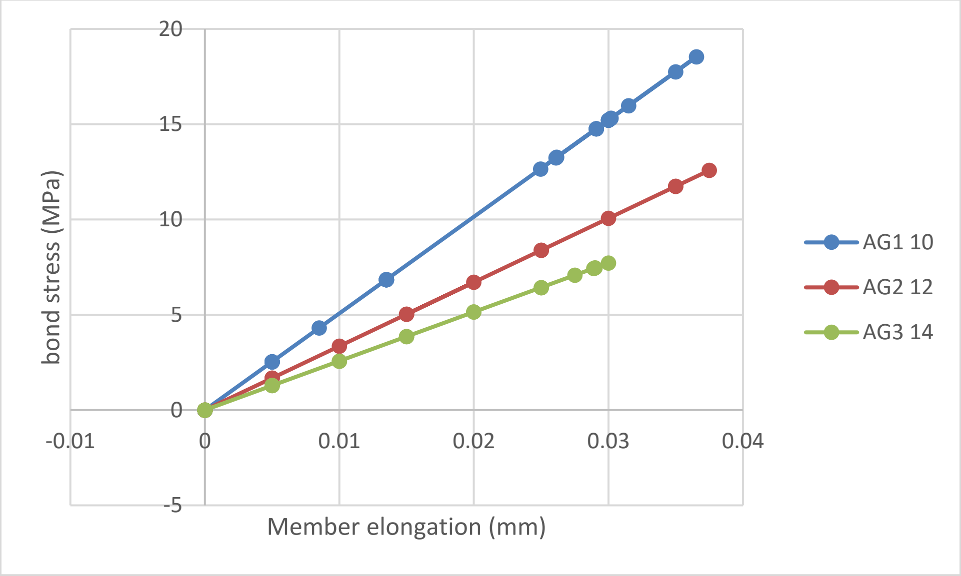

Figure 4-23 average bond stress vs elongation for varying both aggregate and specimen

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

A large amount of experimental and analytical work has been performed to study the size effect on shear and flexural strength of reinforced concrete member, less attention has been given to size effect on bond strength. The experimental result of this paper shows size has significant effect on bond strength of concrete and this results are summarized as

- As the specimen size increases by controlling all other parameters, the average bond strength decreases and elongation increases.
- As the aggregate size increases by controlling all other parameters, the maximum average bond strength and maximum elongation decreases.
- The elongation of the member is more affected by specimen size rather than aggregate size.
- As the specimen size increases the possibility of cracking of concrete before the steel yield increases.
- Dependency of bond strength over range of specimen and aggregate size currently outside the limits of prescribed by codes, but the size has an effect on bond strength and the codes should constitute it.
- Since from the result aggregate size has an impact on maximum average bond strength and elongation, choosing of the possible maximum aggregate size should be given more attention.

5.2 Recommendations

Bond behavior depends on variety of factors and parameters, which is basically to reinforcing unit, to the concrete and to the stress state in both the reinforcement unit and the surrounding concrete. From the result of this paper we conclude that

- Other parameters like bar rib type, rib height, aggregate type and shape effect on bond strength of reinforced concrete member should be checked as further study in the future.
- Size effect on local bond stress behavior should be checked as further study in the future.
- Size effect on local bond stress and average bond stress point of view of reinforced concrete member behavior after post peak should be checked as further study in the future.

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APPENDIX

Concrete Mixed Design Procedures

Mix design is the process of proportioning concrete mixtures. It consists of two interrelated steps, to produce as economically as possible and concrete of good performance. These are:

1. Selection of the suitable ingredients (cement, aggregate, water and admixtures) &
2. Determining their relative quantities ("proportioning")

Trail Mix- Design Using ACI Methods for Conventional Concrete (C25 with a Maximum size of aggregate=9.5mm).

Material properties:-

Concrete with compressive strength of 25 Mpa (C-25) is required to be produced.

From materials quality test we have the following results based on construction material laboratory test by using Abebe Dinku 2002 recommendation.

a. Cement; specific gravity=3.15
b. Coarse aggregates';

- Bulk specific gravity=2.78
- Absorption capacity=1.43%
- Moisture content= 1.67%
- Compacted unit weight=1675KN/m^3

c. Fine aggregate

- Bulk specific gravity=2.48
- Absorption capacity=0.98%
- Moisture content=2.26%
- Fines modules=2.8

- Based on this the mix design procedures are as follows.

1. Choice of the slump

Table 1 Recommended slumps for various types of construction (ACI-2111_91)

Types of construction	**Maximum slump(mm)**	**Minimum slump(mm)**
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

From table 1, take that a type of construction is beams and reinforced wall.

This implies, maximum slump= 100mm and minimum slump= 25mm.

2. Maximum size of aggregate

✓ Fine aggregate=4.75mm

✓ Course aggregate=9.5mm

3. Estimation of mixing water and air content

Assume non air entrained concrete

Table 2 Approximate Mixing Water and Air Content Requirements for Different Slumps and Nominal Sizes of Aggregates (ACI-2111_91)

NON-AIR-ENTRAINED CONCRETE								
Slump (mm)	**9.5mm**	**12.5mm**	**19mm**	**25mm**	**37.5mm**	**50mm**	**75mm**	**150mm**
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	-
More than 175	-	-	-	-	-	-	-	-
Approximate amount of entrapped air in non-air-entrained concrete (%)								
Slump (mm)	**9.5mm**	**12.5mm**	**19mm**	**25mm**	**37.5mm**	**50mm**	**75mm**	**150mm**
All	3.0	2.5	2	1.5	1	0.5	0.3	0.2

From table 2 of ACI standards, for non-air entrained and slump of 75-100, the water in 1m³ of concrete is 228Kg.

4. Water to cement selection table 3

Table 3 Relationship between water-cement or water-cementations materials ratio and

Compressive strength of concrete (ACI-2111_91)

Compressive strength at 28 days (MPa)	**Water-cement ratio by weight (Non-air-entrained concrete)**
40	0.42
35	0.47
30	0.54
25	0.61
20	0.69
15	0.79

From table 3, for C -25 and non-air entrained concrete water to cement ratio is 0.61.

5. Cement content calculation

For slump of 75-100

Water content=288Kg/m³

Water/cement=0.61

$$cementcontent = \frac{watercontent}{\frac{w}{c}}$$

$= \frac{\mathbf{288}}{\mathbf{0.61}}$=**472.13kg/m^3**

6. Estimation of course aggregates content (table 4)

Table 4 Volume of oven-dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate. (ACI -2111_91)

Nominal maximum size of aggregate (mm)	**2.4**	**2.6**	**2.8**	**3.0**
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

From table 4 of ACI, for maximum size of aggregate=9.5mm and fines modules for sand = 2.8, the volume of course aggregate per unit volume of concrete is

$$= 0.46$$

$$requireddrymassofC.A = 0.54 * 1675$$

$$\mathbf{= 904.5kg/m3}$$

7. Estimation of fine aggregates content

At the end of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity is determined by making difference. For this process either of the two procedures may be employed:

- the weight method
- the absolute volume method

If the weight of the concrete per unit volume is assumed or can be estimated from experience, the required weight of fine aggregate is simply the difference between the weight of fresh concrete and the total weight of the other ingredients. Therefore, I n this paper the weight method preferred.

Fine aggregate content (F.A)=unit weight of concrete-(C.A+cement+water)

First estimate the unit weight of fresh concretes from table 5.

Table 5 First estimate of concrete weight (kg/m3)

Nominal maximum size of aggregate (mm)	Non-air-entrained concrete
9.5	2280
12.5	2310
19	2345
25	2380
37.5	2410
50	2445
75	2490
150	2530

From the table 5 the u nit weight of fresh concrete corresponding to max. Aggregate size of 9.5mm and non- air entrained is **2280kg/m^3**.

Fine aggregate content (F.A)=2280-(904.5+472.13+228)**=<u>675.37kg/m^3</u>**

8. moisture adjustment

Absorbed water does not become part of the mixing water and it must be removed from the mixing water, if moisture content is greater than absorption capacity. But, if absorption capacity is greater than moisture content of aggregate, we need to add water up to its moisture capacity. Therefore, in this case since the moisture content of the aggregates are greater than their absorption capacity, water should be deducted from the mixing water.

Removed water from C.A=1.67% - 1.43%=**0.24%**

Removed water from F.A=2.26% - 0.98%=**1.28%**

$$total\ water\ required = 228 - \left[904.5 * \left(\frac{0.24}{100}\right) + 675.37 * \left(\frac{1.28}{100}\right)\right]$$

=217.184kg/m^3

The estimated ingredient of concrete for nominal aggregate size of 9.5mm in one meter cube are summarized as follows.

Ingredients	**Weight per meter cube(kg/m^3)**
Course aggregate	904.5
Fine aggregate	675.37
Cement	472.13
Water	217.184
Concrete unit weight.	**2269.186**

9. Trial batch

Six cubes which are 150x150x150mm^3 and six cylinders which have a diameter of 150mm by a depth of 300mm are required for compressive and tensile strength test respectively. Having total volume of 0.052m^3

Specimen concrete volume= 0.1*0.1*0.3+0.12*0.12*0.4+0.14*0.14*0.5=0.01856

Sub-total=0.052+0.01856=0.07056m^3

Considering 5% west=0.003528 m^3

Total volume=0.07056+0.003528=0.074088 m^3

Ingredients	**Weight in kg**
Course aggregate	904.5*0.074088=67.012
Fine aggregate	675.37*0.074088=50.04
Cement	472.13*0.074088=34.98
Water	217.184*0.074088=16.1

Trail Mix- Design Using ACI Methods for Conventional Concrete (C25 with a Maximum size of aggregate=25mm).

Material properties:-

Concrete with compressive strength of 25 MPa (C-25) is required to be produced.

From materials quality test we have the following result based on construction material laboratory test by Abebe Dinku.

a. Cement type 1; specific gravity=3.15

b. Coarse aggregates';

- Bulk specific gravity=2.78
- Absorption capacity=1.41%
- Moisture content= 1.67%
- Compacted unit weight=1676KN/m^3

c. Fine aggregate

- Bulk specific gravity=2.48
- Absorption capacity=0.98%
- Moisture content=2.26%
- Fines modules=2.8

- Based on this the mix design procedures are as follows.

1. Choice of the slump

Table 1 Recommended slumps for various types of construction (ACI-2111_91)

Types of construction	Maximum slump(mm)	Minimum slump(mm)
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

From table 1, take that a type of construction is beams and reinforced wall.

This implies, maximum slump= 100mm and minimum slump= 25mm.

2. Maximum size of aggregate

- ✓ Fine aggregate=4.75mm
- ✓ Course aggregate=25mm

3. Estimation of mixing water and air content

Assume non air entrained concrete

Table 2 Approximate Mixing Water and Air Content Requirements for Different Slumps and Nominal Sizes of Aggregates (ACI-2111_91)

NON-AIR-ENTRAINED CONCRETE								
Slump (mm)	**9.5mm**	**12.5mm**	**19mm**	**25mm**	**37.5mm**	**50mm**	**75mm**	**150mm**
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	-
More than 175	-	-	-	-	-	-	-	-
Approximate amount of entrapped air in non-air-entrained concrete (%)								
Slump (mm)	**9.5mm**	**12.5mm**	**19mm**	**25mm**	**37.5mm**	**50mm**	**75mm**	**150mm**
All	3.0	2.5	2	1.5	1	0.5	0.3	0.2

From table 2 of ACI standards, for non-air entrained and slump of 75-100, the water in 1m³ of concrete is 193Kg.

4. Water to cement selection table 3

Table 3 Relationship between water-cement or water-cementations materials ratio and Compressive strength of concrete (ACI-2111_91)

Compressive strength at 28 days (MPa)	Water-cement ratio by weight (Non-air-entrained concrete)
40	0.42
35	0.47
30	0.54
25	0.61
20	0.69
15	0.79

From table 3, for C -25 and non-air entrained concrete water to cement ratio is 0.61.

5. Cement content calculation

For slump of 75-100

Water content=193Kg/m³

Water/cement=0.61

$$cementcontent = \frac{watercontent}{\frac{w}{c}}$$

$= \frac{\mathbf{193}}{\mathbf{0.61}}$=**316.39kg/m^3**

6. Estimation of course aggregates content (table 4)

Table 4 Volume of oven-dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate.(ACI -2111_91)

Nominal maximum size of aggregate (mm)	2.4	2.6	2.8	3.0
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

From table 4 of ACI, for maximum size of aggregate=25mm and fines modules for sand = 2.9, the volume of course aggregate per unit volume of concrete is

$$= 0.67$$

$$requireddrymassofC.A = 0.67 * 1676$$

$$\boldsymbol{= 1122.92kg/m3}$$

7. Estimation of fine aggregates content

At the end of Step 6, all ingredients of the concrete have been estimated except the fine Aggregate. Its quantity is determined by making difference. For this process either of the two procedures may be employed:

- the weight method
- the absolute volume method

If the weight of the concrete per unit volume is assumed or can be estimated from experience, the required weight of fine aggregate is simply the difference between the weight of fresh concrete and the total weight of the other ingredients. Therefore, I n this paper the weight method preferred.

Fine aggregate content (F.A)=unit weight of concrete-(C.A+cement+water)

First estimate the unit weight of fresh concretes from table 5.

Table 5 First estimate of concrete weight (kg/m3)

Nominal maximum size of aggregate (mm)	Non-air-entrained concrete
9.5	2280
12.5	2310
19	2345
25	2380
37.5	2410
50	2445
75	2490
150	2530

From the table 5 the u nit weight of fresh concrete corresponding to max. Aggregate size of 25mm and non- air entrained is **2380kg/m^3**.

Fine aggregate content (F.A)=2380-(1122.92+316.393+193)**=747.687kg/m^3**

8. moisture adjustment

Absorbed water does not become part of the mixing water and it must be removed from the mixing water, if moisture content is greater than absorption capacity. But, if absorption capacity is greater than moisture content of aggregate, we need to add water up to its moisture capacity. Therefore, in this case since the moisture content of the aggregates are greater than their absorption capacity, water should be deducted from the mixing water.

Removed water from C.A=1.67 - 1.43=**0.24%**

Removed water from F.A=2.26-0.98=**1.28%**

$$total\ water\ required = 193 - \left[1122.92 * \left(\frac{0.24}{100}\right) + 747.687 * \left(\frac{1.28}{100}\right)\right]$$

=180.734kg/m^3

The estimated ingredient of concrete for nominal aggregate size of 25mm in one meter cube are summarized as follows.

Ingredients	Weight per meter cube(kg/m^3)
Course aggregate	1122.92
Fine aggregate	747.687
Cement	316.39
Water	180.734
Concrete unit weight.	**2367.73**

9. Trial batch

Six cubes which are 150x150x150mm^3 and six cylinders which have a diameter of 150mm by a depth of 300mm are required for compressive and tensile strength test respectively. Having total volume of 0.052m^3

Specimen concrete volume= 0.1*0.1*0.3+0.12*0.12*0.4+0.14*0.14*0.5=0.01856

Sub-total=0.052+0.01856=0.07056m^3

Considering 5% west=0.003528 m^3

Total volume=0.07056+0.003528=0.074088 m^3

Ingredients	Weight in kg
Course aggregate	1122.92*.074088=83.94
Fine aggregate	747.687*0.074088=54.656
Cement	316.39*0.074088=23.44
Water	180.734*0.074088=13.36

Trail Mix- Design Using ACI Methods for Conventional Concrete (C25 with a Maximum size of aggregate=37.5mm).

Materials properties:-

Concrete with compressive strength of 25 Mpa (C-25) is required to be produced.

From materials quality test we have the following result based on construction material laboratory test by Abebe Dinku.

a. Cement type 1; specific gravity=3.15
b. Coarse aggregates';

- Bulk specific gravity=2.78
- Absorption capacity=1.42%
- Moisture content= 1.66%
- Compacted unit weight=1675KN/m^3

c. Fine aggregate

- Bulk specific gravity=2.48
- Absorption capacity=0.98%
- Moisture content=2.26%
- Fines modules=2.8

- Based on this the mix design procedures are as follows.

1. Choice of the slump

Table 1 Recommended slumps for various types of construction (ACI-2111_91)

Types of construction	Maximum slump(mm)	Minimum slump(mm)
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

From table 1, take that a type of construction is beams and reinforced wall.

This implies, maximum slump= 100mm and minimum slump= 25mm.

2. Maximum size of aggregate

- ✓ Fine aggregate=4.75mm

- ✓ Course aggregate=37.5mm

3. Estimation of mixing water and air content

Assume non air entrained concrete

Table 2 Approximate Mixing Water and Air Content Requirements for Different Slumps and Nominal Sizes of Aggregates (ACI-2111_91)

NON-AIR-ENTRAINED CONCRETE								
Slump (mm)	**9.5mm**	**12.5mm**	**19mm**	**25mm**	**37.5mm**	**50mm**	**75mm**	**150mm**
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	-
More than 175	-	-	-	-	-	-	-	-
Approximate amount of entrapped air in non-air-entrained concrete (%)								
Slump (mm)	**9.5mm**	**12.5mm**	**19mm**	**25mm**	**37.5mm**	**50mm**	**75mm**	**150mm**
All	3.0	2.5	2	1.5	1	0.5	0.3	0.2

From table 2 of ACI standards, for non-air entrained and slump of 75-100, the water in 1m³ of concrete is 181Kg.

4. Water to cement selection table 3

Table 3Relationship between water-cement or water-cementations materials ratio and

Compressive strength of concrete(ACI-2111_91)

Compressive strength at 28 days (MPa)	Water-cement ratio by weight (Non-air-entrained concrete)
40	0.42
35	0.47
30	0.54
25	0.61
20	0.69
15	0.79

From table 3, for C -25 and non-air entrained concrete water to cement ratio is 0.61.

5. Cement content calculation

For slump of 75-100

Water content=181Kg/m³

Water/cement=0.61

$$cementcontent = \frac{watercontent}{\frac{w}{c}}$$

$$= \frac{\mathbf{181}}{\mathbf{0.61}} = \mathbf{296.72kg/m^3}$$

6. Estimation of course aggregates content (table 4)

Table 4 Volume of oven-dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate.(ACI -2111_91)

Nominal maximum size of aggregate (mm)	**2.4**	**2.6**	**2.8**	**3.0**
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

From table 4 of ACI, for maximum size of aggregate= 37.5mm and fines modules for sand = 2.9, the volume of course aggregate per unit volume of concrete is

$$= 0.71$$

$$requireddrymassofC.A = 0.71 * 1675$$

$$= \mathbf{1189.25 kg/m3}$$

7. Estimation of fine aggregates content

At the end of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity is determined by making difference. For this process either of the two procedures may be employed:

- the weight method
- the absolute volume method

If the weight of the concrete per unit volume is assumed or can be estimated from experience, the required weight of fine aggregate is simply the difference between the weight of fresh concrete and the total weight of the other ingredients. Therefore, I n this paperthe weight method preferred.

Fine aggregate content (F.A)=unit weight of concrete-(C.A+cement+water)

First estimate the unit weight of fresh concretes from table 5.

Table 5 First estimate of concrete weight (kg/m3)

Nominal maximum size of aggregate (mm)	Non-air-entrained concrete
9.5	2280
12.5	2310
19	2345
25	2380
37.5	2410
50	2445
75	2490
150	2530

From the table 5 the u nit weight of fresh concrete corresponding to max. Aggregate size of 37.5mm and non- air entrained is **2410kg/m^3**.

Fine aggregate content (F.A)=2410-(1189.25+296.72+181)=**<u>743.03kg/m^3</u>**

8. moisture adjustment

Absorbed water does not become part of the mixing water and it must be removed from the mixing water, if moisture content is greater than absorption capacity. But, if absorption capacity is greater than moisture content of aggregate, we need to add water up to its moisture capacity. Therefore, in this case since the moisture content of the aggregates are greater than their absorption capacity, water should be deducted from the mixing water.

Removed water from C.A=1.66 - 1.42=**0.24%**

Removed water from F.A=2.25-0.98=**1.27%**

$$total\ water\ required = 181 - \left[1189.25 * \left(\frac{0.24}{100}\right) + 743.03 * \left(\frac{1.27}{100}\right)\right]$$

<u>=168.71kg/m^3</u>

The estimated ingredient of concrete for nominal aggregate size of 37.5mm in one meter cube is summarized as follows.

Ingredients	Weight per meter cube(kg/m^3)
Course aggregate	1189.25
Fine aggregate	743.03
Cement	296.72
Water	168.71
Concrete unit weight.	**2397.71**

9. Trial batch

Six cubes which are 150x150x150mm^3 and six cylinders which have a diameter of 150mm by a depth of 300mm are required for compressive and tensile strength test respectively. Having total volume of 0.052m^3

Specimen concrete volume= 0.1*0.1*0.3+0.12*0.12*0.4+0.14*0.14*0.5=0.01856

Sub-total=0.052+0.01856=0.07056m^3

Considering 5% west=0.003528 m^3

Total volume=0.07056+0.003528=0.074088 m^3

Ingredients	Weight in kg
Course aggregate	1189.25*0.074088=89.023
Fine aggregate	743.03*0.074088=54.136
Cement	296.72*0.074088=21.983
Water	168.71*0.074088=12.468