HASAN KALYONCU UNIVERSITY
GRADUATE SCHOOL OF
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PULL OUT BOND STRENGTH OF REINFORCING STEEL BARS IN SCC

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IN
CIVIL ENGINEERING

BY
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Pull out bond strength of reinforcing steel bars in SCC

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Peshkawt Yaseen SALEH

ABSTRACT

Pull out bond strength of reinforcing steel bars in SCC

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Reinforced concrete structures may have to fulfill functions that go beyond their simple mechanical resistance. For example, in some cases, information about the cracking resistance, durability aspects and functionality are also essential behaviors of concrete. Most design guides are limited to conventional vibrated concrete, and these guides applied to SCC. There are many factors that affect on the bond strength between steel bars and concrete, such as compressive strength of concrete, diameter of bars, type of reinforcement and concrete cover.In this investigation bond strength of reinforcing steel bars embedded in SCC was studied. Pull out strength tests were conducted on three mixtures of SCC which comprised totally 108 specimens of size (150) mm cubes. To investigate Bond strength development with age , pullout test was measured at different ages of concrete 3, 7, 28 and 56 days . Two embedded size of steel bars were considered namely 10 mm and 16 mm diameters with 600 mm length.Based on the current experimental results, it is concluded that diameter of steel bars does affect their bond strength , the embedded 10 mm diameter bars showed greater bond strength than 16 mm bars by about 3.2 %.The bond strength of both size of bars increased with time, but the rate of increase lowered with time, and showed good correlation with the compressive strength of concrete. Bond strength at age of 3 days to age of 28 days approximately ranged between 80 to 90 % and increased by about 5 to 7 % only for age from 28 to 56 days.Considering three mixture proportions of SCC, The percentage of increase in bond strength of 10 mm bars, at age of 28 days was 4.09 % with increase of cementtious material content from 400 to 433 kg/m^3 and 13 % with increase of cementitious content from 400 to 466 kg/m^3. For bar size of 16 mm the percentage of increase in bond strength for these mixtures was ranged between 17.3 % to 25.3 % respectively .For these bars the bond strength is greater than the tensile strength. The predominant type mode of failure is splitting mode for all the tested specimens and no slip failure occurred in testing all the pull outed specimens throughout the experiments.

Keywords: Self-compacting concrete; Bond strength; bond behavior; pull-out test; reinforced concrete; fly ash; fresh properties.

Özet

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Betonarme yapıların basit mekanik dirençlerinin ötesinde başka bazı fonksiyonları da yerine getirmesi gerekebilir. Örneğin, bazı durumlarda çatlama direnci, dayanıklılık özellikleri ve işlevsellikler betonun esas davranışları hakkında oldukça önem taşımaktadır. Çoğu tasarım rehberleri geleneksel vibrasyonlu beton ve kendiliğinden yerleşen beton ile sınırlıdır. Çelik çubuklar ve beton arasındaki bağlanma mukavemetini etkileyen beton basınç dayanımı, çubuk çapı, güçlendirmeler ve beton yüzeyi türü gibi birçok faktör vardır. Bu araştırmada kendiliğinden yerleşen beton içine gömülü olan betonarme çelik çubukların bağlanma mukavemeti konusu çalışılmıştır. Çekme mukavemeti testlerinde 3 çeşit kendiliğinden yerleşen beton karışımı kullanılmıştır ve toplamda 150mm'lik 108 adet numune oluşturulmuştur. Bağlanma mukavemetinin zamana bağlı gelişmesini incelemek için çekme testleri 3, 7, 28, ve 56 günlük değişik zamanlarda gerçekleştirilmiştir. Gömülü bulunan çelik çubuklar 10mm ve 16mm çapında ve 600mm uzunluğunda düşünülmüştür. Geçerli deneysel sonuçlarına göre, çelik çubukların çaplarının bağ kuvvetini önemli ölçüde etkilediği, gömülü 10 mm çaplı çubukların yaklaşık olarak % 3,2 oranında 16 mm çubuklardan daha fazla bağlanma mukavemeti gösterdiği sonuçlarına varılmıştır. Her iki boyuttaki çubukların bağ kuvveti zamanla artmıştır ancak artış oranı zamanla azalmıştır ve bu artış beton basınç dayanımı ile iyi bir korelasyon göstermiştir. Bağ kuvveti 3. günden 28. güne kadar yaklaşık %80 ile %90 arasında değişirken, 28. günden ile 56. güne kadar sadece %5 ile %7'lik artış göstermiştir. Kendiliğinden yerleşen betonun her üç karışımı oranı göz önünde bulundurulunca, 10mm çapındaki çelik çubukların bağ kuvvetlerindeki artış çimentolu malzeme miktarı kullanımının 400 kg/m^3'den 433 kg/m^3'e artması ile 28. günde %4.09, çimentolu malzeme miktarı kullanımının 400 kg/m^3'den 466 kg/m^3'e artması ile 28. günde %13 olarak belirlenmiştir. 16mm'lik çelik çubuklarda ise bağ kuvvetindeki artış miktarı bu numuneler için %17,3'den %23,3'e şeklinde gözlenmiştir. Bu çelik çubuklar için bağ kuvveti çekme kuvvetinden daha büyüktür. Baskın olan çatlak tip modları test edilen tüm örnekler için kayma modlarıdır ve deneyler boyunca numunelerin çekilmelerinde hiçbir kayma hatası olmamıştır.

Anahta kelimeler: Kendiliğinden yerleşen beton; Yapışma dayanımı; tahvil davranış; Çek- dışarı test; takviyeli beton; sinek kül; taze özellikleri.

To My Father , Mother

And My Wife

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LIST OF SYMBOLS/ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British standar
CLSM	Control low strength materials
CVC	Convantional viberated concrete
CVHSC	Conventionallyvibrated high-strength concrete
ECC	Engineering and Construction Contracting Association
FA	Fly Ash
GFRP	Glass Fiber Reinforced Polymer
HPMC	hydroxy propyl methyl cellulose
HSSCC	high stringt silf compacte concrete
ITZ	interfacial transition zone
LNG	Liquid Nitrogen Gas
LFA	Lignite Fly Ashes
NC	Normal concrete
NV	Non-viberter
NVC	Normally VibratedConcrete

OPC	Ordinary Portland cement
PC	Portland Cement
RC	Reinforce concrete
SCC	Self compacting concrete
SCLC	Self-consolidatinglightweight concrete
SFRC	Steel fiber reinforced concrete
SFRSCC	Steel fiber reinforcedself-compacting concrete
SP	Superplasticize
SQC	Super quality concrete
T-LFA	Treated Lignite Fly Ash
US	United States
U-LFA	Untreated Lignite Fly Ash
VC	Linear variable differential transformer
VC	Vibrated concrete

CHAPTER ONE

INTRODUCTION

1.1 General

Advancement of self-compacting concrete (SCC) is a cult attainment in the construction industry in order to deal with difficulties associated with cast-in-place concrete. Self-compacting concrete is not influenced by the skills of workers, the shape and amount of reinforcing bars or the arrangement of a structure, and due to its high-fluidity and resistance to segregation it can be pumped long distances (Bartos, 2000). The thought of self-compacting concrete was first proposed in 1986 by Professor Hajime Okamura (1997). However, the prototype was first produced in 1988 in Japan by Professor Ozawa (1989) at the University of Tokyo.

To start with the development of Self-compacting concrete was to improve the durability of concrete structures. Since then, various analyses and valuations have been borne out and SCC has been applied in practical structures in Japan, chiefly by large building companies. Investigations for establishing a rational mix-design method and self-compatibility testing methods have been taken away from the standpoint of building it a standard concrete. Self-compacting concrete is cast so that no additional inner or outer vibration is necessary for the concretion. It runs like “honey” and possesses a really smooth surface level after putting. With respect to its constitution, self-compacting concrete consists of the same elements as conventional vibrated concrete, which are cement, aggregates, and water, with the addition of chemical and mineral admixtures in different dimensions (see Chapter 3). Ordinarily, the chemical admixtures used are high-range water reducers (superplasticizers) and viscosity-modifying agents, which modify the rheological properties of concrete. Mineral admixtures are used as an extra fine material, besides cement, and in some cases, they replace cement. In this field, the cement content was partly put back with mineral admixtures, e.g. fly ash, admixtures that improve the flowing and strengthening characteristics of the concrete.

1.2 Historical Development of Self-Compacting Concrete

Self-compacting concrete, in principle, is not modern. Unique applications like underwater concreting have always required concrete, which could be identified without the need for compaction (Bartos, 2000). In such circumstances vibration was just unacceptable. Early self-compacting concretes relied on very high contents of cement paste and, once superplasticizers became available, they were totalled in the concrete mixes. The mixes required specialized and well-controlled placing methods in order to avoid segregation, and the high contents of cement paste made them prone to shrinkage. The overall costs were very high and applications remained very limited.

The first appearance of “modern” self-levelling concrete or self-compacting concrete (SCC) is associated with the movement towards better quality concrete pursued in Japan around 1983, where the lack of uniform and complete compaction had been named as the main agent responsible for the miserable execution of concrete structures (Dehn et al., 2000). Referable to the fact that in that location were no practical means by which full compaction of concrete on a site was ever to be fully guaranteed, the focal point, therefore, turned onto the elimination of the need to compact, by shaking or whatever other substance. This contributed to the evolution of the first practicable SCC by researchers Okamura and Ozawa, around 1986, at the

University of Tokyo and the large Japanese contractors (e.g. Kajima Co., Maeda Co., Taisei Group Co., etc.) promptly brought up the thought. The contractors used their large in-house research and growth facilities to produce their own SCC technologies. Each company produced their own mix designs and prepared their own staff to act as technicians for testing on sites their SCC mixes. A real important aspect was that each of the large contractors also built up their own testing devices and test methods (Bartos, 2000). In the early 1990's there was exclusively a limited public knowledge about SCC, mainly in the Japanese words. The central and practical know-how was kept hidden by the big corporations to maintain commercial advantage. The SCCs were used under trade names, such as the NVC (Non-vibrated concrete) of Kajima Co., SQC (Super quality concrete) of Maeda Co. or the Biocrete (Taisei Co.). Simultaneously with the Japanese developments in the SCC area, research and development continued in mix-design and laying of underwater concrete where new admixtures were producing SCC mixes with performance matching that of the Japanese SCC concrete (e.g. University of Paisley / Scotland, University of Sherbrooke / Canada) (Ferraris, 1999).

1.3 Research Significance

Self-compacting concrete is widely used in the recent years. Most design guides are fixed to conventional concrete. Reinforced self-compacted concrete structures should have to accomplish functions that extend beyond their simple mechanical resistance. For example, understanding the bond mechanism is of outstanding importance for the design (anchorage lengths, load carrying capacity, gap width,). And in some cases Predicting the mechanical behaviour and characterizing the crack evolution (opening and spacing) is thus key points in the evaluation of this type of reinforced concrete structures. As the cracking properties (opening and spacing) are influenced by the strain distribution along the interface between steel and concrete this effect has to be brought into account numerically and characterized through an experiment. For self-compacting concrete (SCC) however few test results are useable and in practice the standards for conventional vibrated concrete (CVC) apply to self-compacting concrete SCC as well.

To occupy in this lack of cognition, this investigation is a footprint in developing self-compacting concrete from the local materials for our region and understanding the behaviour of bond strength of self-compacted concrete reinforced with deformed steel bars.

1.4 Research Objective

Research work deals withthe bond resistance of two types reinforcing deformed bars (10 mm and 16 mm) embedded in self-compacted concrete, the testing method, by means of “cube-test”specimen, was based on RILEM RC6 “part 2, Pullout testOne way to evaluate the steel–concrete bond is to investigate the bond stress–slip evolution generally obtained through classical pull-out tests.The test was done on three mixtures of SCC at different ages, variables was water to cementations material ratio of SCC, compressive strength and diameter of deformed bars. The aim of the research is to study bond strength development with time for three mixtures of SCC and correlating bond strength to the compressive strength of SCC. The test was done by classical portable pull-out test machine with a capacity of 300 kN and accuracy of 0.1 kN. Pullout stress at failure were recorded and correlated with the compressive strength of concrete.

1.5Outlines of the thesis

The thesis is divided into five chapters.

- Chapter 1 provides an introduction, background, thesis objectives and thesis organization,
- Chapter 2 gives a brief literature review.,
- Chapter 3 experimental program, Properties of cement, aggregates, mineral and chemical admixtures used in the concrete production as well as the tests on hardened properties of concrete are included
- Chapter 4 rustle and discussion.
- Chapter 5 summarizes the major findings of the study, reference and appendix

CHAPTER TWO

LITERATURE REVIEW

Recently self-compacting concrete was classed as an advanced construction material. As the name suggests, it does not require to be vibrated to achieve full compaction. This offers many benefits and advantages over conventional concrete. These include an improved quality of concrete and reduction of on-site repairs, faster building times, lower overall costs, facilitation of introduction of automation into concrete expression. An important improvement of health and safety is also achieved through elimination of handling of vibrators and a substantial reduction of environmental noise loading in and around a site. The theme of SCC mixes includes substantial proportions of fine-grained inorganic materials and this gives possibilities for the use of mineral mixes, which are currently waste products with no practical applications and are costly to dispose of (St John, 1998).

2.1 Previous research work on SCC

Self-compacting concrete extends the possibility of use of various mineral by-products in its manufacturing and with the densification of the matrix, mechanical behaviour, as measured by compressive, tensile and shear strength, is increased. On the other hand, the use superplasticizers or high range water reducers, improves the stiffening, unwanted air entrainment, and flowing ability of the concrete. Practically, all cases of structural constructions are possible with this concrete. The role of SCC doesn't only reduce the construction period, but also guarantees quality and strength of concrete. This non-vibrated concrete allows faster location and less finishing time, leading to improved productivity. In the following, a summary of the articles and papers found in the literature, about the self-compacting concrete and some of the projects carried out with this type of concrete, is presented.

A novel case of concrete, which can be squeezed into every corner of a formwork purely by means of its own weight, was proposed by Okamura (1997). In 1986, he started a research project along the flowing ability and workability of this peculiar type of concrete, later called self-compacting concrete. The self-compatibility of this concrete can be largely affected by the characteristics of materials and the mix proportions.

In his study, Okamura (1997) has fixed the coarse aggregate content to 50% of the solid volume and the fine aggregate content to 40% of the mortar volume, so that self-compactability could be achieved easily by adjusting the water to cement ratio and superplasticizer dosage only.

A model formwork, comprised of two vertical sections (columns) at each terminal of a horizontal trough, was used by professor Okamura to observe how easily self-compacting concrete could flow through obstacles. Image 2.1 shows the ends of small pipes mounted across the horizontal trough and used as obstacles. The concrete was set into a right-hand tower, fell through the obstructions, and mounted in the left-hand tower.

Fig 2.1 Small pipes used as obstacles in formwork (Okamura, 1997)

The obstacles were taken to simulate the confined zones of an existent social organization. The concrete in the left-hand tower rose to about the same degree every bit in the right-hand tower. Similar experiments of this type were carried out over a period of about one year and the applicability of self-compacting concrete for practical structures was verified. This research was begun at the suggestion of professor Kokubu (Okamura, 1997) from Kobe University, Japan, one of the advisors of Hajime Okamura. They believed that it would be easy to create this new concrete because the antiwashout underwater concrete was already in practical usage. Antiwashout underwater concrete is cast underwater and segregation is strictly suppressed by adding a large quantity of a viscous agent (antiwashout admixture), which prevents the cement particles from circulating in the surrounding water.

Nevertheless, it was found that antiwashout underwater concrete was not applicable for structures in clear air for two reasons: first, trapped air bubbles could not be rejected due to the high viscosity; and second, compaction in the restricted areas of reinforcing bars was difficult. So, for the achievement of self-compactability, a superplasticizer was indispensable. With a superplasticizer, the paste can be made more valuable with little concomitant decrease in viscosity, compared to the drastic effect of the water, when the cohesion between the aggregate and the paste is weakened (Fig 2.2).

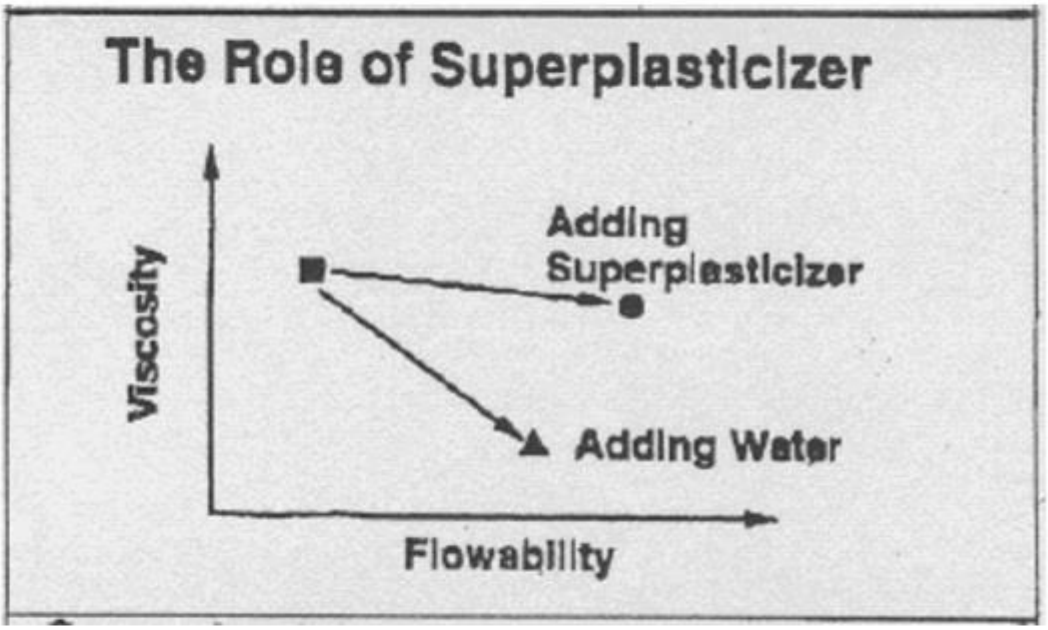


Fig 2.2 Effect of superplasticizer on viscosity (Okamura, 1997).

Other researchers in Japan have started to investigate self-compacting concrete after Okamura began his research in 1986, looking to improve its characteristics. One of those was Ozawa (1989) who has done some research independently from Okamura, and in the summer of 1988, he succeeded in producing self-compacting concrete for the foremost time. The year after that, an open experiment on the new type of concrete was kept at the University of Tokyo, in front of more than 100 researchers and engineers. As a result, intensive research has commenced in many situations, particularly in the research institutes of large construction companies and at the University of Tokyo.The two researchers were trying to determine different coarse and fine aggregate contents from those developed by Okamura. The coarse aggregate content was changed, along with water-powder (cement, fly ash and slag) ratio, being 50%, 48% and 46% of the whole volume. The objective of Khayat's (1997) et al. The inquiry was to measure the uniformity of in situ mechanical properties of self-consolidating concrete used to cast experimental wall elements. Eight optimized SCC mixtures with slump flow values greater than 630 mm and a conventional concrete with a slump of 165 mm were investigated. The self-compacting concrete mixtures incorporated various combinations of cementitious materials and chemical mixtures.

The water-cementitious materials ratios ranged from 0.37 to 0.42. Experimental walls measuring 95 cm in distance, 20 cm in width, and 150 cm in height were cast. After casting, no consolidation was used for the SCC mixtures, while the medium fluidity conventional concrete received thorough internal vibration. Several cores were obtained in order to measure the uniformity of compressive strength and modulus of elasticity along the top of each wall. Khayat (1997) et al. Found out that all burdens from both types of concrete exhibited little variation in compressive strength and modulus of elasticity in relation to the top of the wall, showing a high level of strength uniformity. However, compressive strength and modulus of elasticity were greater for SCC samples than those obtained from the medium fluidity conventional concrete.

Subramanian and Chattopadhyay (2002) are research and development engineers at the ECC Division of Larsen & Toubro Ltd (L&T), Chennai, India. They have over

10 years of experience in the development of self-compacting concrete, underwater concrete with antiwashout admixtures and proportioning of special concrete mixtures. Their research was focused on several tests carried out to arrive at an approximate mix proportion of self-compacting concrete, which would apply the subroutine for the choice of a viscosity modifying agent, a compatible superplasticizer and the purpose of their doses. The Portland cement was partially replaced with fly ash and blast furnace slag, in the same percentages as Ozawa (1989) has done before and the maximum coarse aggregate size did not exceed 1”.

2.2 Previous research work on bond strength

Casanova et al, (2013) studied on contribution; an experimental campaign based on unconfined and actively confined pull-out tests is presented to investigate the bond stress slip behavior. This effort aims at underlining passive (concrete cover) and active (outside pressure) confinement effects on the maximal bond stress. Experimental results are connected with a numerical approach in order to anticipate the development of the adhesion strength. Equations are finally proposed that distinguish splitting failure (a part of the concrete tensile properties) and pullout failure (a subprogram of the compressive concrete properties).

Self-Compacting Concrete (SCC) has been distinguished as a promising replacement of Normally Vibrated Concrete (NVC) by (Sfikas and Trezos, 2013). Since current literature has already provided sufficient data to give confidence in SCC bond behaviour, further analysis should focus on confirmation or more specific analysis. The impingement of water-to-binder ratio variations and different silica fume levels of cement replacement on SCC bond has been the incentive of the present study. Pull-out tests in cube specimens have been conducted for 11 SCC and

4 NVC mixtures. Various bond stresses have been assessed. The composition changes seem to be better reflected on lower bond stresses, which decrease linearly in higher water content and higher silica fume replacement levels. SCC develops an improved bond capacity compared to same strength NVC with similar theme.

In the study of Pour-Ali et al (2015) The pilot test was carried out using a Santam Universal (STM-150) testing machine as schematically illustrated in (Fig.2.3) In this test, RC samples were poured similar to those prepared for electrochemical tests but the size of all samples were equal and the top and bottom ends of bare repairs were not masked with epoxy. Pullout test was performed on as-cured (uncorroded condition) and saturated, after 180 and 360 days immersion in 3.5 wt. % NaCl solution (corroded condition), RC samples at a constant loading rate of 1 mm/minute. It should be mentioned that none of the steel reinforcements reached the yield point during the pullout tests. The maximum pull-out forces were recorded to calculate the ultimate bond strength (sbu) according to Eq.

$$\tau_{bu} = \frac{P_{max}}{\pi DL} (MPa) \qquad \text{(E 1.1)}$$

Where Pmax is the ultimate pull-out load, L is the embedded length of reinforcement bar in concrete and D is the bar diameter.

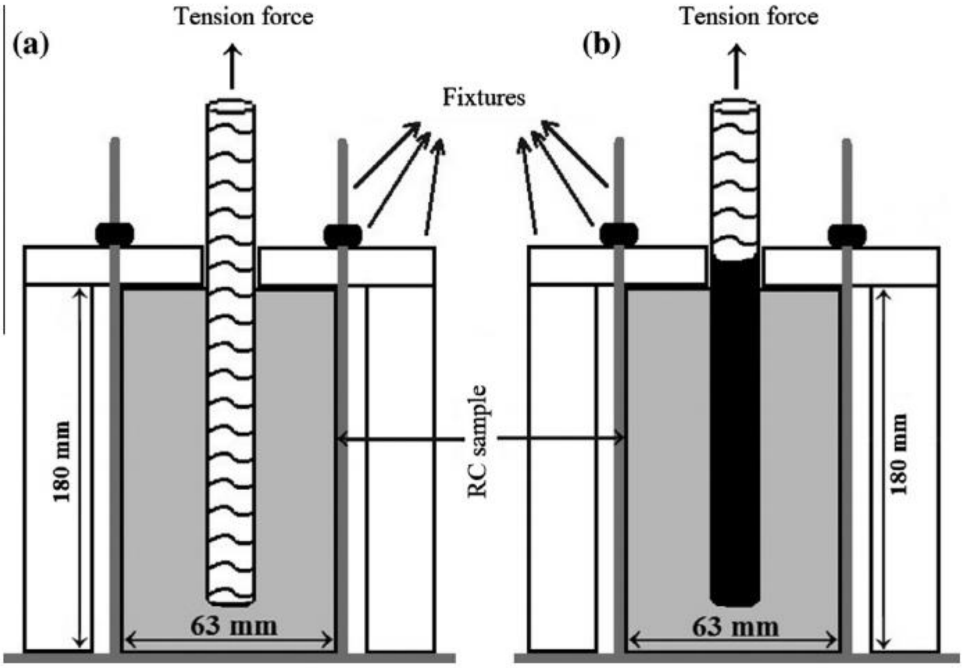


Fig 2.3 Pullout test (Pour-Ali et al, 2015).

Islam et al, (2015) worked on Bond characteristics of straight- and headed-end, ribbed-surface, GFRP bars embedded in high-strength concrete. Given the experimental findings of 180 pullout tests conducted on GFRP bars embedded in high strength concrete blocks covering different parameters. The studied parameters were bar diameter size (12 or 16 mm), embedment length (4 or 6 times the bar diameter), bar end condition (straight and headed), and concrete cover (1.5, 2.5, and 5 or 7 times bar diameter for straight bars and 8 or 10.5 times bar diameter for headed bars) in addition to a case of no embedment length except the head length for headed-end bars. In aggregate, 30 variables were studied, while each variable was conducted on 6 identified specimens in order to increase the reliability of the solutions. Grounded along the outcomes of the parametric study, the bond stress was recorded to be reciprocally proportional to the embedment length and bar diameter as expected. In summation, the smaller concrete cover appeared to cause a substantial effect on bond stress, leading to side blowout failure rather than bar pullout or concrete splitting in the case of headed-end GFRP bars. In summation, the GFRP bar with headed-end showed significant increase in pullout strength compared to that for the straight-end bars. At long last, an empirical expression was aimed to estimate the development length of GFRP bars with either straight or headed-end, and then compared with the available design standards such as CSA-S806-02, CSA S6-06, ACI 440-1R-06, and JSCE-97. The comparison indicated that the results produced by CSA S6-06 standards were the nearest to the experimental findings showed about 2% safety margin exceeding the obtained development length of the proposed construction.

For traditional steel reinforcement, bond failure is attributed to bearing causing side splitting or shearing of concrete. On the other hand, bearing stress of the

GFRP bars can exceed the shear strength between the surface deformations and the bars core resulting in a bond failure at this interface as depicted in (Fig. 2.4)

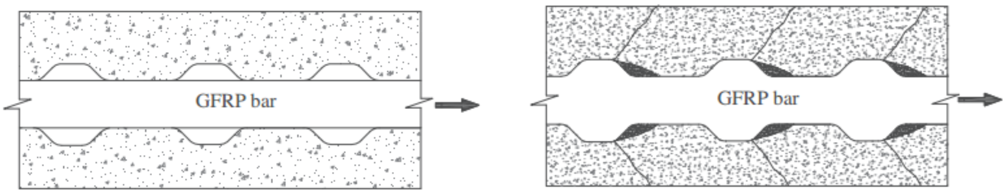


Fig 2.4 Pullout failure modes (Islam et al, 2015)

2.2.1 Bond strength of reinforcing bars in SCC

Dehn (2000) et al. have focused their research work on the time development of SCC compressive and splitting tensile strength and the bond behavior between the reinforcing bars and the self-compacting concrete compared to normal concrete.

In edict to secure a full production of SCC, a mix design should be done, hence that the predefined properties of the fresh and hardened concrete would be hit for sure. All the ingredients should be organized so that bleeding and segregation would be forbidden.

Because of these views, their mix design was based on experience from Japan, Netherlands, France, and Sweden. Referable to the fact that the load bearing capability of a reinforced concrete construction is considerably determined by the bond behaviour between the reinforcing bars and the concrete, the following particulars were involved into account:

- anchorage of the reinforcing bars
- crack width control
- lapped reinforcing bars

For this reason, investigations on the bond behaviour between the re-bars and the SCC were necessary, particularly viewing the time evolution of the bond strength. These investigations showed, that the main parameters which influence the bond behavior are the surface of the re-bars, the number of load cycles, the mix design, the direction of concreting, as well as the geometry of the (pull-out) test specimens (Fig 2.5). The bond behaviour was determined under uniform static loading using pullout specimens having a uniform concrete cover around the reinforcing bar. The bar diameter for the whole test series was 10 mm and the concrete cover around it had a diameter of 10 cm and a length of also 10 cm.

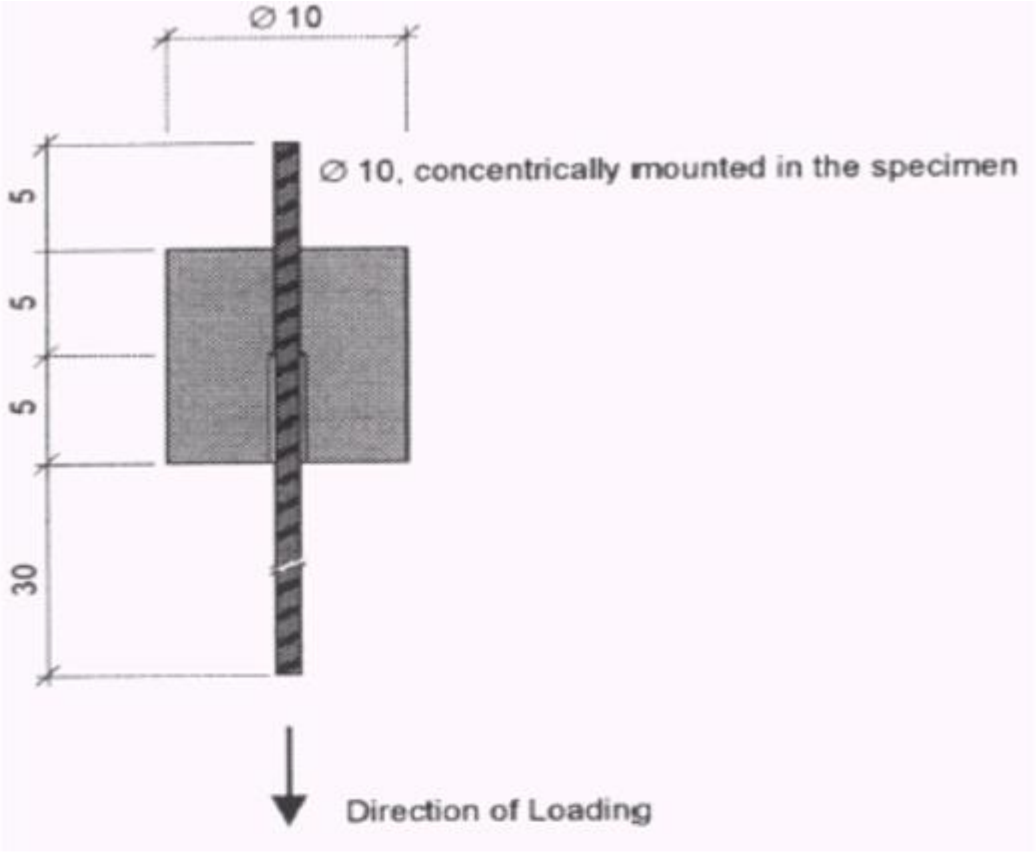


Fig 2.5 Pullout specimen (Dehn et al., 2000).

To keep off an unwanted force transfer between the reinforcing bar and the concrete in the unbounded area, the re-bars were encased with a plastic pipe and sealed with a highly flexible silicone material. The re-bars were placed concentrically and the concrete was cast parallel to the loading direction. The trials were carried out on an electro mechanic testing machine where the specimens were loaded with a freight rate of 0.0008 mm/Sec. The applied force of the machine was measured corresponding to the slip displacement of the reinforcing bar on the non-loaded side. The gain of the slip path was constantly supervised during the whole testing period. Experimental results showed higher compressive strengths (36%) and splitting tensile strengths (28%) of the SCC specimens compared to normal concrete specimens. As well, the bond behaviour measured at 1, 3, 7 and 28 days after concreting was better for self-compacting concrete than that of normally vibrated concrete.

Asl et al (2008) carried out to study self-compacting concrete (SCC) is a highly fluid yet stable concrete that can flow consistently under its own weight, pass between bars, and fill in formwork without the need of compaction. The application of SCC effectively resolves the difficulties of concreting in situations with complicated formwork and congested reinforcements. In this study, the bond between SCC and steel reinforcement was investigated. The bonding strengths of reinforcing bars were measured using cubic specimens of SCC and of normal concrete. The SCC specimens were cast without applying compaction, whereas the specimens of normal concrete were cast by conventional practice with substantial compaction and vibration. The results showed that SCC specimens generated higher bond to reinforcing bars than normal concrete specimens and the correlation between bond strength and compressive strength of NC is more consistent.

Valcuende and Parra (2009) worked on examining the bond strength between reinforcement steel and concrete, and the top-bar effect on self-compacting concretes. Eight different concretes were used, four self-compacting (SCC) and four normally-vibrated (NVC). Examinations were conducted on 200 mm cube specimens and 1500 mm high columns. It was found that, at moderate load levels, SCC performed with more rigour, which resulted in greater mean bond stresses. The ultimate bond stresses are also somewhat greater, although, due probably to the negative effects of the bleeding, having less impact on failure, the differences between SCC and NVC are reduced considerably, and even disappear completely for concretes of more than 50 MPa. On the other hand, the top-bar effect is much less marked in the SCC, and therefore a change in the factor that takes into account this effect in the formulas used for calculating the anchorage length of the reinforcement is proposed for these concretes.

Hassan et al, (2010) studied on The bond strength of reinforcing bars embedded in full-scale heavily reinforced concrete sections made with industrial self-consolidating concrete (SCC) was investigated and compared with that of normal concrete (NC). The current ability of SCC mix through the dense reinforcement was visually monitored from a transparent formwork. The bond stress was tested for bars located at three different heights (150 mm, 510 mm, and 870 mm from the rear end of the pullout specimens) and at different tested ages (1, 3, 7, 14, and 28 days). The bond stress-free end slip relationship, the top bar effect and the effect of age on bond stress was investigated in both SCC and NC pullout specimens. Bond stresses predicted based on some major codes were compared with those obtained from experiments. The results indicated that casting SCC was much faster and easier and could be done with less labor effort and no concrete blockage among the heavy reinforcements compared to NC. The results also showed that the bond stress was slightly higher in the SCC pullout specimen compared to the NC pullout specimen. The difference was more pronounced in the top bars and at 28 days of testing.

(Fig. 2.6) shows a typical pullout test setup used for each test. The protruded steel bar was raised within a hollow hydraulic jack and a hollow load cell. The hydraulic jacking system was taken to apply concentric pullout force to the reinforcing bar. When the bond slip occurred, the free end displacement of the protruded bar was measured automatically by one (LVDT) attached to the loose terminal of the pullout bar. A computer assisted data acquisition system was automatically monitoring the shipment and the displacements at preselected time intervals throughout the loading history.

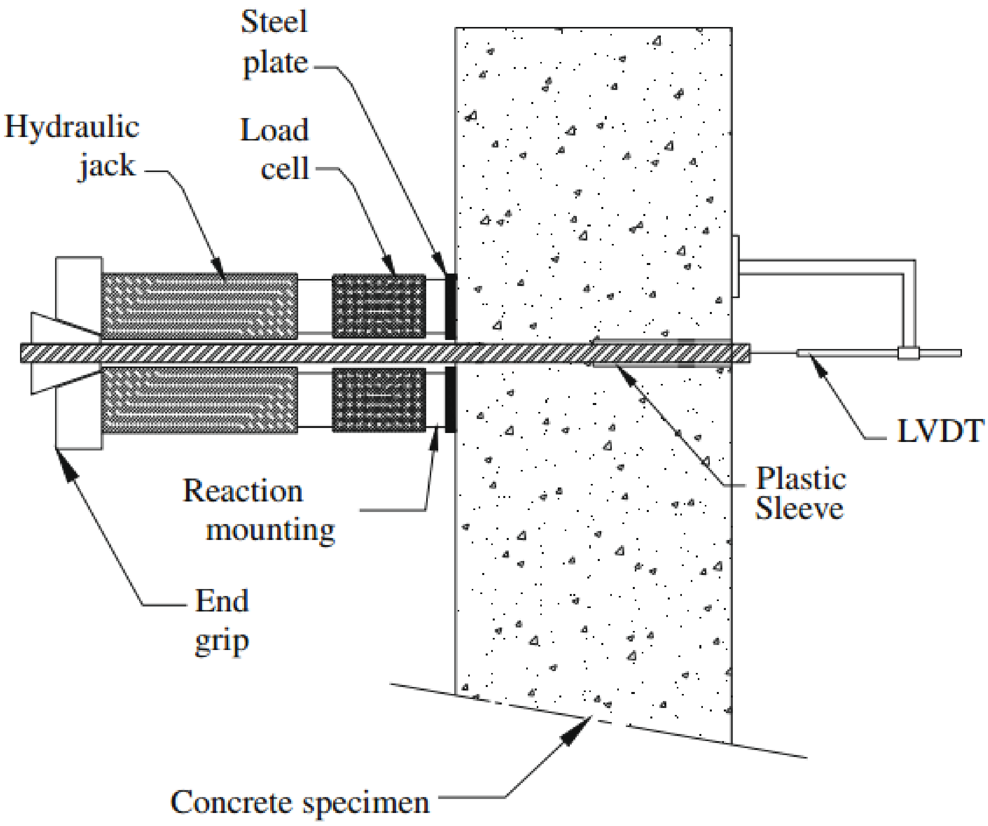


Fig 2.6 Pull out test setup (Hassan et al., 2000)

Pozolo and Andrawes (2011) presented an analytical method for predicting the transfer length of steel strands in prestressed girders using pull-out test results. The observational data from a series of 56 pilot tests is used to derive bond stress–slip relationships for 12.7 mm steel strands embedded in SCC and CC. Modifiable factors are applied to correlate pullout bond stresses to transfer bond stresses in pre-stressed members, and the modified relationships are integrated into three-dimensional finite element models to predict transfer lengths in pre-stressed SCC girders. The analytical predictions correlate well with experimental results and transfer length requirements of current US design codes.

Karahan et al, (2012) presented the fresh, mechanical and transport properties of expanded shale aggregate self-consolidating lightweight concrete (SCLC) containing metakaolin assessed by means of slump flow, flow time, V-funnel, L-box, compressive, flexural/splitting/bond strength, water absorption, porosity, sorptivity and rapid chloride permeability tests. Metakaolin content based SCLC mixtures were developed by incorporating 0%, 20%, 40% and 60% of as a replacement by weight of fly ash while keeping a constant cement and mineral admixture content of 450 kg/m3 and 150 kg/m3, respectively. These included four mixtures containing 0%, 5%, 10% and 15% metakaolin content as a partial binder replacement. It was observed that expanded shale aggregates SCLC can be produced with the density lower than 2000 kg/m3 which was increased by the addition of metakaolin. Increases in metakaolin content worsened the filling and passing ability of SCLC and by the addition of metakaolin no positive consequence on the strength properties on SCLC was monitored. Replacement of 20%, 40% and 60% of metakaolin with fly ash resulted 3%, 8% and 10% reduction in porosity and water absorption with respect to control mixture, respectively. The initial and secondary sorptivity values of SCLC mixtures with metakaolin replacement were equal or lower than the control mixture without metakaolin. Moreover, increases in metakaolin content showed significant improvement in chloride ion penetration resistance of SCLC.

Bond strength was calculated based on the maximum pullout load sustained during the test and compared according to metakaolin content. All pullout specimens failed due to splitting of concrete, and no pullout failure was discovered. Splitting failures of specimens are illustrated in (Fig. 2.7)

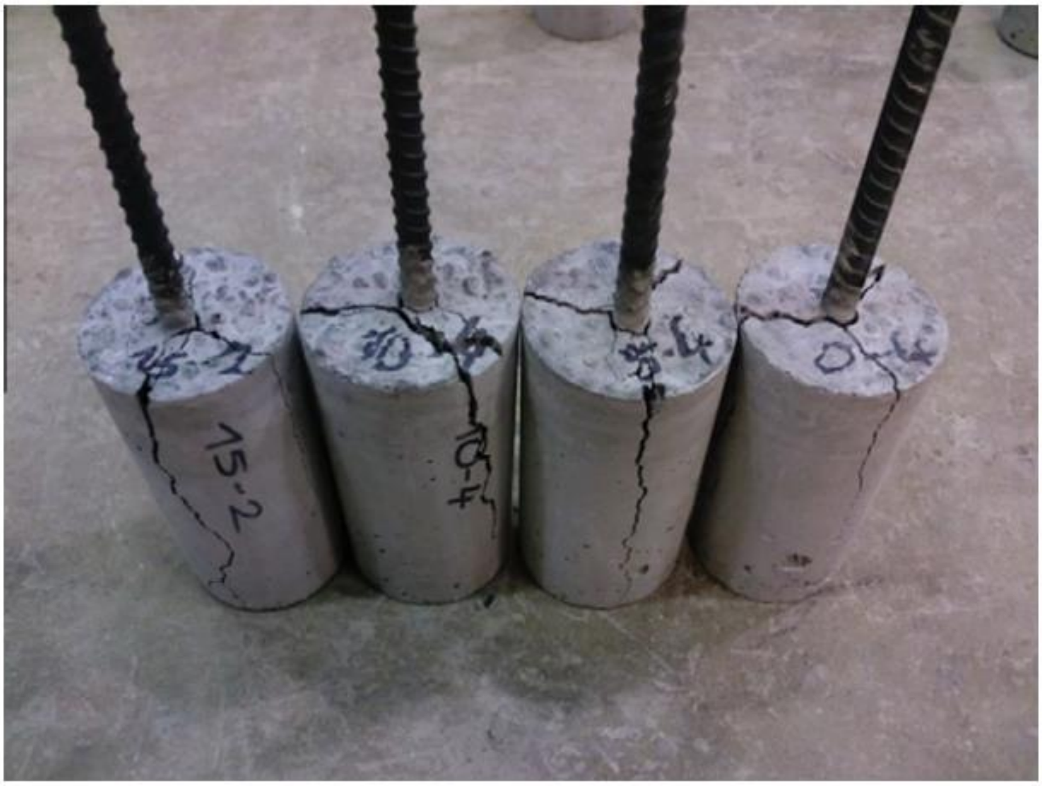


Fig 2.7 Typical crack pattern for SCLC specimens after pullout test (Karahan et al., 2012)

Helincks et al., (2013) carried out to investigate the bond and shear performance of powder type self-compacting concrete (SCC). In order to examine the bond strength of reinforcement in concrete, pullout tests (according to the RILEM recommendation RC6 part 2) were performed. In aggregate, 72 pullout specimens were tested, cast with different concrete mixtures and rebar diameters (8, 12, 16, and 20 mm). It was found that SCC shows normalized characteristic bond strength values as high as or higher than vibrated concrete (VC). In addition, as the bar diameter increases, larger bond strengths are measured, with the highest values for bars with diameter 12 or 16 mm. When larger diameters up to 20 mm are used, a decrease in bond performance is noticed.

Pop et al., (2013) investigated on the bond behavior between steel reinforcement and powder-type self-compacting concrete (SCC). A sum of 135 pullout cubes was cast by using four self-compacting mixes (SCC) and two vibrated concretes (VC). The main analyzed parameters were the concrete compressive strength, the reinforcement bar diameter, the embedded length of bars and cement/limestone ratio. The outcomes indicated that the ultimate bond strength can be greater in self-compacting concrete compared to vibrated concrete. At the same load level the bars in SCC tend to give a smaller case than in VC. Considering the influence of bar diameter and embedded length, it seems that SCC and VC behave in a similar way.

Alizadeh et al, (2014) carried out to Control low strength materials (CLSM) are valuable and self-compacting construction materials that have been applied in a broad mixture of applications, and describes the purpose of an optimized CLSM mixture that was applied as a structural fill for construction of a bridge abutment. The primary performance criteria for selection of a potential CLSM mixture where compressive strength to hold the bridge loads, excavatability and flowability to fill the entire abutment in one continuous stream. Several CLSM mixtures were produced and tried out in the lab for engineering properties including flowability, density, compressive strength and strain–strain behaviour. Since it was a critical area of concern in the design of the CLSM bridge abutment, the bond strength, performance of the CLSM to steel anchors was also investigated. In pullout tests, a CLSM mixture with a higher compressive strength resulted in higher bond strength and more brittle slippage. A mathematical simulation of pullout tests indicated that the bond strength decreases with increase in bar size and embedment length.

CLSM is much lower in strength than concrete and so its bond performance to steel rabies was identified as a critical area of concern in the design of the CLSM bridge abutment. Due to the importance for the internal stability of the abutment, the bond strength was evaluated by a pilot test using a wooden box of 0.61 m 0.61 m 0.91 m (2 ft 2 ft 3 ft) divided into four equal partitions (Test 1). Four rebars, 12.7 mm (0.5 in.) diameter with the embedment length of 0.91 m (36 in.), were placed and secured in the center of each partition, (Fig. 2.8).

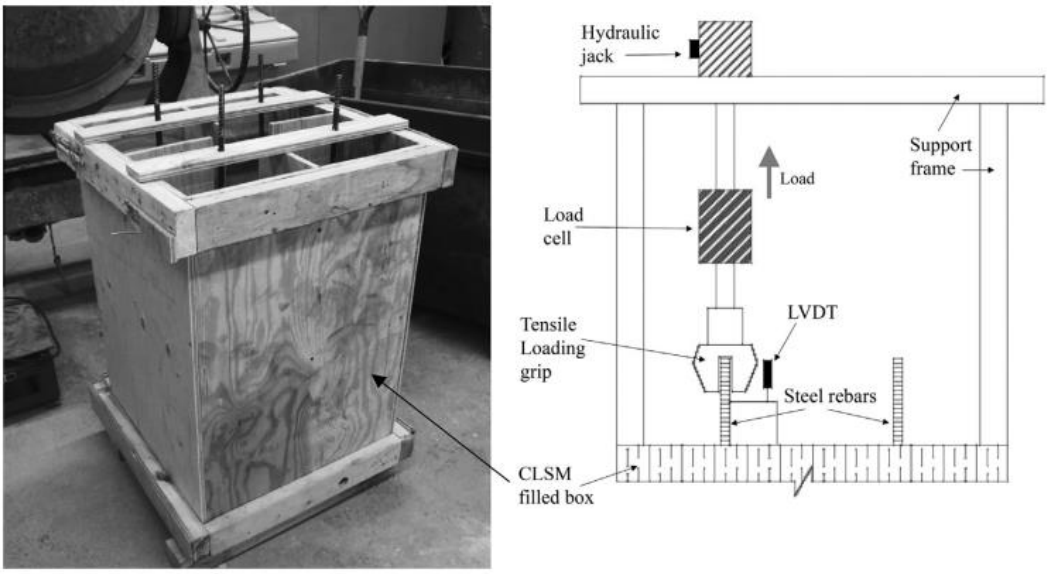


Fig 2.8 Pullout test set-up, box and location of rebars (Alizadeh et al., 2014).

2.2.2 Bond strength of fibers in FRC

Laranjeira and Aguado (2010) studied on predicting the pullout response of inclined hooked steel fibers; Steel fiber reinforced concrete (SFRC) is symptomatically an anisotropic material due to the random orientation of fibers within the cement matrix. Fibers under different inclination angles provide different strength contributions at a given crack width. Therefore the pullout response of inclined fibres is a paramount subject to understand and quantify SFRC behaviour, particularly in the case of fevers with hooked ends, which are currently the most widely used. Several experimental results were taken to validate the approach and to assure its suitability on distinct material properties and boundary conditions. The right agreement on calling the pullout behaviour of these fibres encourages its use towards a fresh concept of invention and optimization of SFRC.

Ali et al, (2013) Effect of fibre embedment lengths, diameters, pretreatment conditions and concrete mix design ratios on the bond strength between single coconut fibre and concrete is investigated. Fibers are prepared and categorized manually. Fiber diameters are measured by a stereomicroscope. Fiber and concrete properties are also determined experimentally. The simplified equations are proposed for estimating the fiber tensile stress, elastic modulus and toughness. Single fiber pull-out tests are carried out to determine load slippage curves with the help of an Instron tensile machine having load cell. Bond strength and energy required for fibre pullout are calculated from the observational data. The results show that fibers have the maximum bond strength with concrete when

- embedment length is 30 mm,
- fibers are thick,
- treated with boiling water, and
- Concrete mix design ratio is 1:3:3. Similar effects are observed for the energy required for fibre pullout. Obtained with the knowledge, empirical equations are also developed to determine the bond strength and energy required for fibre pullout.

Zīle (2013) predicted simple model of the influence of fibre geometry on the pullout of mechanically deformed steel fibres from the cementitious matrix is proposed.

During the pullout the mechanically deformed fibre is subjected to repetitive bending and unbending which cause an increase of the tension in the fibre. This increase of the tension depends on the amount of plastic work needed to straighten the fibre during the pullout. The model input parameters are mechanical and geometrical properties of mechanically deformed fibres. Model predictions were compared to the experimental results on the hooked-end and crimped steel fibre pullout and good agreement were observed.

Solitaire et al, (2013) studied the interfacial bonding between steel fibres and cement-based matrix. The fibres were treated chemically using a zinc phosphate conversion to achieve enhanced bonding with the mortar matrix. In order to attain a fuller position on the issue of chemical treatment different fibre parameters were studied in this enquiry, such as the fibre pattern, distance and diameter. In this respect, single sided fibre pullout tests were conducted on treated as well as on as received (untreated) fibres of hooked-end, straight and undulated shape. The analysis of the experimental results revealed that the fibre shape is of great importance since it contributes to mechanical interlocking that prevail during the pullout of the fibres. Chemical treatment was also demonstrated to act as an important function in the fibre–matrix interface, especially when mechanical interlocking is absent. Treated fibres exhibited a modified surface with a rough topology caused by precipitation of ZnPh crystals on the character. Optimum fibre con-figuration for maximum pullout performance can be taken based on the fibre surface contact region, since the pullout load and pullout energy is immediately linked to this attribute.

Mazaheripour et al, (2013) carried out reinforcing bars made of Glass-fibre-Reinforced Polymers (GFRPs) are more and more common as internal reinforcement of concrete structures and infrastructures. Since the design of GFRP reinforced concrete members is often controlled by serviceability limit state criteria (i.e. Deflection or cracks width control), an accurate knowledge of the GFRP-concrete bond behaviour is needed to formulate sound design equations. Furthermore, bond laws currently available and widely accepted for conventional steel repairs cannot be straightforwardly applied to GFRP ones. Hence, an experimental program consisting of 36 pullout bending tests was carried out to evaluate the bond performance between GFRP bars and steel fibre reinforced self-compacting concrete (SFRSCC) by analysing the influence of the following parameters: GFRP bar diameter, surface characteristics of the GFRP bars, bond length, and SFRSCC cover thickness. Based on the results obtained in this study, pullout failure was occurred for almost all the specimens. SFRSCC cover thickness and bond length plaid important role on the ultimate value of bond stress of GFRP bars. Moreover, the GFRP bars with ribbed and sand-coated surface treatment showed different interfacial bond behaviors.

Ganesan et al, (2014) carried out to examine the effect of steel-polypropylene hybrid fibres on the adhesion strength and bond stress–cutting response of deformed reinforcement bars embedded in high performance concrete. A total of 96 specimens was cast and tested in the present investigation. The main variables considered were the mass fraction of crimped steel fibres, volume fraction of polypropylene fibres and the diameter of reinforcement bars. The combination of 1% volume fraction of steel fibres and 0.10% volume fraction of polypropylene fibres gave better performance with regard to bond strength than the other combinations considered in this work.

Sawant et al, (2014) deals with an experimental investigation and results obtained on the high strength steel fibre reinforced concrete. The effects of these fibres on workability, density, and on the various strengths of high strength concrete (M60 grade concrete) are studied. This study emphasises on the Pullout strength of concrete. The fibre content varied from 0.5 to 5% by weight of cement at the interval of 0.5 %. Concrete cubes of 150x150x150 mm with 16mm tow bar embedded in concrete at the midpoint of the cube were cast. All the specimens are water cured and tested at the age of 7 and 28 days. Workability of wet mix is found to be reduced with increased fibre content. Super plasticizer is used to increase workability. Ductility and bond of concrete are found to increase in Steel Fibre Reinforced Concrete (SFRC) as observed from the results. New expressions for Pullout strength by regression analysis are proposed in relation with volume fraction of fibers (%VF) and bond strength. A significant improvement in the Pullout strengths is observed due to inclusion of steel fibers in the concrete. Maximum fiber content is found to be strength dependent.

2.2.3 Bond strength of reinforcing bar in other types of concrete

Ashtiani et al., (2013) carried out to investigate bond properties between reinforcement and HSSCC as well as conventionally vibrated high-strength concrete (CVHSC). Appropriate mix designs for both HSSCC and CVHSC were first developed to achieve comparable concrete compressive strength of about 90 MPa. The effects of bar grade, diameter, bond length, and concrete type were investigated by means of pull-out tests for both concrete types; where, special attention was paid to the post-yield slip behaviour of different steel grades. It was found that the difference in ductility of bars with different grade results in different rate of diameter reduction due to axial tensile stress, which consequently affects their bond performance; especially in the post-yield range. Available bond models were applied to the experimental outcomes of this study and modifications and/or new expressions are suggested where possible.

The test setup of a typically instrumented specimen is shown in Fig. 2.9

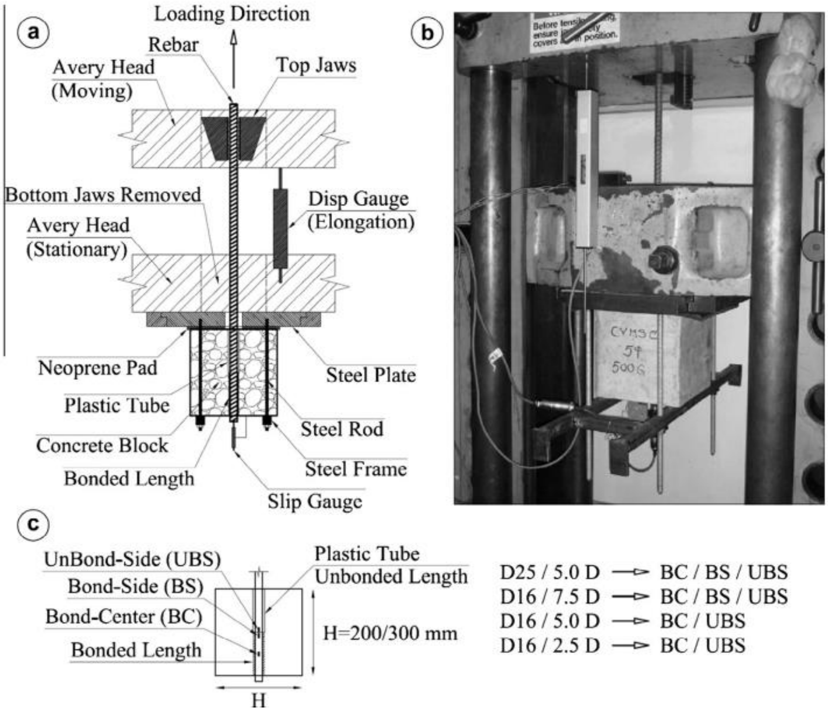
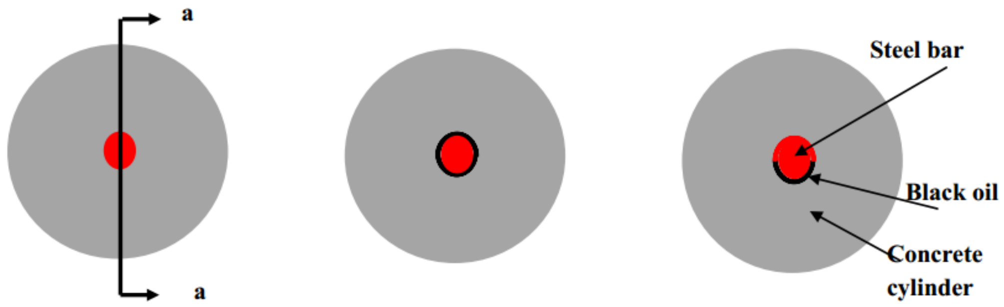


Fig 2.9 Pullout test (Ashtiani et al., 2013).

2.2.4 Bond strength of reinforcing bars in conventional concrete

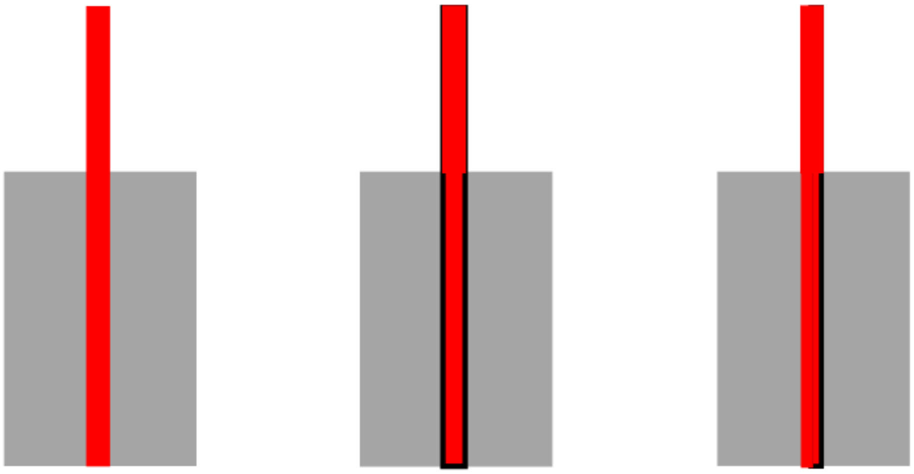
Albarwary and Haido (2013) investigated bond strength of the oil polluted steel bars with concrete. Examinations were conducted on 72 cylindrical concrete specimens with compressive strength of 24 MPa at age of 28 days. Two embedded lengths of steel bars were considered in present tests, namely 30 cm and 15 cm with four bar diameters. Grounded along the current experimental results, it is resolved that the pollution of steel bars with oil does not affect their bond strength if the embedded length of the bars is increased and their diameters are decreased. For these bars the bond strength is greater than the tensile strength. It is discovered that the embedded length of the bar inversely affects the deterioration of the bond strength due to the bar pollution. For the polluted and non-polluted bars it can be stated that small bar sizes has greater bond strength than larger bar sizes if the embedded length is small. The predominant type mode of failure is the splitting mode for all the tested specimens and no slip failure occurred in testing all the polluted and non-polluted bars throughout the experiments

In that respect are three cases of pollution of steel bar are used demonstrated in Fig. 2.10



A- Non-polluted bar B- 100%-polluted bar C- 50%-polluted bar

(Top view)



Section a-a

Fig. 2.10 Case of steel bar oil pullotion

2.2 Influence of Admixtures on Concrete Properties

In the following are presented several papers, found in the literature, on the effects of mineral and chemical admixtures on the fresh and hardened concrete. The mineral admixtures referred to is fly ash. The chemical admixtures considered are high range water reducer or superplasticizer and viscosity-modifying agent.

2.3 Influence of Mineral Admixtures

Mineral admixtures are added to concrete as part of the total cementitious system. They may be used in addition to or as a partial replacement of Portland cement in concrete depending on the properties of the materials and the desired effect on concrete (Mindess et al., 2003). Mineral admixtures are used to improve a particular concrete property such as workability, strength or compatibility. The optimum amount to use should be established by testing to determine (1) whether the material is indeed improving the property, and (2) the correct dosage rate, as an overdose or under does can be harmful or not achieve the desired effect, because they react differently with different cements (Kosmatka et al., 2002).

2.3.1 Fly Ash

Gebler and Klieger (1983) studied concretes containing fly ash in order to determine its effect on the air-void stability. 10% to 20% by mass of fly ash was used in the total amount of cementitious material. The tests undertaken indicated that air contents of concrete containing class C fly ash appeared to be more stable than those of concrete containing Class F fly ash. This happened primarily because Class C fly ashes have lower organic matter content and carbon content values. The surveys uncovered that the higher the organic matter content of a fly ash, the higher would be the air-entraining admixture requirement for concrete in which the mixture is used. Practically, all concretes containing fly ash required more air-entraining admixture than concretes without fly ash and the concretes containing Class C fly ash tended to lose less air than concretes with Class F fly ash.

Other experiments carried out by Ozawa (1989) focused on the influence of mineral admixtures, like fly ash and blast furnace slag, on the flowing ability and segregation resistance of self-compacting concrete. He found out that the flowing ability of the concrete improved remarkably when Portland cement was partially replaced with fly ash and blast furnace slag.

After trying different proportions of admixtures, he concluded that 10-20% of fly ash and 25-45% of slag cement, by volume, proved the best flowing ability and durability characteristics.

Nick and Singh (1997) conducted tests on concretes containing between 15% and 25% by mass Class F and Class C fly ashes, to evaluate the time of setting, bleeding, compressive strength, drying shrinkage, and abrasion resistance. The effects of moisture and temperature during curing \were also examined. The outcomes of the research showed that concretes containing Class C fly ash and were moist cured at 73°F (23°C) developed higher early age (1 to 14 days) compressive strengths than concretes with Class F fly ash. The long-term (90 days and greater) compressive strength of concretes containing fly ash was not significantly influenced by the class of fly ash. The air-cured concretes containing Class F fly ash did not develop strengths equivalent to air-cured normal concretes and air-cured concretes containing Class C fly ash developed relatively greater compressive strengths than air-cured concretes containing Class F fly ash. For concretes containing either class of fly ash, compressive strengths at 7 days increased with an increase in curing temperature. Concretes with fly ash showed less bleeding than conventional ones.

The slump flow and funnel tests showed values within the ranges of other tests previously undertaken. The compressive strengths of hardened concrete specimens decreased with the increasing proportion of U-LFA over 25%, while they remained approximately constant when T-LFA was used in percentages that exceeded 25%. After 28 days, compressive strengths between 50 MPa and 60 MPa and splitting tensile strengths between 4 and 5 MPa were obtained from self-compacting concretes, with w/c ratios ranging from 0.3 to 0.46.

Sarker, (2011) evaluates the bond strength of fly ash based geopolymer concrete with reinforcing steel. Pull-out test in accordance with the ASTM A944 Standard was carried out on 24 geopolymer concrete and 24 ordinary Portland cement (OPC) concrete beam-end specimens, and the bond strengths of the two types of concrete were compared. The compressive strength of geopolymer concrete varied from 25 to 39 MPa. The other test parameters were concrete cover and bar diameter. The reinforcing steel was 20 mm and 24 mm diameter 500 MPa steel deformed bars. The concrete cover to bar diameter ratio varied from 1.71 to 3.62. Failure occurred with the splitting of concrete in the region bonded with the steel bar, in both geopolymer and OPC concrete specimens. Comparability of the test results shows that geopolymer concrete has higher bond strength than OPC concrete. This is because of the higher splitting tensile strength of geopolymer concrete than of OPC concrete of the same compressive strength. A comparison between the splitting tensile strengths of OPC and geopolymer concrete of compressive strengths ranging from 25 to 89 MPa shows that geopolymer concrete has higher splitting tensile strength than OPC concrete. This suggests that the existing analytical expressions for bond strength of OPC concrete can be conservatively used for calculation of bond strength of geopolymer concrete with reinforcing steel.

2.4 Influence of Chemical Admixtures

Chemical admixtures represent those ingredients which can be added to the concrete mixture immediately before or during mixing. The role of chemical admixtures such as water reducers, retarders, high-range water reducers or superplasticizers (SP), and viscosity-modifying admixtures is necessary in order to improve some fundamental characteristics of fresh and hardened concrete. They make more efficient use of the large amount of cementitious material in high strength and self-compacting concretes and help to obtain the lowest practical water to cementing materials ratio.

Chemical admixtures efficiency must be measured by comparing strengths of trial batches. Also, compatibility between cement and supplementary cementing materials, as well as water reducers, must be investigated by trial batches. From these, it will be possible to determine the workability, setting time, bleeding, and amount of water reduction for giving admixture dosage rates and times of addition. Due to the fact that this research dealt only with superplasticizers and viscosity modifiers, papers found in the literature about these types of chemical admixtures would be presented in the following.

2.4.1 Superplasticizers

A survey of four commercially available superplasticizers used in type I Portland cement concrete mixes was made by Whiting (1979). They stood for both melamine- and naphthalene-based formaldehyde condensation products. Hardened concrete specimens were prepared and tested for compressive strength development, drying shrinkage, freeze-thaw resistance, and resistance to deicing scaling. From his research, Whiting found out that high range water reducers were capable of lowering the net water content of concrete mixtures from 10% to 20% when used in dosages recommended by the manufacturers.

ASL et al, (2008) worked on Bond strength of reinforcement steel with self-compacting concrete and at early ages, appeared the effect of super plasticizing admixtures in the SCC mix, the development of compressive and bond strength of SCC is slow. So in the case of SCC more attention needs to be paid to the consideration of construction safety.

2.5 Examples of Self-Compacting Concrete Applications

Since the development of the prototype of self-compacting concrete in 1988, the use of this type of concrete in actual structures has gradually increased. Due to its special properties, self-compacting concrete has been chosen to partially replace the conventional concrete in a few construction projects of major importance, in Japan and Canada. The following are some instances of construction applications, which used self-compacting concrete.

The Bankers Hall project, which was one of the largest commercial office projects in Calgary, Western Canada, involved the placement of self-compacting concrete in two mat foundations with congested reinforcement (Nmai and Violetta, 1996). The amount of concrete used to be approximately 9000 m3 and the mixture was proportioned so that it would have very good flowing characteristics in order to satisfy the pumping and placement requirements, because of the intricate reinforcement. A very significant application of self-compacting concrete was the two anchorages of the Akashi-Kaikyo (Straits) Bridge opened in April 1998 in Japan (Ouchi and Hibino, 2000), a suspension bridge with the longest span in the world, approx. 1,991 meters (Fig 2.11). The bulk of the cast concrete in the two anchorages was around 290,000 m3. A new construction system, which made full use of the public presentation of self-compacting concrete, was put in for this. The concrete was mixed at the batching plant beside the site and was pumped out of the plant. It was transported 200 meters through pipes to the casting site, where the pipes were arranged in rows of 3 to 5 meters apart. The concrete was cast from gate valves located at 5-meter intervals on the tubes. These valves were automatically controlled so that a surface level of the cast concrete could be maintained. In the last analysis, the role of self-compacting concrete shortened the anchorage construction period by 20%, from 2.5 to 2 age.

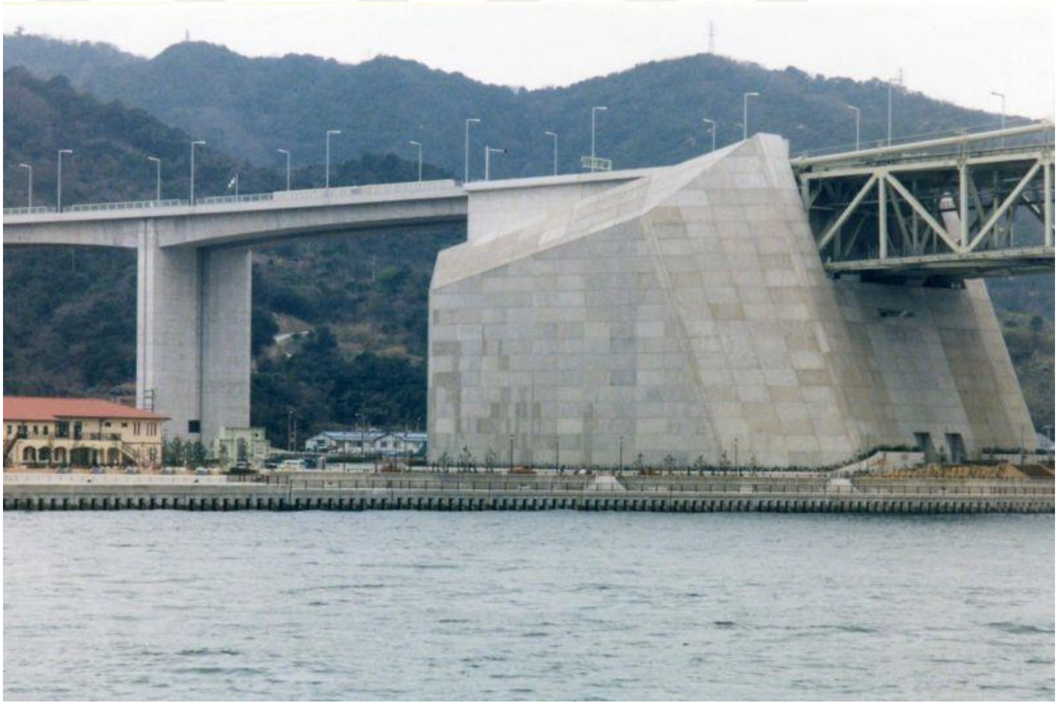


Fig 2.11 Anchorage of Akashi-Kaikyo Bridge, Japan (Ouchi and Hibino, 2000).

The Burj Dubai structure represents the stateof-the-artin super high-rise buildings. During its construction the most recent accomplishments in all fields have been united, including concrete production technology. Several different concrete mixes were used in this project. It was necessary to place 230000m3 of fresh concrete.

That is, the quantity that was built-in into tower, podium and office annex excluding foundations. The designed concretes were obtained using

Portland cement mixed with silica fume, fly ash or ground slag. As a consequence, different materials having high density and high final strength were obtained (concrete C50 was built-in into floor structures and C60 and C80 into vertical load-bearing members).

The structure has sufficient rigidity, toughness and high load-bearing capacity. In the course of construction of the building the concrete was pumped to higher and higher heights so it was necessary to provide extraordinary flowing ability of concrete through pipes. A world record was achieved: on November 8, 2007 highest vertical concrete pumping for buildings, 601m, was executed. Everything in this fantastic project was carefully planned. Thus, concrete was poured usually at night to enable work at lower temperatures and higher humidity. Concrete was additionally cooled

By adding a part of water in the form of ice. Total height, 818 m, was reached on January 17, 2009 (Fig 2.12)

Fig. 2.12 Burj Dubai structure (Ruza, 2009)

Nowadays, self-compacting concrete applications are limited to special cases where it is impossible to use ordinary concretes. In these cases, the quality control relies on several different non-standard, and mostly not fully applicable, tests supplemented by a significant personal expertise of specialist suppliers or contractors. Due to this fact, special steps must be considered in order for the self-compacting concrete to be considered a standard concrete.

CHAPTER THREE

EXPERIMENTAL STUDY

3.1 Materials

This section will present the chemical and physical properties of the all ingredients. The relevant ASTM (American Society for Testing and Materials) procedures were followed for determining the properties of materials used in this investigation.

3.1.1 Portland Cement

An ordinary Portland Cementtype I ordinary Portland cement conforming to the Iraq Standard manufactured by MAS industrial company was used. The physical properties and the chemical composition of the cement are presented in Table 3.1. It has a Blaine fine of 3393 cm2/g and specific gravity of 3.15 g

.

Table 3.1 Physical characteristics and chemical composition of cement and mineral admixtures

Chemical requirements		**Result**	**Acc. Iraq stand. 5/1984**
Lime saturation factor (L.S.F)		0.96	0.66-1.02
Sluphate Tri-Oxide (So3)		2.3	2.8 Max. %
Magnesium Oxide (MgO)		1.88	5.0 Max. %
Loss on ignition (L.O.I)		3.04	4.0 Max. %
Insoluble Residue (Ins. Res.)		0.74	1.5 Max. %
Physical Requirements		Result	Acc. Iraq Stand. 5/1984
Compressive strength (Mpa)	**3 Days**	30.1	Not less than 15
	7 Days	36.1	Not less than 23
	28 Days	47.7	Not specified
Initial Set. Time, minute		120	Not less than 45
Final Set. Time, hour		02:38	Not more than 10
Expansion (Le-Chatelie), mm		0.6	Not more than 10
Blaine cm2/g		3393	Not Less than 2300

3.1.2 Mineral Admixtures

The mineral admixture used in the experimental program was a class F fly ash (FA). The Fly ash was obtained from Ceyhan Yumurtalık Therm al power. Their physical and chemical properties are presented in Table 3.2

Table 3.2.

Chemical analysis (%)	**Fly Ash**
CaO	4.24
SiO2	56.2
Al2O3	20.17
Fe2O3	6.69
MgO	1.92
SO3	0.49
K2O	1.89
Na2O	0.58
Loss of ignition	1.78
Specific gravity (g/cm3)	2.25
Specific surface (cm2/g)	2,870

3.1.3Chemical Admixtures

A polycarboxylic-ether type superplasticizer (SP) having a specific gravity of 1.07 was used in all mixtures to obtain the required workability. The properties of superplasticizer are listed in Table 3.3 as provided by the supplier.

Table 3.3 Properties of superplasticizer

Properties	**Superplasticizer**
Name	Glenium 51
Color tone	Dark brown
State	Liquid
Specific gravity (kg/l)	1.07
Chemical description	Modified polycarboxylic type plymer
Recommended dosage	%1-2 (% binder content)

3.1.4 Aggregates

For the aggregates natural (Kalak River) sand and gravel were employed. The particle size distributions and physical properties of the aggregates are presented in Tables 3.4 to 3.7

Table 3.4 Computation of Fineness Modulus for the gravel specimen

Sieve size (mm)	**Weight retained (kg)**	**Cumulative weight retained (kg)**	**% of cumulative weight retained**	**%cumulative passing**
50.8	0	0	0	100
38.1	0	0	0	100
25.4	0	0	0	100
19	0	0	0	100
12.5	2.2	2.2	44	56
9.5	2.44	4.64	92.8	7.2
4.75	0.232	4.872	97.44	2.56
2.36	0.074	4.946	98.92	1.08
1.16	0.004	4.95	99	1
Pan	0.02	4.97	99.4	0.6
Sum	4.97		531.56	
F.M	5.32			

Mass of sample taken = 5 kg

Fineness Modulus = (sum of cumulative % of weight retained on sieves)/100

Table 3.5Computation of Fineness Modulus for the sand specimen

Sieve size (mm)	**Weight retained (kg)**	**Cumulative weight retained (kg)**	**% of cumulative weight retained**	**%cumulative passing**
9.5	0	0	0.00	100.00
4.75	0.121	0.121	4.03	95.97
2.36	0.694	0.815	27.17	72.83
1.18	0.347	1.162	38.73	61.27
0.6	0.818	1.98	66.00	34.00
0.3	0.727	2.707	90.23	9.77
0.15	0.232	2.939	97.97	2.03
Pan	0.06	2.999	99.97	0.03
Sum	2.999		424.10	
F.M	**4.24**			

Mass of sample taken = 3 kg

Fineness Modulus = (sum of cumulative % of weight retained on sieves)/100

Table 3.6properties of the sand

Sand		
Property	**Units**	**Average value**
1. Bulk Specific gravity at (SSD)	Dimensionless	2.68
2. Bulk Specific gravity at (dry)	Dimensionless	2.65
3. ApparentSpecific gravity	Dimensionless	2.73
4.Water absorption	%	1.34
5. Fineness modulus		4.24
6. Sieve analysis (grading)		See Fig. 3.1., Cu = 9, Cc= 0.35

Table 3.7properties of the gravel

Gravel		
Property	**Units**	**Average value**
1. Specific gravity (SSD)	Dimensionless	2.73
2. Specific gravity (dry)	Dimensionless	2.71
3. Apparent	Dimensionless	2.74
4.Water absorption	%	0.4
5. Fineness modulus	Dimensionless	5.32
6. Rodded unit weight	Kgm^{-3}	1732.6
7. Maximum size	mm	19
8. Shape (Roundness)		Well rounded(0.8)
9. Shape (Sphericity)		Medium sphericity (0.5 - 0.70)
10. sieve analysis (grading)		See Fig.3.2 , Cu = 1.38, Cc= 1.09

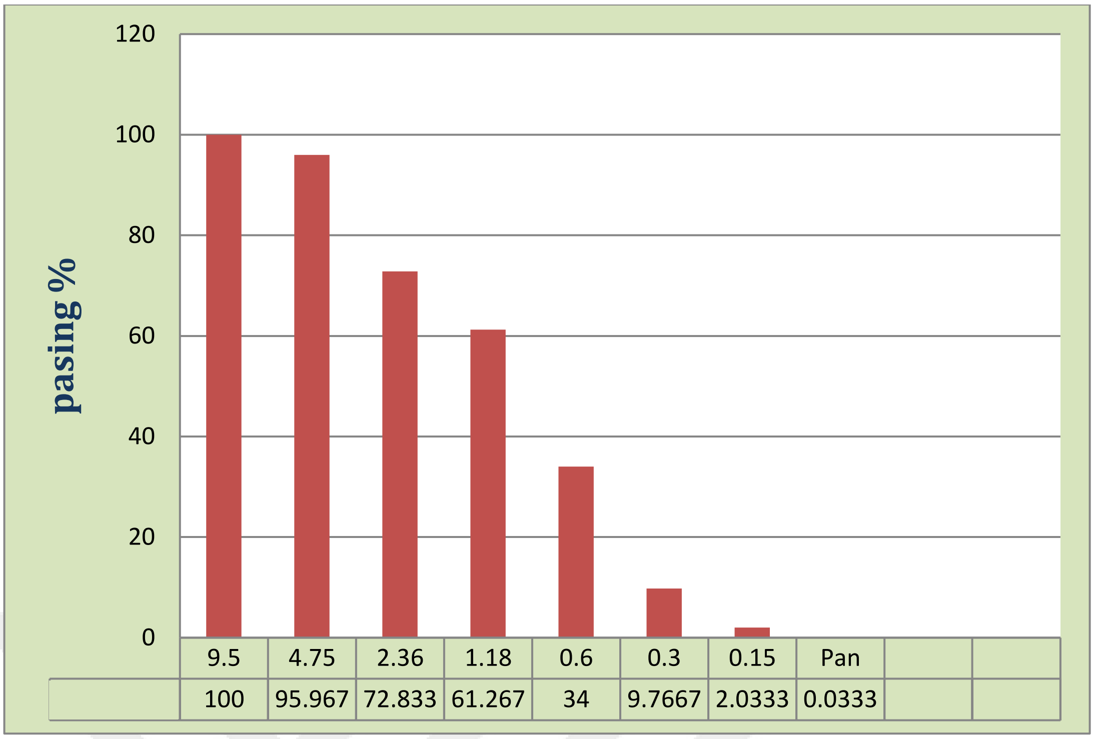


Fig.3.1. Particle size distribution for the sand specimen

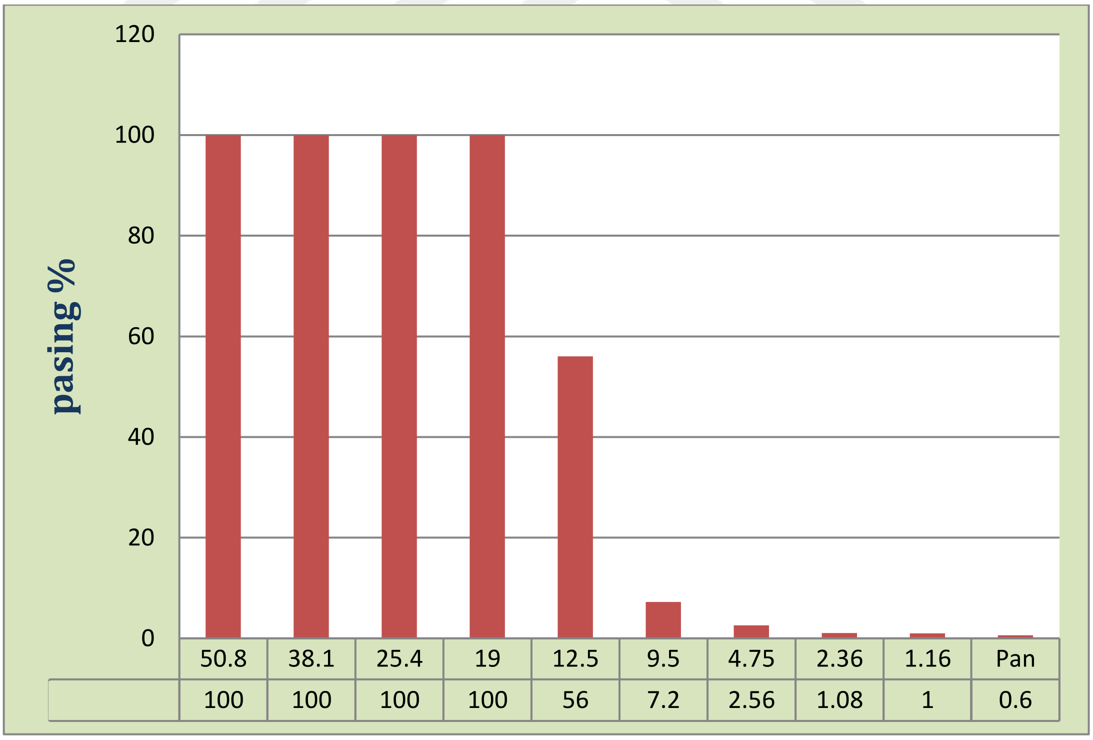


Fig.3.2. Particle size distribution for the gravel specimen

3.1.5 Stone Powder

Specification of Stone Powder demonstrated in table 3.8 was used in mix design

Table 3.8 specification of stone powder

Particulars	Result in Percent
Silicon as SiO_2	01.64 %
Aluminum as Al_2O_3	00.28 %
Iron as Fe_2O_3	00.14 %
Calcium as CaO	54.32 %
Calcium as $CaCO_3$	97.00 %
Magnesium as MgO	00.40 %
Magnesium as $MgCO_3$	00.84 %
Loss on Ignition (L.O.I.)	43.08 %

3.1.6 Reinforcing steel bars

In experimental work for this study were used two types from steel bar (10 mm and 16 mm) and the specified shown in table (3.9 and 3.11)

Table 3.9 Specification of Steel bar type (10 mm)

s	Actual Diameter (mm)	Mas (kg/m)	Yield stress 0.35 % (Mpa)	Ultimate stress (Mpa	Elongation (%)	Grad (SI)		Required grad (SI)	Bending test (Pass/fail)	Manufacture company (country)
1	9.97	0.61	560	779.5	23.5	550	550	420	Pass	Erbil Steel
2	9.96	0.61	565	785.8	24.9	550				
3	10.11	0.63	570	769.9	23.1	550				

Sampling (according to IO-NCCLR sampling Boulder): For each diameter one sample (3 bars for tension test +1 bar for bending test) should be taking for the specified quantities shown in sampling table 3.10:

Table 3.10 specified quantities of (10 mm)

Bar Diameter (mm)	< 10	10-16	20-32	>32
Quantity (ton)	25	35	45	55

Table 3.11 Specification of Steel bar type (16 mm)

s	Actual Diameter (mm)	Mas (kg/m)	Yield stress 0.35 % (Mpa)	Ultimate stress (Mpa)	Elongation (%)	Grad (SI)		Required grad (SI)	Bending test (Pass/fail)	Manufacture company (country)
1	16.05	1.59	515	770	20.4	420	520	420	Pass	Erbil Steel
2	16	1.58	520	774.7	20.5	520				
3	16.07	1.59	520	771.5	20.2	520				

Sampling (according to IO-NCCLR sampling Boulder): For each diameter one sample (3 bars for tension test +1 bar for bending test) should be taking for the specified quantities shown in sampling table 3.12:

Table 3.12 specified quantities of (16 mm)

Bar Diameter (mm)	< 10	10-16	20-32	>32
Quantity (ton)	25	35	45	55

- Tests were performed according to **ASTM A370-05 & E290- 97R04** and evaluated according to **ASTM 615-09B and ASTM A706-09B**

3.2. Mix Design

A total of three mixtures were designed having a constant water-binder ratio of 0.42 with total cementitious materials content of ranges between (400-466) kg/m3. In the production SCC concretes the mineral admixtures used was25% cement + Fly ash and chemical admixture 1.5 % by weight of cement.

The mixture proportion according to ACI 237.1 where upset are shown in table 3.13

Table 3.13 Mix proportion for three mixes of self-compacted concrete According to ACI 237

Constituents	Mix-1	Mix-2	Mix-3
Cement	300	325	350
Fly Ash (25 %)	100	108	116
w/cm	0.42	0.42	0.42
Chemical admixture (1.3 %) by weight of cement	4	4.25	4.5
Water	164	177.6	191
Stone powder (15 %)	45	49	53
% paste(Without air)	0.325912	0.352916	0.37987
% Volume of mortar	0.7	0.7	0.7
Sand/ Aggregate	0.49	0.49	0.49
Sand	952.4965	879.8571	807.3495
Total Aggregate	1943.87	1795.627	1647.652
Estimated Density	2556.87	2459.527	2362.402

3.3Mixture Proportion and Casting methods

In order to commence the experimental of our study, this is one of the two main parts, we started by preparing and cleaning all the utilities that we might need to conduct our experiments. For the very reason I set up a plan to carry out my tests, which included three mixes, each mix needed 4 different periods of times to achieve the results. The periods consisted of (3, 7, 28, and 56). For each period the experiment needed three models. In addition each mix was made of three groups.

First group was exclusively related to compressive strength, while second and third group was about pull-out test.

For groups second and third, for each mix needed 12 (10mm) steel bar, and 12 (16mm), so that the total for all the mixes add up to 36 (10mm) steel bars, and 36 (16mm) steel bars, all with the length of 60cm. This was followed by preparing 72 cubs (150*150*150) in diagram made of plastic, and it was cleaned and lubricated from inside with oil, this is to ease the process of pulling out the concrete. For groups second and third needed a method to hold the steel right in center of the cube, for this purpose we sought assistant from a blacksmith to design the very tool to hold the steel bars. Therefore, 48 models were made, as referred to in fig (3.3).

Fig 3.3 hold to the steel bars

Afterwards the cubs were prepared as referred to in Fig (3.4).

Fig (3.4) prepared the cube before casting

Then with using an electric mixer as shown in Fig (3.5).

Fig (3.5) the electric mixer of concrete was used

Finally started casting according to the measures . After preparing all the materials, mixed the gravel with the sand in mixer and run it for 2 minutes, to have the ultimate mix. Then mixed the fly ash and the cement in a bucket separately with (30%) of the water that was prepared for the mix, afterwards I add this mix to the main mixer with stone powder.

Then the remaining water which makes about (70%) was mixed with superplasticizer in a separate bucket and was add gradually to the main mixer as is shown in Fig (3.6).

Fig (3.6) the photographic of concrete mixing by mixture

Then 12 cubs was filled with the mix that was in the mixer as it is shown in Fig (3.7).

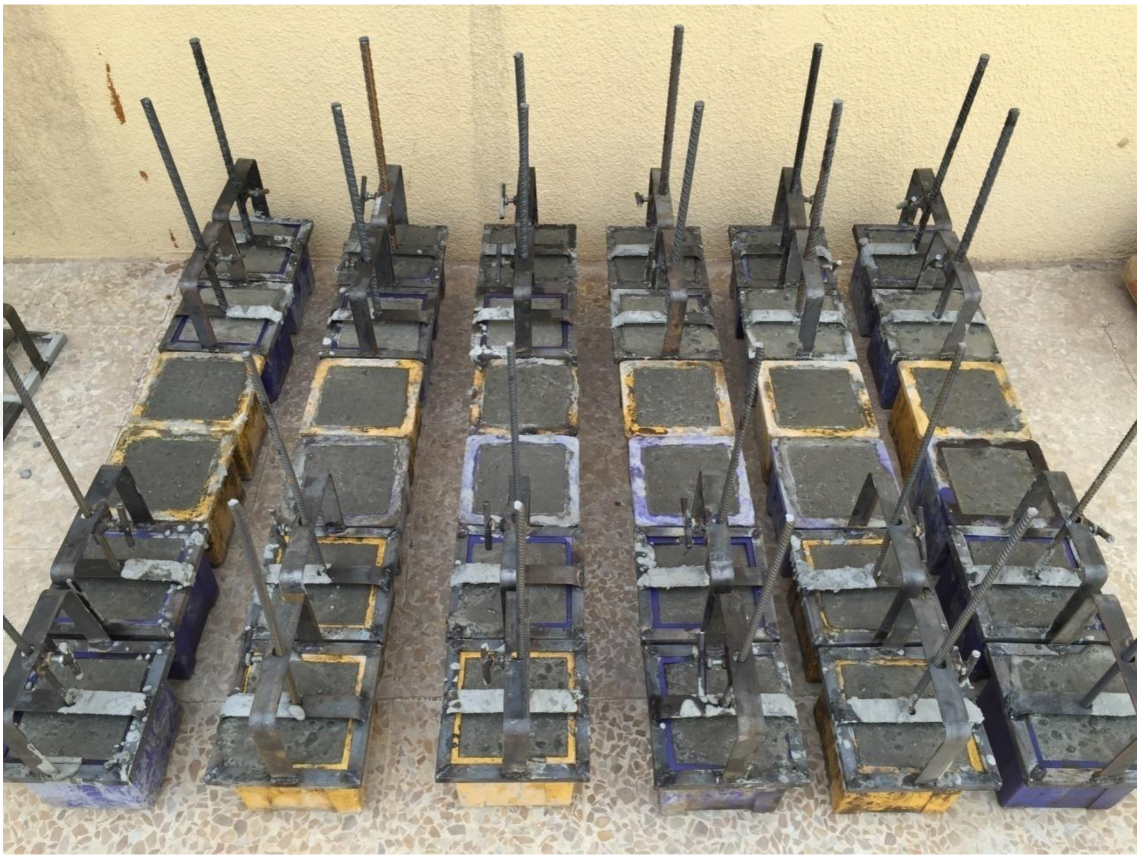


Fig (3.7) photographic of specimens of concrete

This procedure was repeated three times for each mix. After that these cubs were placed in a shaded place as in Fig (3.7).

After 24 hours from this process, and with the help of air- compressor I managed to pull out the concert out of the cast., and then they were color coded; first mix was plain (colorless), second mix was colored in blue and the third mix was colored with white paint, finally they were all dipped in water until the testing day as it is referred to in Fig (3.8)

Fig (3.8) photographic all specimens dipped in water

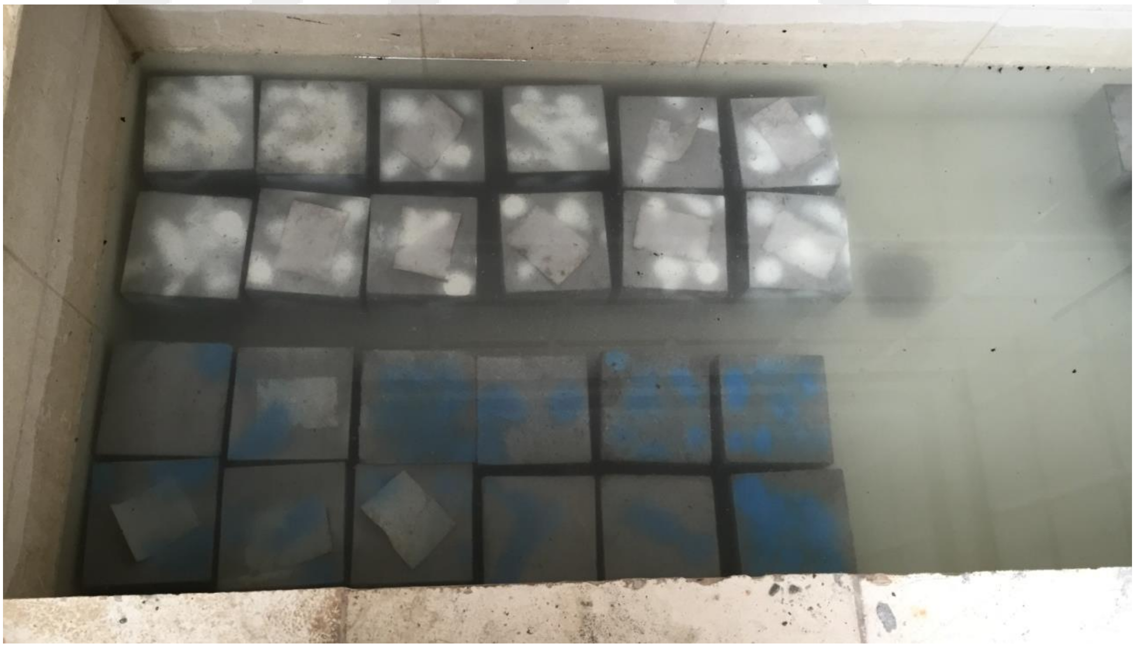
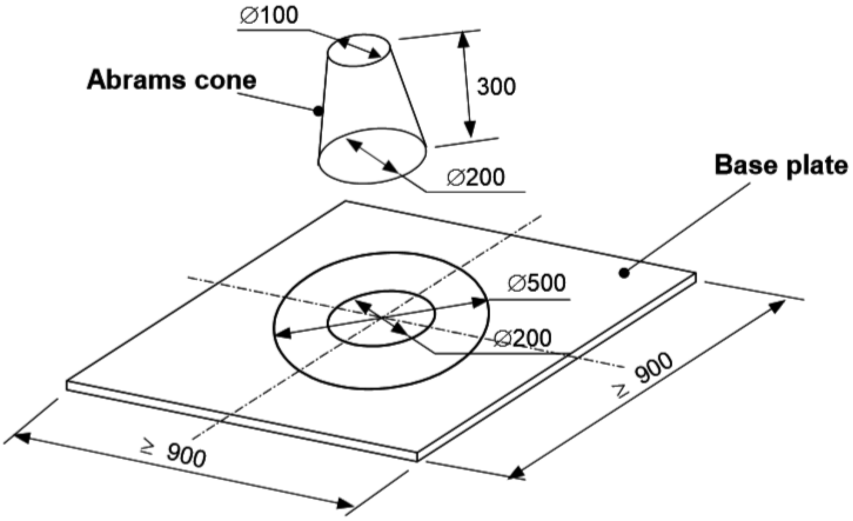


Fig (3.8) photographic all specimens dipped in water

3.3 Testing fresh properties of SCC

3.3.1 Slump Flow

A sample of freshly mixed concrete is placed in a mold shaped as the frustum of a cone.The concrete is placed in one lift without tamping or vibration. The mold is raised, andthe concrete allowed spreading. After spreading ceases, two diameters of the concretemass are measured in approximately orthogonal directions and slump flow is the averageof the two diameters. The test shown in fig 3.9



a- Base plate and Abrams cone

Fig (3.9) slump flow test

b- Clean slump plate

Fig(3.9) slump flow plate

c- The test operation

Fig (3.9) slump flow test

3.3.1.1 Slump Flow Time T_{50}

The slump flow experiment employed for checking the flow rate and flow ability ofself-compacting concrete in unconfined positions. It can easily be specified for all SCCs, as the main inspect at which the designed concrete match the specifications. To measure the slump flow, the slump flow cone is fully filled with SCLWCswithout compaction and the upper surface is leveled. The cone is raised upward slowly and an average diameter is determined from the spread concrete as illustrated in Fig 3.10. Moreover, the time at which the cone is raised and when the moving concrete attaches the 500 mm diameter circle is measured. This is known as T500 time according to EFNARC [61], thus a shorter time means higher flow ability. There are three flow classes for different application areas of these classes are given in Table3.14. Eventually, visual observations during the measurement of the T500 time provide information about uniformity and tendency of segregations.

Fig (3.10) slump T_{50} test

Table 3.14 Slump flow, viscosity, and passing ability classes according to EFNARC

Slump flow classes	**Slump flow diameter (mm)**
SF1	550 - 650
SF2	660 – 750
SF3	760 – 850
Viscosity classes	$T_{50}(S)$
VS1/VF1	≤2
VS2/VF2	>2
Passing ability classes	
PA1	≥0.8 with two rebar
PA2	≥0.8 with three rebar

3.3.1.2 Slump Flow with J-Ring

The J-ring test aims at investigating both the filling ability and the passing ability of SCC. It can also be used to investigate the resistance of SCC to segregation by comparing test results from two different portions of sample. The J-ring test measures three parameters: flow spread, flow time T50J (optional) and blocking step. The J-ring flow spread indicates the restricted deformability of SCC due to blocking effect of reinforcement bars and the flow time T50J indicates the rate of deformation within a defined flow distance. The blocking step quantifies the effect of blocking. And the procedure the test did by cleaned base plate in a stable and level position. Then fill the bucket with 6~7 liters of representative fresh SCC and let the sample stand still for about 1 minute (± 10 seconds). Under the 1 minute waiting period pre-wet the inner surface of the cone and the test surface of the base plate using the moist sponge or towel, and place the cone in the center on the 200 mm circle of the base plate and put the weight ring on the top of the cone to keep it in place. (If a heavy cone is used, or the cone is kept in position by hand no weight ring is needed). After that place the J-ring on the base plate around the cone.

And fill the cone with the sample from the bucket without any external compacting action such as rodding or vibrating. The surplus concrete above the top of the cone should be struck off, and any concrete remaining on the base plate should be removed.

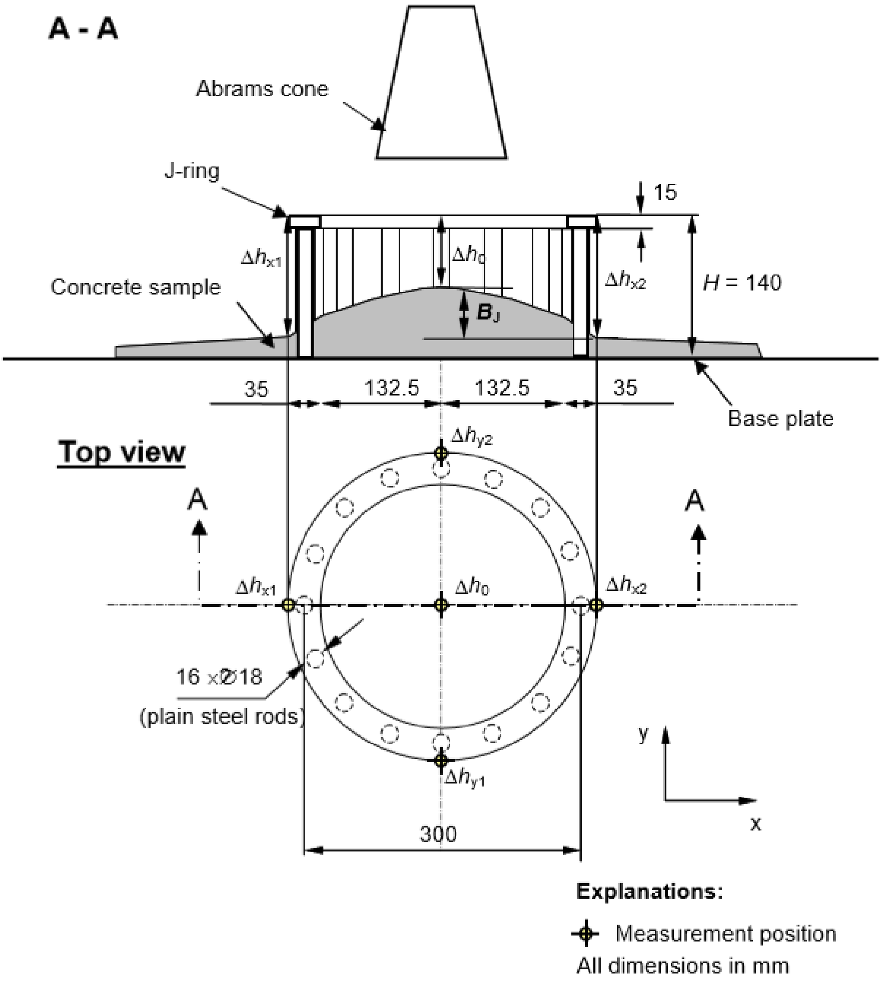


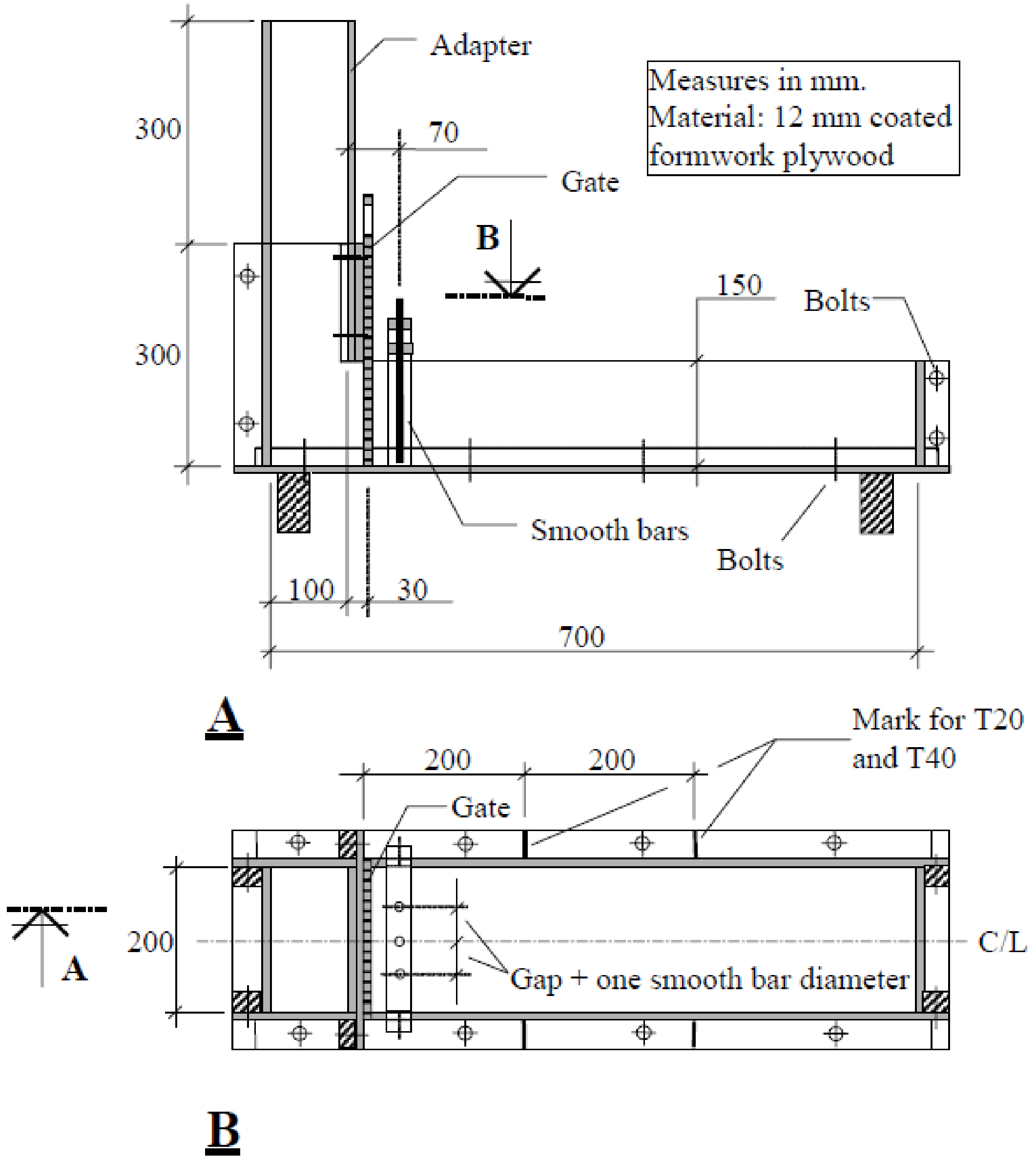
Fig (3.11) Dimensions of the J-ring and positions for measurement of height differences

Fig (3.12) j-ring test

3.3.2 L-Box test

L-box test investigate the ability of concrete to pass between narrow openings and enclosed spaces such as packed reinforcement sections without having uniformity loss, segregation, or blockage. As shown in Fig 3.13, L-box is “L” shaped apparatus, having vertical and horizontal parts with a moving gate. Two or three steel reinforcing bars put in front of the gate to represent an obstruction for the concrete to move.

The test procedure is pouring the fresh concrete in the vertical section and let it to rest for a couple of seconds. After, the gate is opened and let the concrete flows to the horizontal section through the gaps between the obstructing bars. The horizontal section of the box can be marked at 200 mm and 400 mm from the gate and the times taken to reach these points measured. These are known as T200 and T400 time sand are an indication for the filling ability. When the movement stopped, the depths of concrete that are directly behind the gate (H1) and at the end of the horizontal section of L-box (H2) are measured and the ratio of H2/H1 is computed. Passing ability classes according to the L-box height ratio values are given in Table 3.14, whereas, Fig (3.13and 3.14) exhibits photographic view of L-box test.



Detailed dimensions

Fig (3.13) a L-box test

fig(3.13) b L-Box apparatus

The test operation

Fig(3.14) The test operation

3.4 Tests for Hardened Properties

3.4.1 Determination of Compressive Strength

The compression test was carried out on the specimens by a 3000 kN capacity testing machine. Compressive strength test was conducted at the ages of 7,14, 28 and 56 days on three 150 mm cube samples for each concrete mixture .The test was conducted per ASTM C39 (2005).the show in Fig3.15

Fig(3.15) The compressive strength test operation

3.4.2 Pull-out test

The test specimen shall be mounted in a suitable testing in such a manner that the bar is pulled axially from the cube. The end of the bar at which the pull is applied shall be that which projects from the top face of the cube as cast.

The load shall be applied to the reinforcing bar at a rate not not greater than 250 kg/min,or at no-load speed of the testing machine head of not greater than 1.25 mm/min, depending on the type of testing machine used and the means provided for ascetaining or indicated speeds.

The movement between the reinforcing bar and the concrete cube ,as indicated by the dial micrometers shall be read at a sufficient number of intervals throughout the test to provide at least 15 readings by the time

- The application of (10-100T)Digital anchor Pull Out test Equipment :

  Pull out resistance test of anchor bolt, anchor cable, steel bar, expansion bolt, chemical anchor bolt, anchoring parts, also can test the glass curtain wall field pull out resistance, it is kind of common civil engineering testing equipment.
- The Features of (10-100T)Digital anchor Pull Out test Equipment :

  1-High quality steel cast body, quick reset, over load protection, digital readout, Dust-proof, Peak value keep.

  2-Dust-proof system and high quality sealing ring with hydraulic cylinder guarantee long tooling life Suitable for laboratory and field use

  3-Hydraulic cylinder; 10T-30T: manual reset;.

- The procedure of the pullout test shown by sketch , see Fig 3.17

At operation test we have three type of results:

- Failures concrete at take result for time (3 , 7 and 28)days of first and second Mixes ,and failure concrete at time (3 and 7)days for Mix three . the shown in Fig 3.18
- The slip of the bar occurred at the time (56)days of first and second Mixes and slip of the bar occurred at the time (28 and 56)days of the Mix three, the shown in Fig 3.19
- The cut of steel bar occurred at the time (56)days for the second and the third Mix, the shown in Fig 3.20

a- Pullout test apparatus

b- The test operation

fig(3.16) Pullout test apparatus

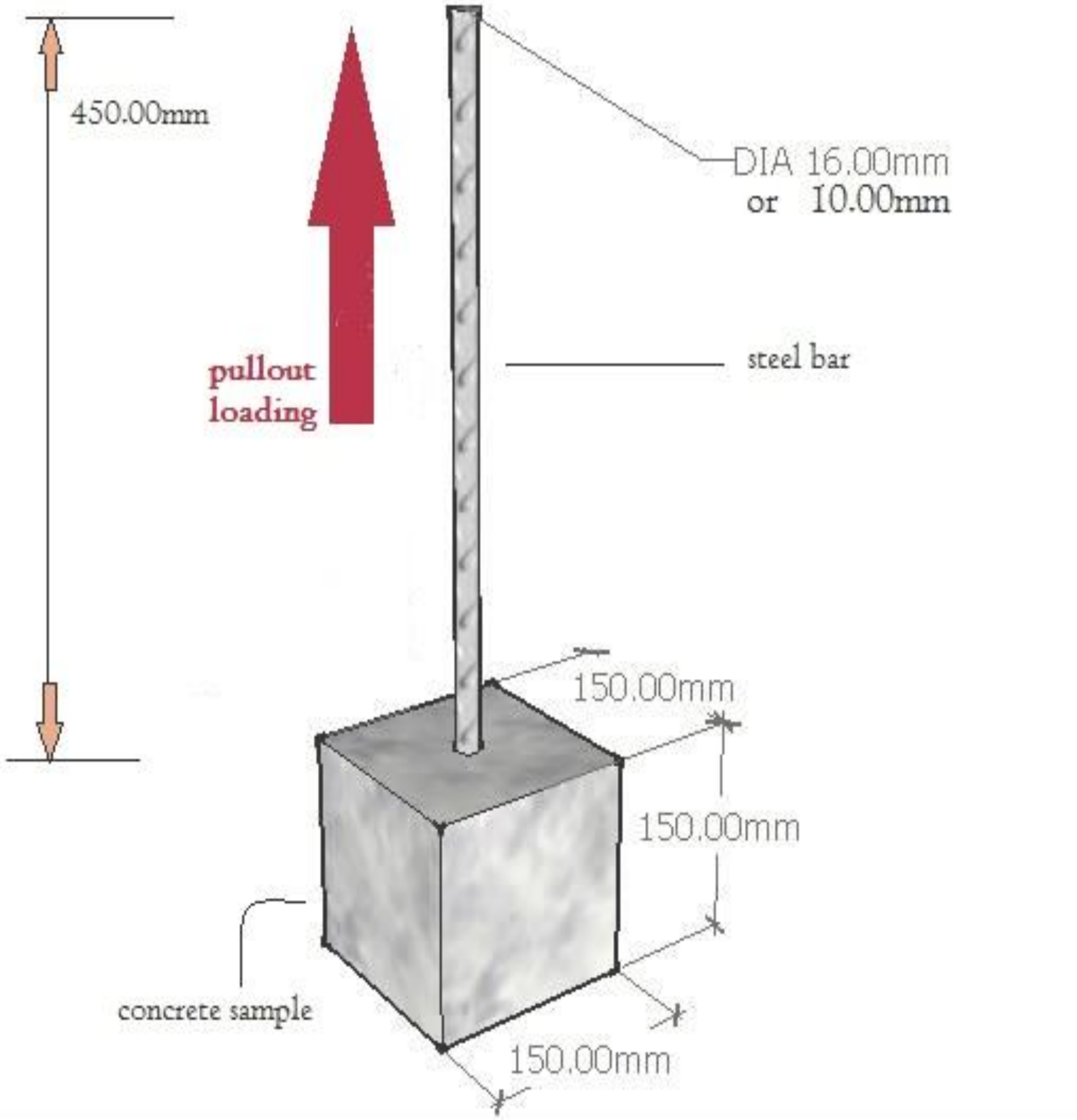


Fig (3.17) procedure of pullout

fig(3.18) failure concrete

Fig(3.19)Slip of the bar

Fig (3.20) cut of the steel bar

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Fresh Concrete Properties

4.1.1 Slump Flow Diameter and Slump Flow Time

The SCCs produced in this study had slump flow diameters ranging from 625 to 650 mm that was obtained by using 1.5% superplasticizer of cemention, as shown in Table 4.1

According to Table 3.13 (Chapter 3), the required superplasticizer content was varying according to the mineral used (at all type of concrete the superplasticizer was used had 1.5% from the content of cemintaion) Slump flow classes of the produced SCCs were defined and illustrated in Fig 4.1. Generally, SF1 type slump classes' self-compacting concretes were produced.

Table 4.1 Slump flow, J-Ring and L-box properties of SCC

Type	**Slump flow**		**J-Ring**		**L-box (H_1=91mm)**	
Mixes	T_{500} (s)	D (mm)	T_{500} (s)	D (mm)	H_2 mm	H_2/H_1
Mix 1	1.72	625	3.18	435	79	0.868
Mix 2	2.18	520	3.12	451	74.6	0.8197
Mix3	1.61	650	2.97	585	85.4	0.938

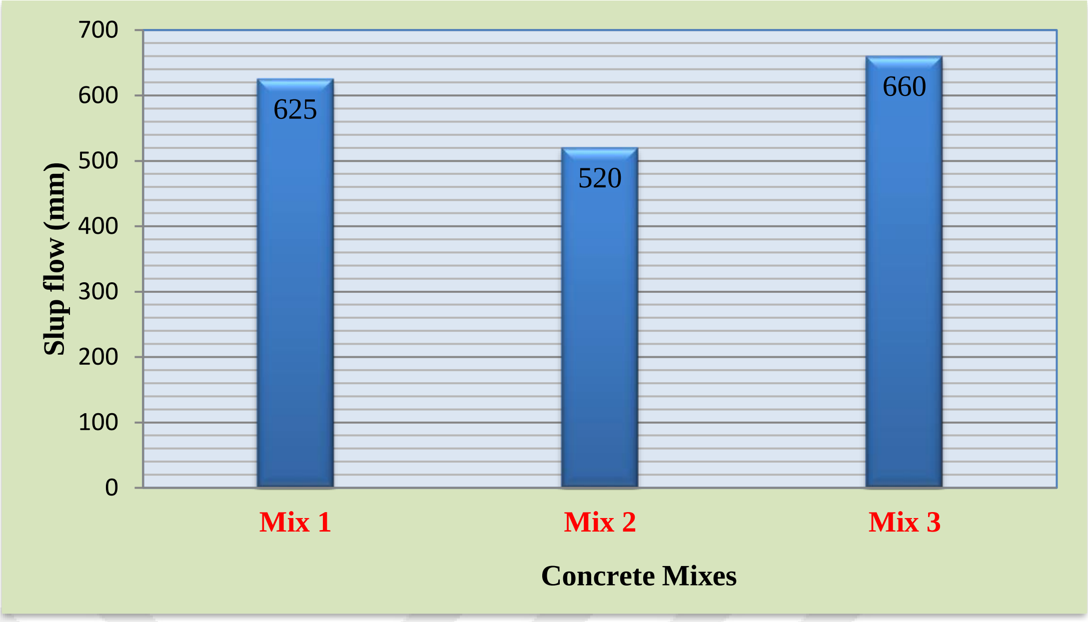


Fig 4.1 Variation of slump flow diameter and slump classes

According to Efnarc (2005), SCC guide, SF1 class self-compacting concretes (625-650) can be applied to many normal structural members (e.g. walls, columns) T_{50} slump flow times of the produced self-compacting concretes are presented in Fig 4.2.The T500 slump flow time was generally less than 2.5 s except for the mixture (M2) remarkably increased the slump flow time of the SCC,

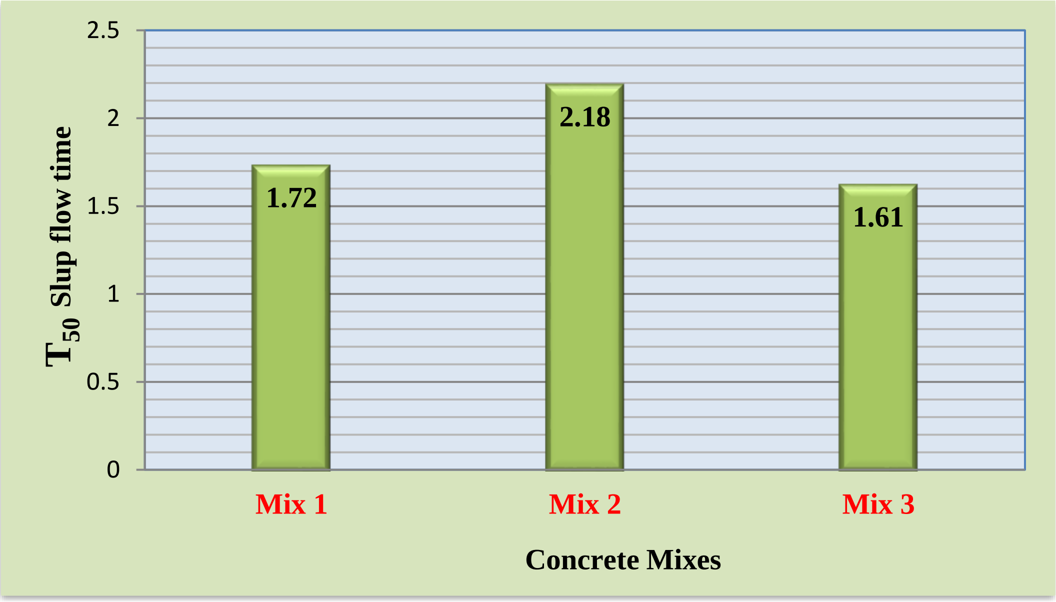


Fig 4.2 Variations of slump flow timeand slump classes

4.1.2 Slump Flow and Time with J-ring

According to Table 4.1 the slump flow diameters with J-ring had ranging from 435 to 485 mm, in Fig 4.3 shown the Variation of slump flow diameter with J-Ring, for Mix2 is 451 mm, T_{50} slump flow times with J-ring of the produced self-compacting concretes are presented in Fig 4.4.The T_{50} slump flow time with J-ring was generally less than 3.5 s except for the mixture (M1) remarkably increased the slump flow time of the SCC,

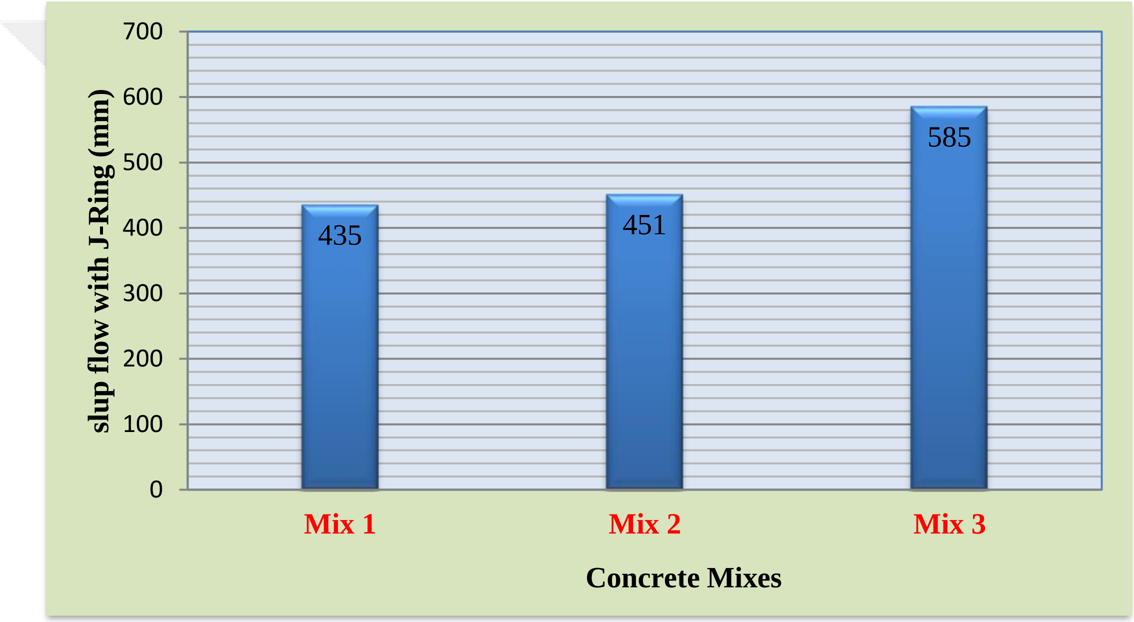


Fig 4.3 Variation of slump flow diameter with J-Ring and slump classes

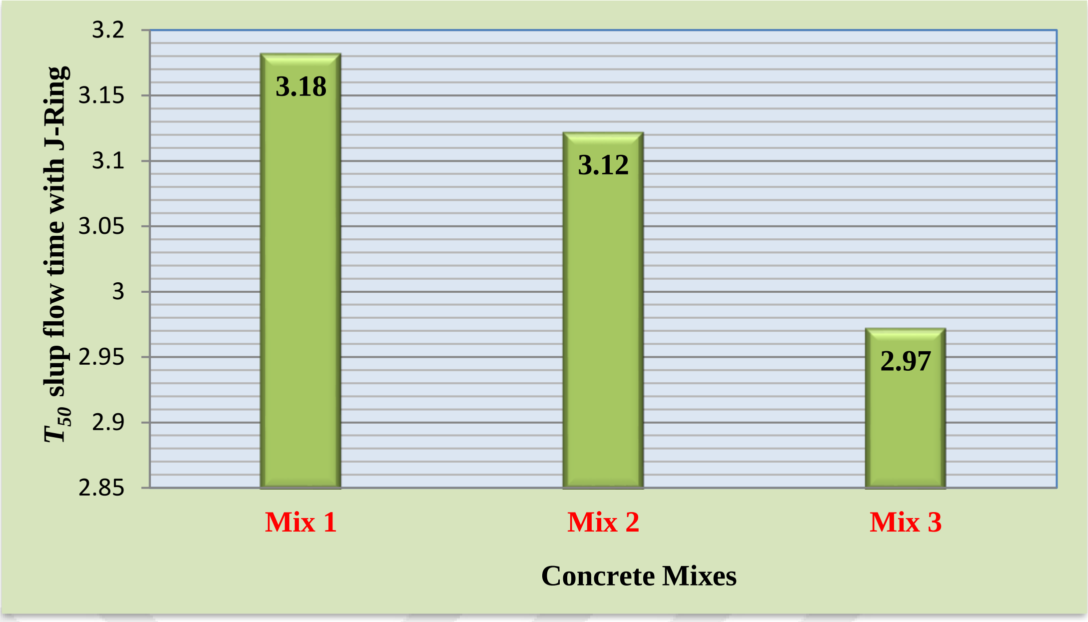


Fig 4.4 Variations of slump flow time with J-Ring and slump classes

4.1.3 L-box Height Ratio

To identify the passing ability of the produced SCC, L-box test was used. In the current study, three bar L-box height was utilized. The test provided H2/H1 ratio as a measure of the flow ability among reinforcing bars. The variation in the three bar L-box height ratio is illustrated in Fig 4.5.To affirm that a self-compacting concrete has the passing ability, L-box height ratio must be between (0.8-1). According to the Table 4.1.As clearly seen in Fig 4.5, the mixture M_2 has the lowest H2/H1 ratio of 0.819 . While the other mixes of SCC had H2/H1 ratios of (0.868–0.938) to M_1 and M_3 respectively.

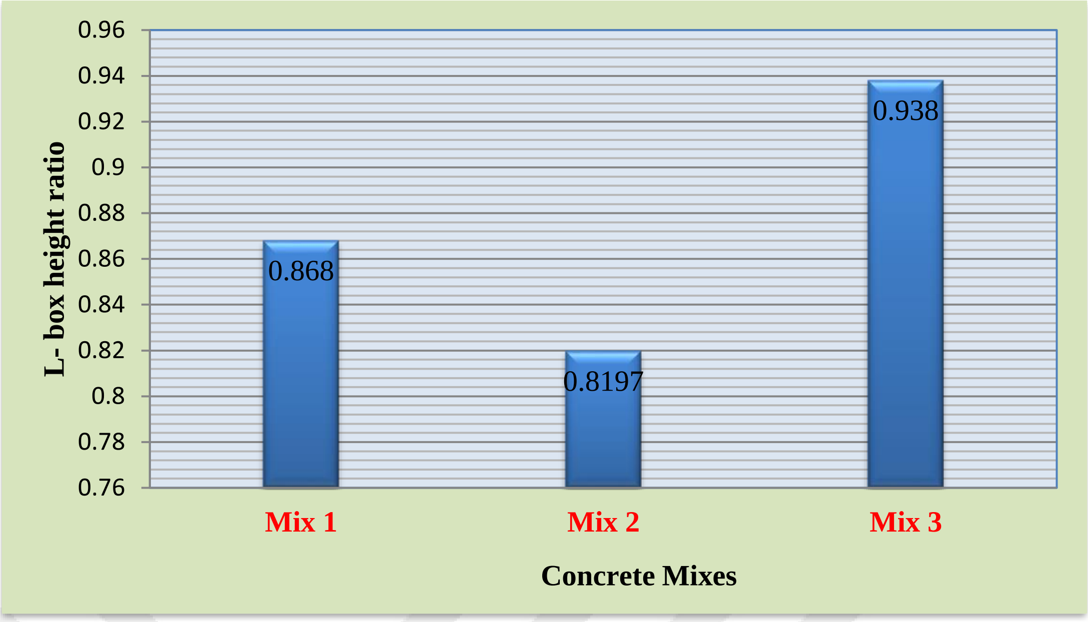


Fig 4.5 Variation of L-box height ratio values

4.2.1 Compressive strength

The data concerning the variation of compressive strength with curing condition and mineral admixture for concretes incorporated with 30% FA given in Tables4.2

Table 4.2 the compressive strength results

Time (day)	Mix 1 (Mpa)	Mix 2 (Mpa)	Mix 3 (Mpa)
3	21.15	21.76	26.46
7	24.52	26.4	29.83
28	31.32	37.43	40.57
56	40.8	44.33	49

The strength values for the plain in water cured are 21.15 and 49 MPa, respectively. High compressive strength for concrete in the mix (3) for water cured is 49.The effect of changing of cementation material on compressive strength of concrete is well observed in Fig 4.6.The Fig indicated that there was an increase in compressive strength with the increase in cementation material content. This is more pronounced for concretes subjected to water curing (WC) is higher. The slow development of compressive strength in SCC at early age is generally demonstrated it. While specimens stay for long time in water, compressive strength systematically increases.

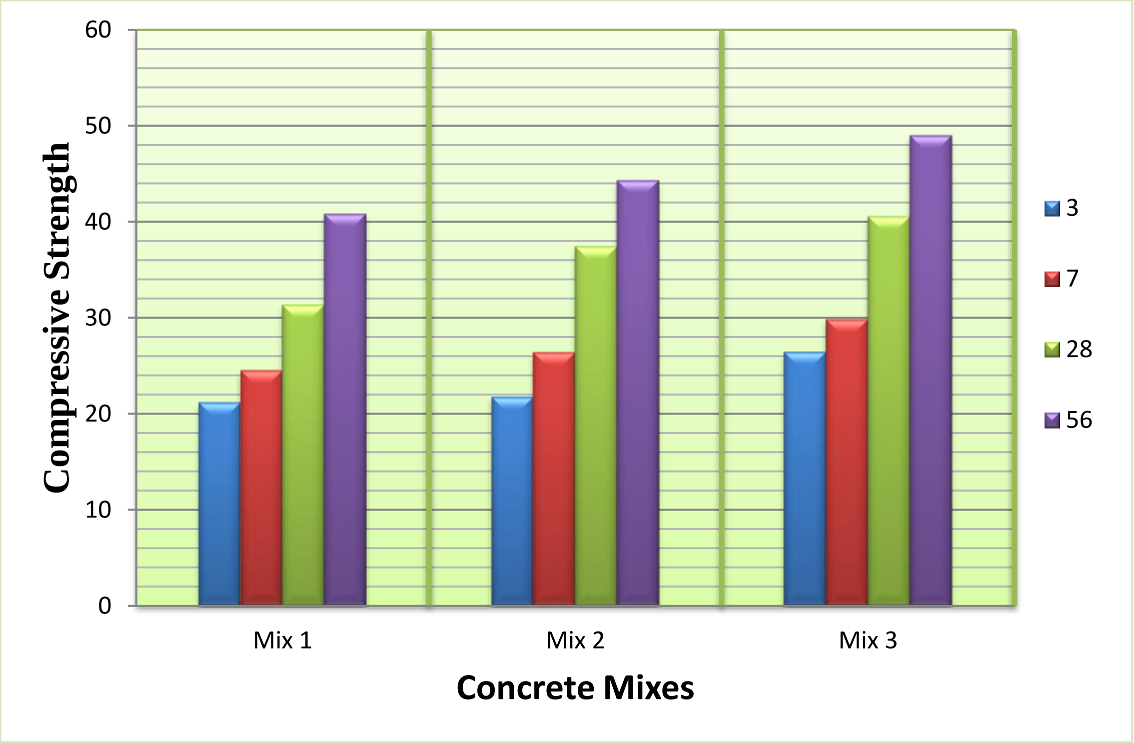


Fig 4.6Compressive strength results

4.2.2 Development of bond strength with age

The results of pull-out tests on the bond strength development of reinforcing bars in SCC in Table 4.3. During the pull-out test, the pull-out load is recorded. The pull-out load is then converted into bond stress based on the embedment reinforcing bar diameters.

Table 4.3 the pull out test results

Time (Days)		**3**	**7**	**28**	**56**
Mix 1	10 mm	**8.011**	**8.47**	**9.54**	**10.24**
	16 mm	**7.25**	**7.5**	**8.125**	**9.24**
Mix 2	10 mm	**8.68**	**8.96**	**9.92**	**10.95**
	16 mm	**7.84**	**8.7**	**9.5**	**10.03**
Mix 3	10 mm	**9.39**	**9.92**	**10.77**	**11.37**
	16 mm	**8.125**	**9.174**	**10.15**	**10.75**

The relationship between bond strength with time per day observed in the figs 4.7 to 4.9

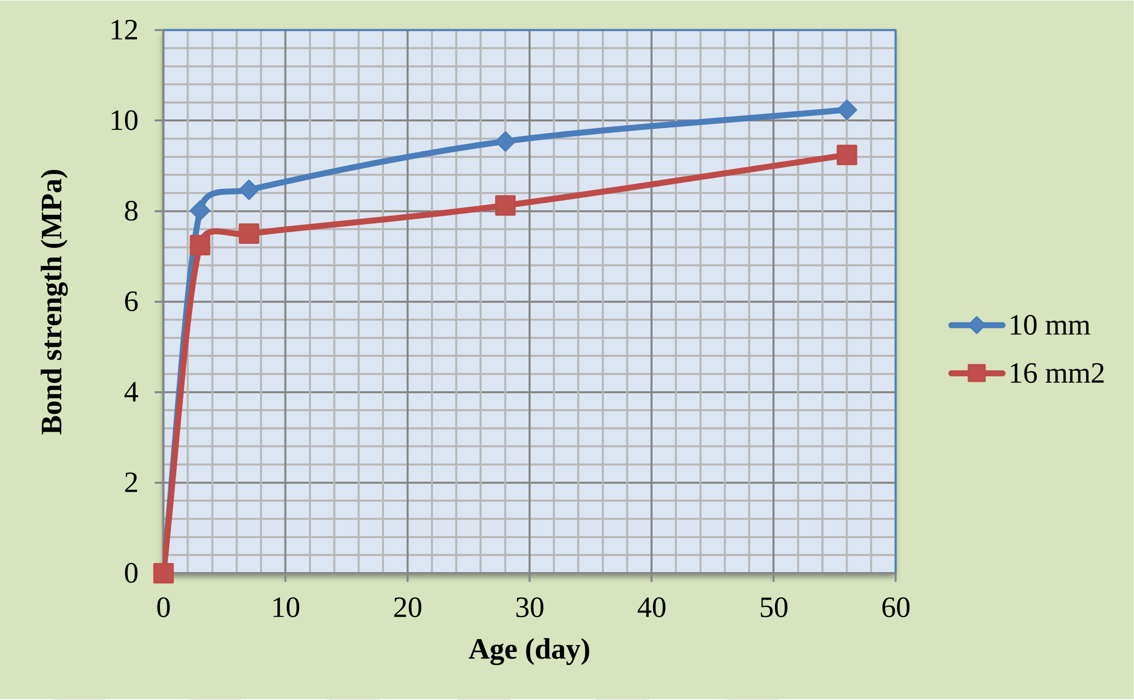


Fig 4.7Bond strength development in SCC in Mix 1

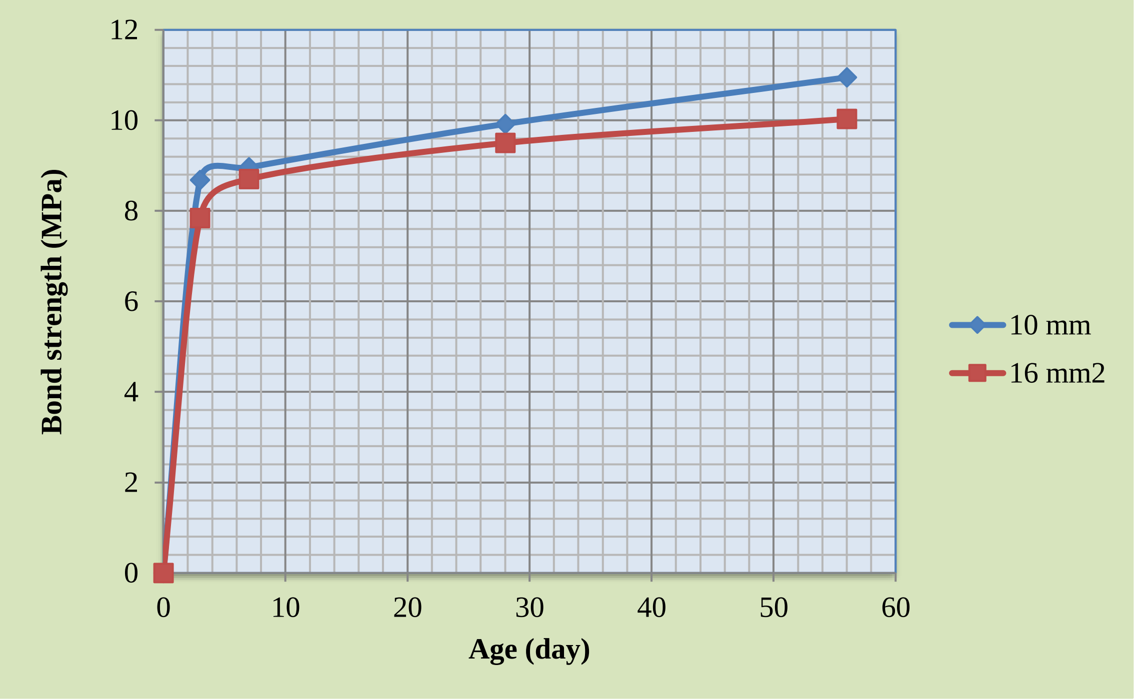


Fig 4.8Bond strength development in SCC in Mix 2

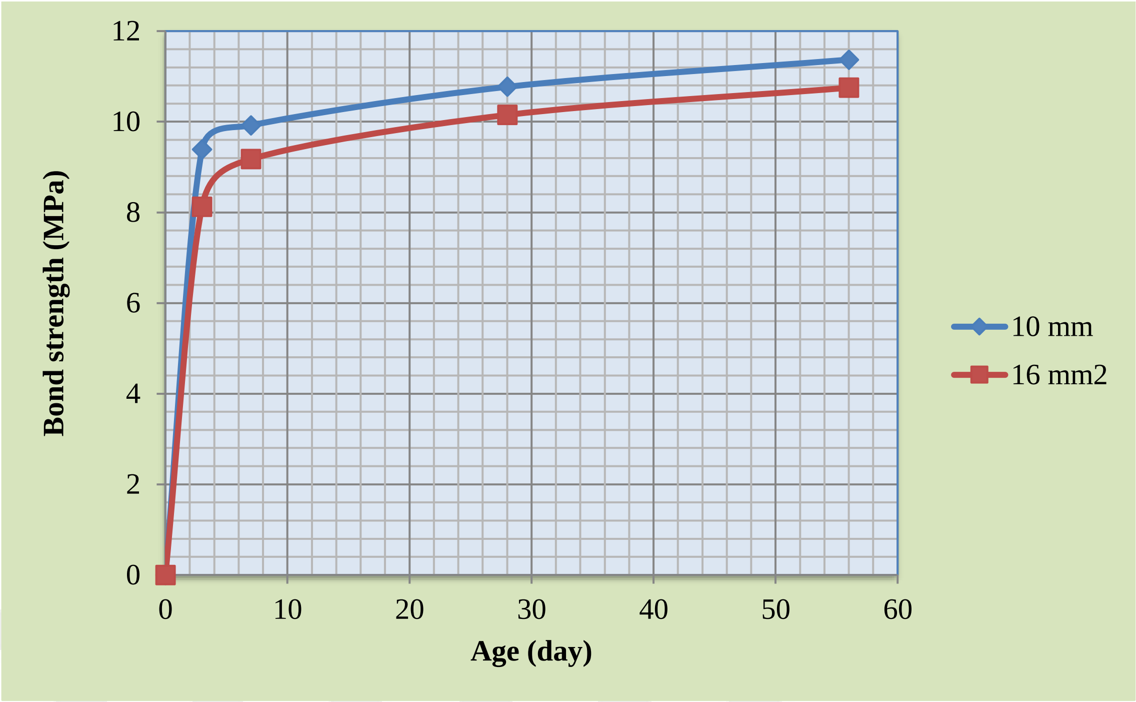


Fig 4.9Bond strength development in SCC in Mix 3

Figs. 4.10 to 4.13 summarize the Relationship between Bond and compressive strength corresponding to all studied mixes. In order to get an overview of the impudence of the embedded bar diameter, the results are presented according to the bar diameter in four graphs.

It is clear for all ages and for both bar diameter increasing the cementation concrete will increase the bond strength between reinforces bars and the concrete.

Also the relation between bond strength and concrete compressive strength is clear in the Fig (4.10 to 4.13) so that increasing the compressive strength of with the age of concrete from 3 days to 56 days the bond strength is increased for all Mixes.

4.2.3 Influence Bar Diameter

Bond in RC members depends on type of bar, state of stress in both bar and concrete, strength of concrete, concrete cover, confinement, space between adjacent bars, number of layers of reinforcement bars, position of reinforcing bars, and casting direction , there are many factors that influence bond behavior between concrete and bar diameter , the size of bar diameter influence the bond strength with bars with bigger diameters developing less bond strength than smaller bars, the effect of the bar diameter was observed on the bond stress,as show in Figs(4.7 to 4.9) the bond strength of 10 mm diameter reinforcing bars is higher than bond strength of 16 mm diameter reinforcing

bars for all concrete ages and this is true for all studied mixes. Also as shown in Figs from(4.10 to 4.13) for different concrete compressive strength the bond strength of 10 mm diameter is higher than bond strength of 16 mm diameter bar for all age levels .The ratio of increased bond strength when the bar diameter was changed from 10 mm to 16 mm were about %12 to %18 . For different concrete ages the bond strength between the reinforced bars and concrete for Mix_3 is higher then Mix_2 and Mix_1.The bond strength is incresed from Mix_1 to Mix_3 by about %15 as show in the Fig (4.10 to 4.13).The pullout studies were done for two different bar diameters, 10mm and 16mm, to understand the influence of bar diameter on the bond strength with different embedment diameter. The increase in diameter of the reinforced bar has a significant impact on the bond strength.

The bond strength of reinforcing bars in concrete decreases with increasing the embedment diameter, they bond strength of larger diameter bars decreases as compared with smaller diameter bars.

The maximum bond stress (τmax) of 11.37 MPa for Mix$_3$ at age 56 days was the highest value achieved with 150 mm embedment length using 10mm diameter bar, The fact is that as the surface area of embedment increases, the maximum bond stress decreases. The bond stress due to frictional resistance (τf) with 16mm diameter bars varies between 7.25 MPa and 10.75 MPa, while it varies between 8.01 MPa and 11.37 MPa using 10mm diameter bars. This indicates that the frictional bond resistance has been slightly high when 10 mm diameter bars were used. İt was that concrete the bond strength decreases as the bar diameter increases.

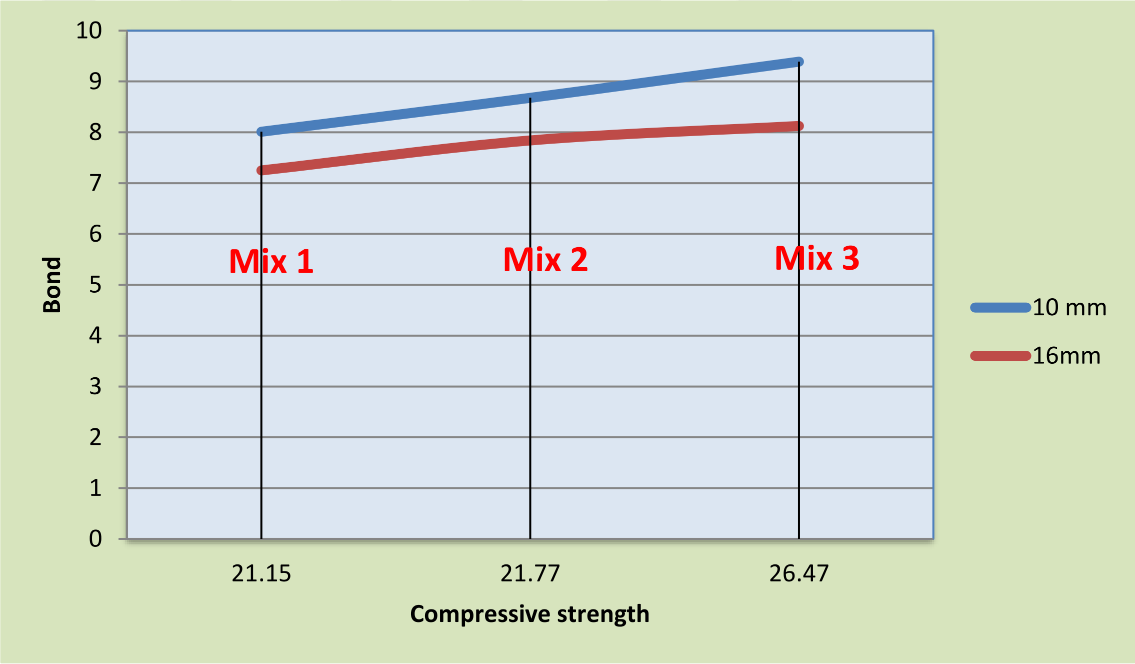


Fig 4.10 Relationship between Bond and compressive strength at age (3) days

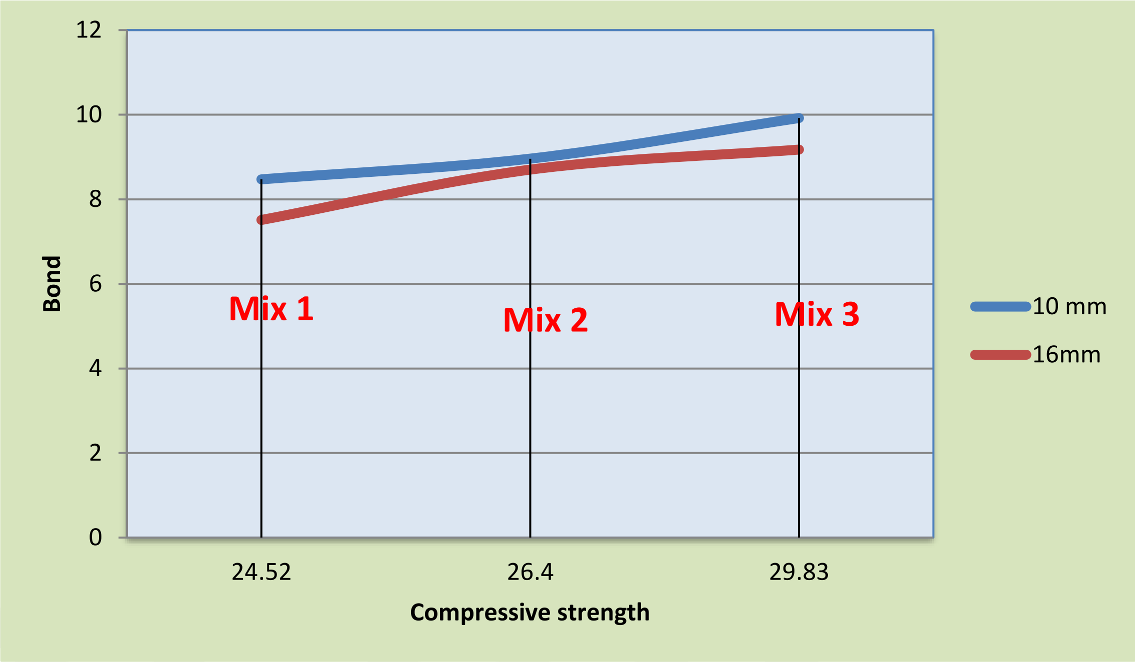


Fig 4.11 Relationship between Bond and compressive strength at age (7) days

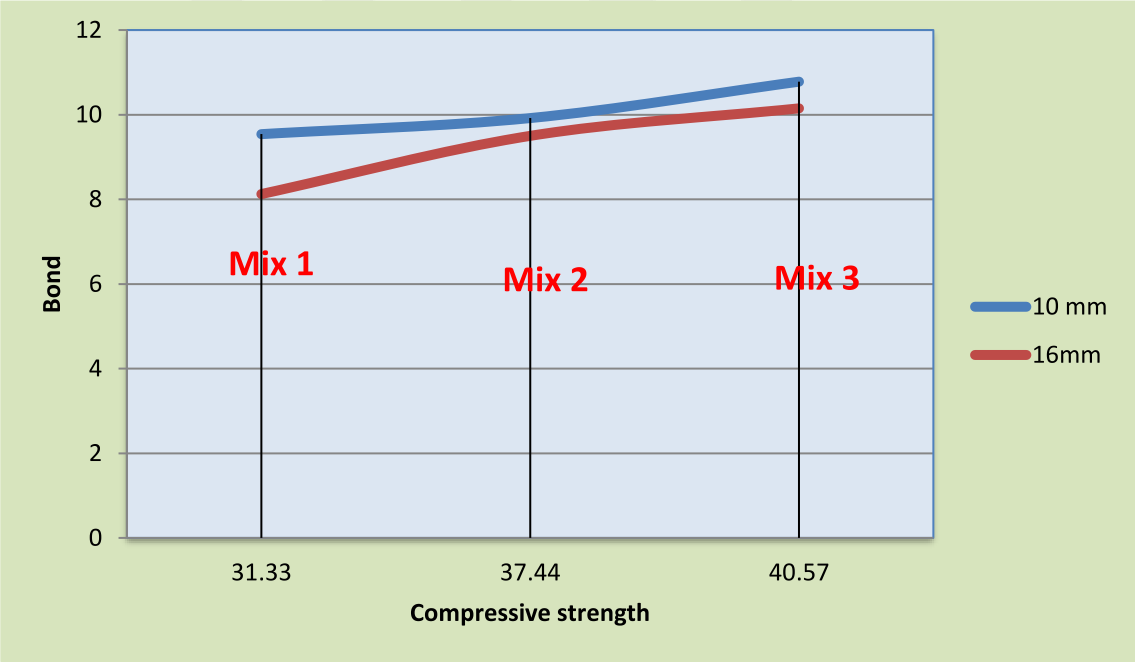


Fig 4.12 Relationship between Bond and compressive strength at age (28) days

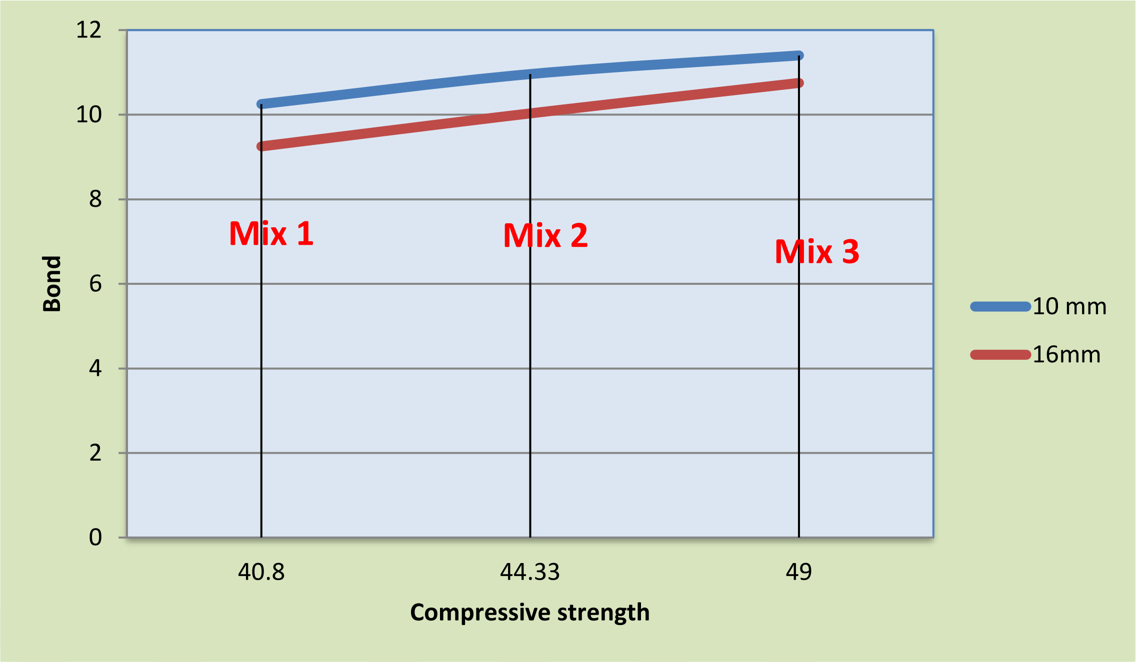


Fig 4.13 Relationship between Bond and compressive strength at age (56) days

4.2.4 Influence of powder content of SCC

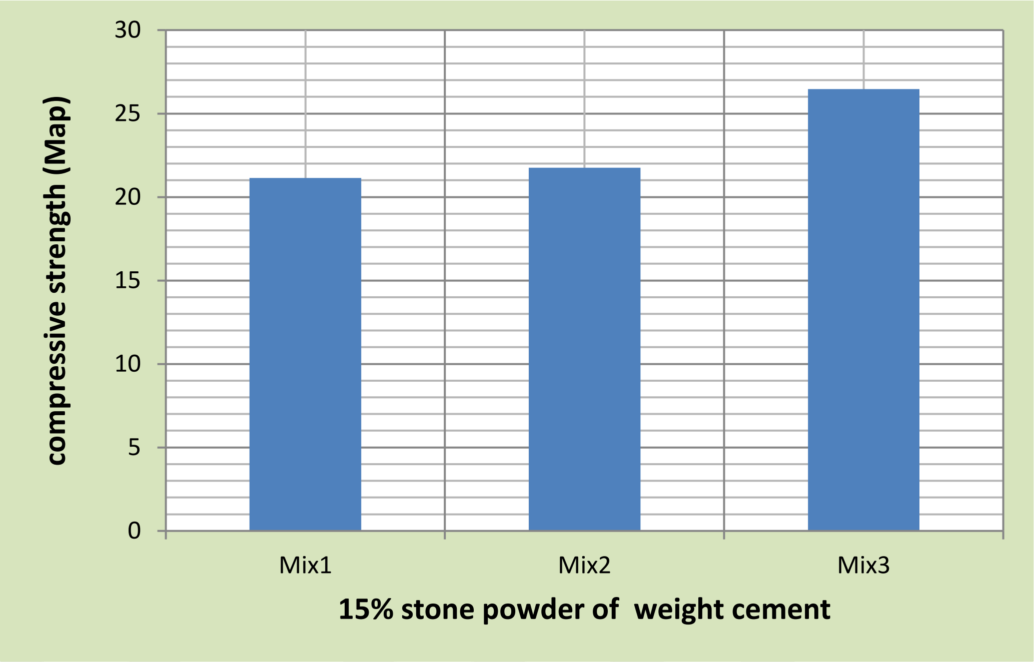
The introduction of new admixtures and cementitious materials has allowed the production of SCC. These materials are used to prevent segregation, bleeding, and increase flowability. The superplasticizer and mineral admixture hold the aggregates in suspension, and the combination of powder materials is also used to control the hardened properties, such as strength.

Stone powder as addition was used in this study,according to present study the different content of stone powder for Mix proportions 1,2 and 3,shows significant effect of stone powder on the concrete compressive strength and bond strength between reinforced bars and concrete . To achieve satisfactory combinations of high fluidity and stability, SCC requires high powder volumes at relatively low water/powder ratios with significant quantities of superplasticizers.

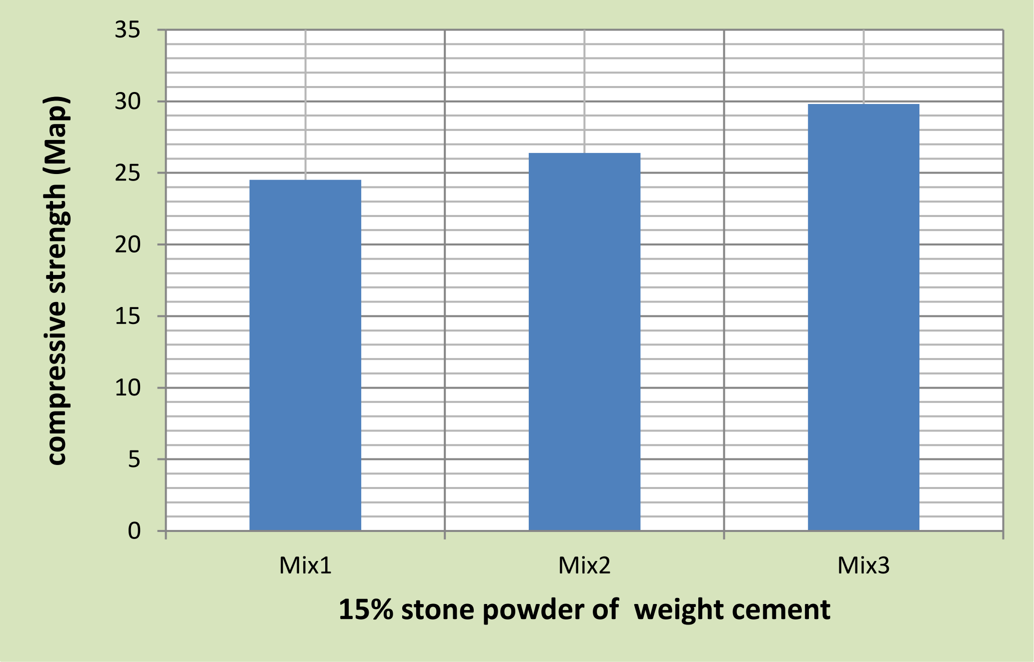
According to the manufacturer, the powder had a specific gravity of 2.2, specific surface area of 17 m2/gm.

stone powder addition of fine particles can result in a considerable increase in the specific surface area of the powder, which results in an increase of water demand to achieve a given consistency. On the other hand, for a fixed water content, high powder volume increases antiparticle friction due to solid–solid contact. This may affect the ability of the mixture to deform under its own weight and pass through obstacles.stone powder was used as a filler in the current work. However, stone powders are most frequently used in the SCC mixes reported in the literature.

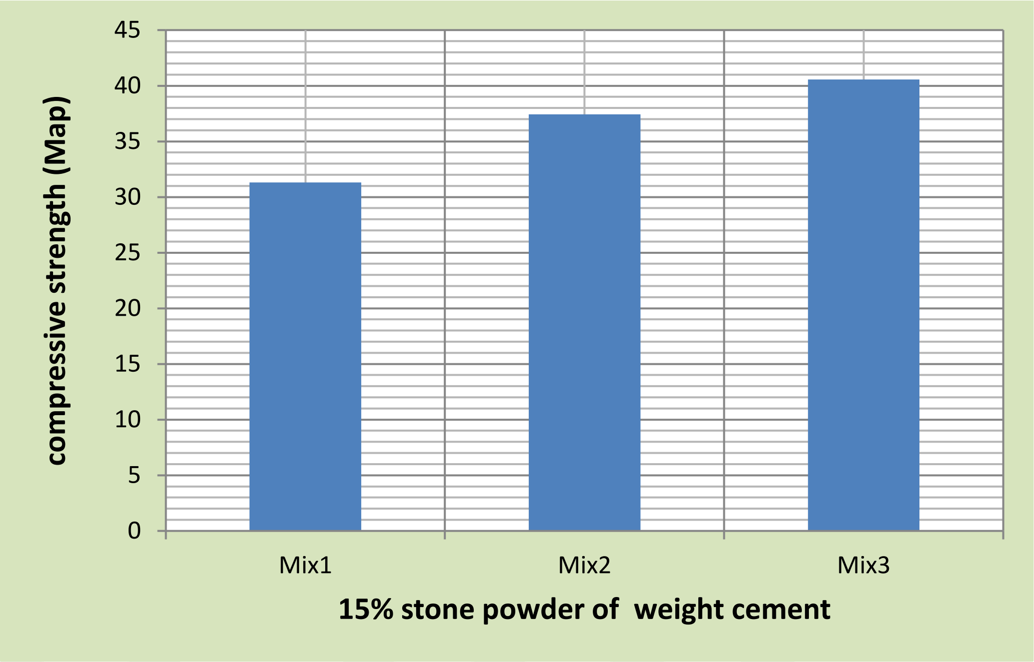
The strength of the SCC mixes containing the limestone and chalk powders was significantly greater than that of the conventional vibrated reference concrete at the same water/cement ratio. For the limestone powder mixes, the cube compressive strengths were (2.88- 25.1)% higher at 3 days ,(7.66- 21.61)% higher at 7 days , (19.41- 29.5)% higher at 28 days and (8.65- 20.09)% higher at 56 days, compared with the corresponding reference concrete. This compares favourably with the use of PFA in the SCC mix, which usually shows no significant strength increase over the reference mix at early ages. Suitable dosage of superplasticizer Glenium 27 appeared to be dependent more on the type than on the fineness of the powder used. stone Powder, which has been brought from local market is used to increase the amount of powder (cement filler) in the SCC mixes.



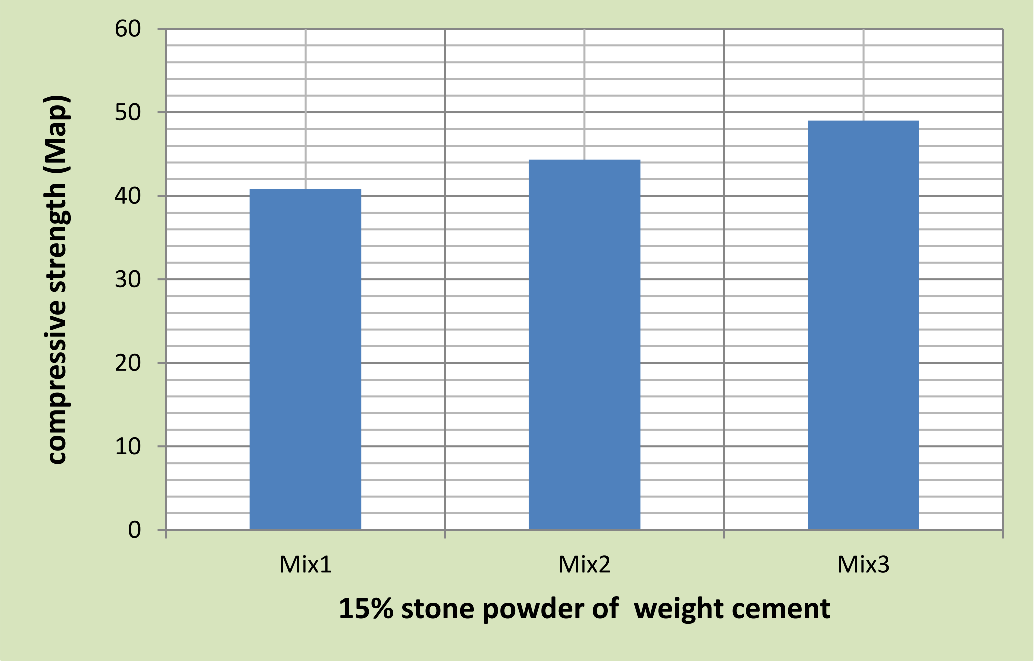
Fig(4.14)Relationship between compressive strength and stone powder at age 3 days



Fig(4.15) Relationship between compressive strength and stone powder at age 7 days



Fig(4.16) Relationship between compressive strength and stone powder at age 28 days



Fig(4.17) Relationship between compressive strength and stone powderat age 56 days

4.2.5 Relationship between compressive and bond strength

As shown in table 3.13 for the different Mix proportion the bond strength was increased from (8.01 to 8.67 and 9.39) Map, when the compressive strength at 3 days was increased from (21.15to 21.76 and 26.46) Map respectively for a bar diameter of 10 mm shown in Fig 4.18. The compressive strength increased 2.88% and 25.1% for Mixes 1to2 and 3. The bond stress similar was increased 8.29% and 17.22% respectively.

For bar size of 16 mm the bond strength was increased from (7.24 to 7.83 and 8.12) Map by increasing the compressive strength from (21.15to 21.76 and 26.46) Map respectively shown in Fig 4.18.

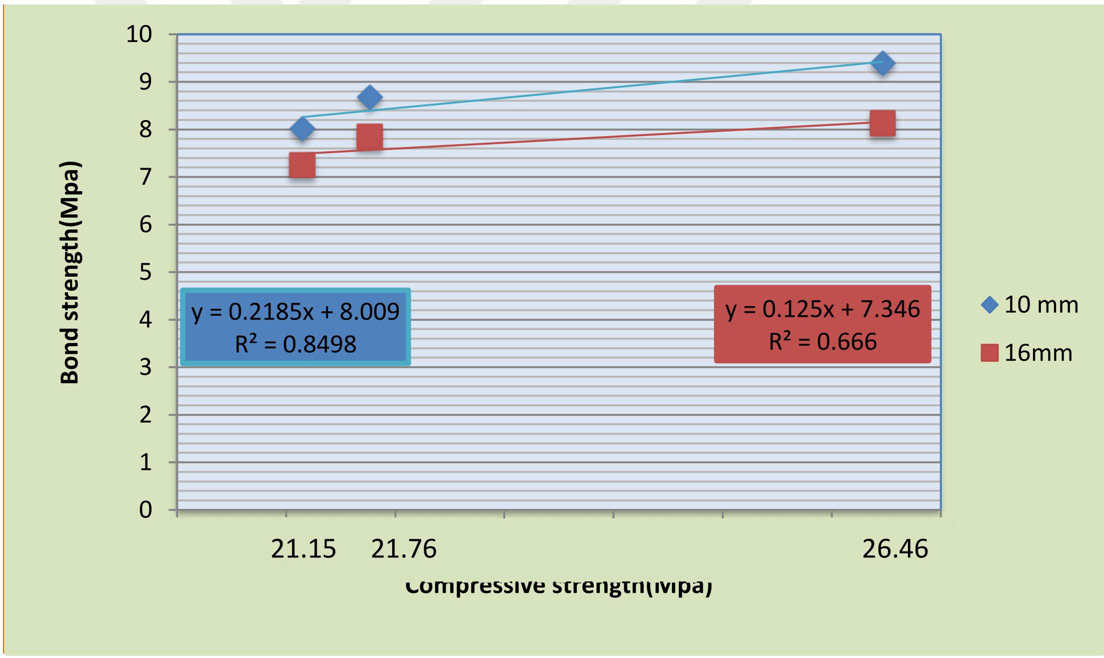


Fig 4.18 Relationship between Bond and compressive strength

The compressive strength increased 2.88% and 25.1% for Mixes 1to2 and 3. The bond stress similar was increased 8.14% and 12.15% respectively.

As shown in table 3.13 for the different Mix proportion the bond strength was increased from (8.47 to 8.95 and 9.92) Map, when the compressive strength at 7 days was increased from (24.52 to 26.4 and 29.82) Map respectively for a bar diameter of 10 mm shown in Fig 4.19. The compressive strength increased 7.66% and 21.61% for Mixes 1to2 and 3. The bond stress similar was increased 5.66% and 17.11% respectively.

For bar size of 16 mm the bond strength was increased from (7.51 to 8.69 and 9.17) Map by increasing the compressive strength from (24.52 to 26.4 and 29.82) Map respectively shown in Fig 4.19.

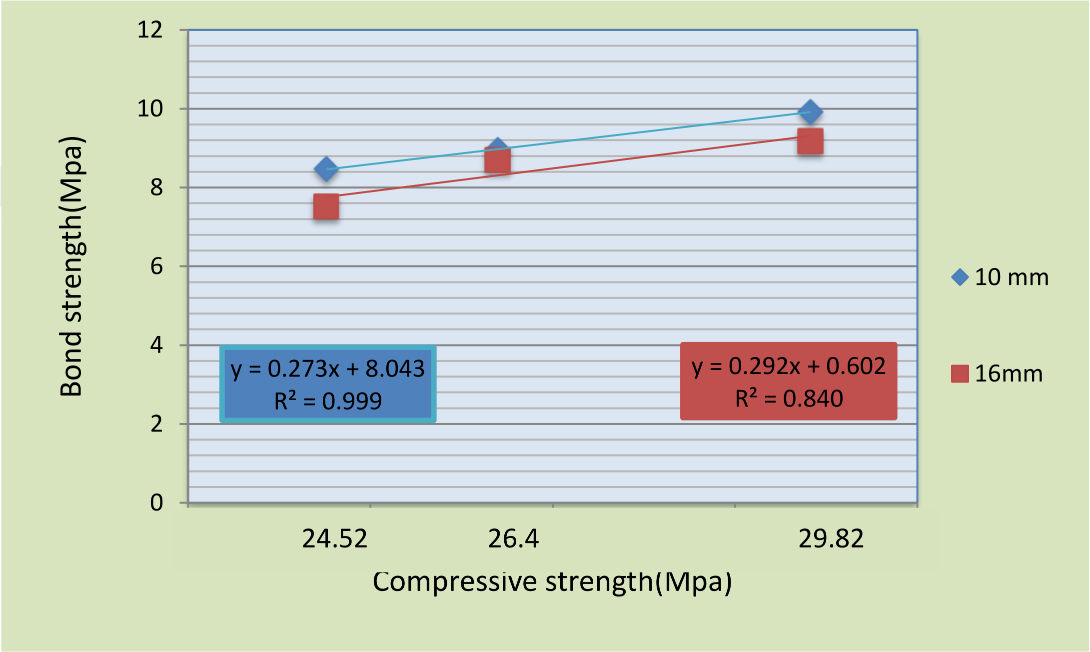


Fig 4.19 Relationship between Bond and compressive strength

The compressive strength increased 7.66% and 21.61% for Mixes 1to2 and 3. The bond stress similar was increased 15.71% and 22.1% respectively.

As shown in table 3.13 for the different Mix proportion the bond strength was increased from (9.53 to 9.92 and 10.77) Map, when the compressive strength at 28 days was increased from (31.32 to 37.4 and 40.56) Map respectively for a bar diameter of 10 mm shown in Fig 4.20. The compressive strength increased 19.41% and 29.5% for Mixes 1to2 and 3. The bond stress similar was increased 4.09% and 13.01% respectively. For bar size of 16 mm the bond strength was increased from

(8.1 to 9.5 and 10.15) Map by increasing the compressive strength from (31.3 to 37.4 and 40.56) Map respectively shown in Fig 4.20.

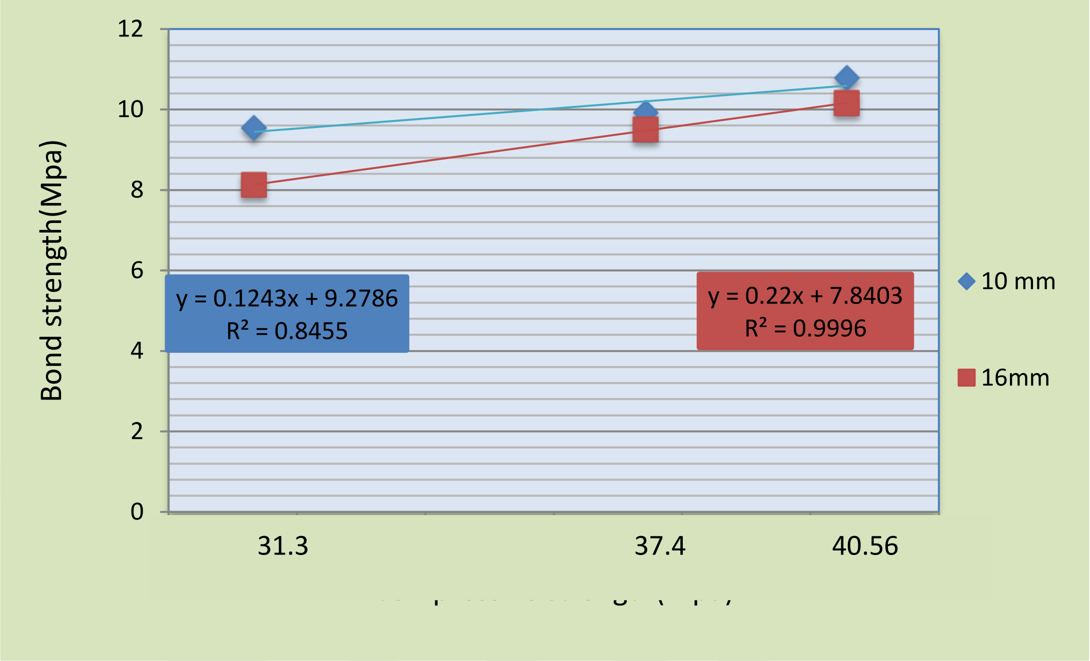


Fig 4.20 Relationship between Bond and compressive strength

The compressive strength increased 19.41% and 29.5% for Mixes 1to2 and 3. The bond stress similar was increased 17.28% and 25.3% respectively.

As shown in table 3.13 for the different Mix proportion the bond strength was increased from (10.24 to 10.95 and 11.37) Map, when the compressive strength at 56 days was increased from (40.8 to 44.33 and 49) Map respectively for a bar diameter of 10 mm shown in Fig 4.21. The compressive strength increased 8.65% and 20.09% for Mixes 1to 2 and 3. The bond stress similar was increased 6.93% and 11.03% respectively. For bar size of 16 mm the bond strength was increased from (9.2 to 10.02 and 10.75) Map by increasing the compressive strength from (40.8 to 44.33 and 49) Map respectively shown in Fig 4.21.

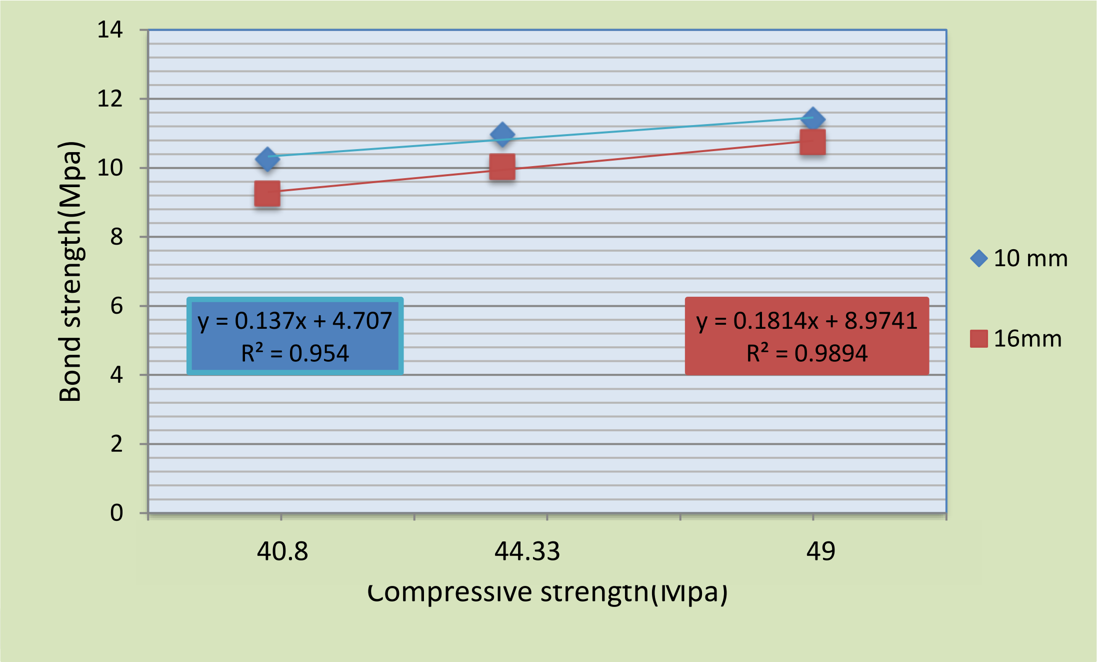


Fig 4.21 Relationship between Bond and compressive strength

The compressive strength increased 8.65% and 20.09% for Mixes 1to 2 and 3. The bond stress similar was increased 8.91% and 16.84% respectively.

CHAPTER FIVE

CONCLUTION

In this thesis, Bond strength development with age , pullout test was measured at different ages of concrete 3, 7, 28 and 56 days . Two embedded size of steel bars were considered namely 10 mm and 16 mm diameters with 600 mm length were investigated. According to the results obtained from the experimental study, the following conclusions can be drawn:

- The bond strength of both size of bars increased with time, but the rate of increase lowered with time, and showed good correlation with the compressive strength of concrete.

- Bond strength at age of 3 days to age of 28 days approximately ranged between 80 to 90 % and increased by about 5 to 7 % only for age from 28 to 56 days.

- Considering three mixture proportions of SCC, The percentage of increase in bond strength of 10 mm bars, at age of 28 days was 4.09 % with increase of cementtious material content from 400 to 433 kg/m^3 and 13 % with increase of cementitious content from 400 to 466 kg/m^3

- Experimental study indicated that utilization of mineral admixtures like Fly ash effects on Bond strength development behaviors of SCC significantly.

REFRENCE

A. Foroughi-Asl1, S. Dilmaghani and H. Famili,“ Bond strength of reinforcement steel in self-compacting concrete”, International Journal of Civil Engineering,Vol: 6, No. 1, March (2008)

A. Orbe, J. Cuadrado , R. Losada and E. Roj,“Framework for the design and analysis of steel fiber reinforced self-compacting concrete structures”, Construction and Building Materials 35,676–686, (2012)

A. Torre-Casanova , L. Jason , L. Davenne and X. Pinelli ,“Confinement effects on the steel–concrete bond strength and pull-out failure”, Engineering Fracture Mechanics 97,92–104, (2013)

A.A.A. Hassan , K.M.A. Hossain and M. Lachemi,“Bond strength of deformed bars in large reinforced concrete members cast with industrial self-consolidating concrete mixture”, Construction and Building Materials 24, 520–530, (2010)

Achillides Z., Pilakoutas K. ,“Bond behavior of fiber reinforced polymer bars under direct pullout conditions”, Journal of Composites for Construction, 8 (2), pp. 173-181, (2004)

Ahsanollah B. and Halit Y.,“Pull-out behavior of steel fiber embedded in flow able RPC and ordinary mortar”, Construction and Building Materials 75,255–265, (2015)

Ali Al. and Laith S.,“Influence of Draft Tube Diameter on Operation Behavior of Air Lift Loop Reactors”, Al-Khwarizmi Engineering Journal, Vol. 6, No. 2, PP 21-32 (2010)

Ali T. Jasim,“ Production of Self-Compacting Concrete Using Limestone”, University of Kufa – College of Engineering - Civil Engineering Dept.Journal of K erbala University , Vol. 9 No.1 Scientific,(2011)

Alyamac K.E .and Ince R. ,“ A preliminary concrete mix design for SCC with marble powder Construction and Building Materials”, pp. 1201-1210, (2009)

Amgad G.,“bond strength of self-consolidating concrete for prestressed concrete applications”,Research Assistant Professor ,College of Engineering & Technology University of Nebraska Lincoln, NDOR Project Number SPR-P1(04) P571, December (2004)

Amin A., Joaquim B. and Vitor C.,“Relation between fibre distribution and post-cracking behaviour in steel fibre reinforced self-compacting concrete panels”, Cement and Concrete Research 51,57–66, (2013)

Andrew P. and Bassem A. ,“Analytical prediction of transfer length in prestressed self-consolidating concrete girders using pull-out test results”, Construction and Building Materials 25, 1026–1036, (2011)

Azizinamini M. , Roller J. and Ghosk K.,“ Bond performance of reinforcing bars embedded in high strength concrete”, ACI StrJl, 90(5): 554–561,(1993)

B. Singh, Ishwarya G., M. Gupta and S.K. Bhattacharya ,“Geopolymer concrete: A review of some recent developments”, Construction and Building Materials 85, 78–90, (2015)

B.D. Ellis, D.L. McDowell and M. Zhou,“Simulation of single fiber pullout response with account of fiber morphology”, Cement & Concrete Composites 48, 42–52, (2014) Beeralingegowda B. and Gundakalle V. D. , “the effect of addition of limestone powder on the properties of self-compacting concrete”, International Journal, ISSN: 2319-8753, Vol. 2, Issue 9, September (2013)

Cattaneo, S., and Rosati, G.,“Bond and Splitting in High-Performance Compacting Concrete: Experimental Determination”, Magnel Laboratory for Concrete Research, Ghent University, Belgium, conference paper, November (2008)

Chinn, J., Feruson, P.M., and Thompson, J.N. ,“Lapped Splices in R.C.Beam”,ACI Journal, V.52, No.2, Oct. 1955, PP.201-214.

Cristina F., Aires C., Joaquim B. and Delfina G.,“Durability of steel fiber reinforced self-compacting concrete”, Construction and Building Materials 80,155–166, (2015)

D. Coronelli, “Corrosion cracking and bond strength modeling for corroded bars in reinforced concrete”, ACI Structural Journal, vol. 99, no. 3, pp. 267-276, (2002)

D.V. Soulioti , N. Barkoula , F. Koutsianopoulos , N. Charalambakis and T. Matikas ,“The effect of fibre chemical treatment on the steel fiber/cementitious matrix interface”, Construction and Building Materials 40,77–83, (2013)

Dehn, F., K. Holschemacher, and D. Weisse, “Self-Compacting Concrete - Time Development of the Material Properties and the Bond Behavior”, LACER No. 5, pp.115-123 (2000).

E. Zīle and O. Zīle,“Effect of the fiber geometry on the pullout response of mechanically deformed steel fibers”, Institute of Polymer Mechanics, University of Latvia, 23 Aizkraukles iela, LV-1006 Riga, Latvia, Cement and Concrete Research 44,18–24, (2013) Emadaldin G., Alireza R. and Mohammad S.,“Bond behavior of steel and GFRP bars in self-compacting concrete”, Department of Civil and Environmental Engineering, Amirkabir University of Technology, Tehran, Iran, Construction and Building Materials 61,230–240,(2014)

Erhan G. , Mehmet G. , Emad B. and Kasım M.,“ Strength and permeability properties of self-compacting concrete with cold bonded fly ash lightweight aggregate”,Construction and Building Materials 74 ,17–24, (2015)

F. Laranjeira, C. Molins and A. Aguado,“ Predicting the pullout response of inclined hooked steel fibers”,Department of Construction Engineering, Universitat Politècnica de Catalunya UPC, Edifici C1, Campus Nord UPC, Jordi Girona 1-3, 08034 Barcelona, Spain, Cement and Concrete Research 40 ,1471–1487, (2010)

F. M. ALMEIDA et al.,“ Variability of the bond and mechanical properties of self-compacting concrete”, ibracon Structures and Materials Journal, vol:1,(2008)

F. Soltanzadeh, J.A.O. Barros and R.F.C. Santos, “High performance fiber reinforced concrete for the shear reinforcement: Experimental and numerical research", Construction and Building Materials 77, 94–109, (2015)

F.M. Almeida, M.K. El Debs and A.L.H.C. El Debs,“ Evaluation of the bond strength behavior between steel bars and High Strength Fiber Reinforced Self-Compacting Concrete at early ages”, ISBN 978-0-415-47535-8,(2008)

Fiber-Reinforced Concrete”, 5th RILEM Symposium on Fiber-Reinforced Concrete, Lyon, France, pp. 567-576,(2000)

G. Appa Rao, K. Pandurangan and F. Sultana,“ Studies on the pull-out strength of ribbed bars in high-strength concrete”, University of Stuttgart, Stuttgart 70569, Germany

G. Appa Rao,“ parameters influencing bond strength of rebars in reinforced concrete”, International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online), Vol: 4 (1) January-March, pp.72-81, (2014)

G. AppaRao and D. Kadhiravan, “nonlinear fee modeling of anchorage bond in reinforced concrete”,International Journal of Research in Engineering and Technology EISSN: 2319-1163 | PISSN: 2321-7308(2013)

G. DE SCHUTTER,“ guidelines for testing fresh self-compacting concrete”, European Research Project: Guidelines TESTING-SCC, Growth Contract No. GRD2,2000-30024, September(2005)

H. Mazaheripour, J. Barros , J. Sena-Cruz , M. Pepe and E. Martinelli,“Experimental study on bond performance of GFRP bars in self-compacting steel fiber reinforced concrete”, Composite Structures 95,202–212, (2013)

H.Ji Chen, C.Hur Huang and Z.Yu Kao,“ Experimental Investigation on Steel-Concrete Bond in Lightweight and Normal Weight Concrete”, Department of Civil Engineering, National Chung-Hsing University, Taichung 40227, Taiwan

Harajli M.H. ,Hamad B.S. and Rteil, A.,“Effect of confinement on bond strength between steel bars and concrete”, ACI StrJl 101 (5): 595-603, (2004)

Hui Z. , Wei S. , Xiaoming W. and Bo G. ,“The properties of the self-compacting concrete with fly ash and ground granulated blast furnace slag mineral admixtures”, Journal of Cleaner Production 95 ,66-74, (2015) Hui Z., Wei S. , Xiaoming W. and Bo G. ,"The properties of the self-compacting concrete with fly ash and ground granulated blast furnace slag mineral admixtures", Journal of Cleaner Production 95,66-74, (2015)

I.M. Nikbin , M.H.A. Beygi , M.T. Kazemi , J. Amiri , S. Rabbanifar , E. Rahmani and S. Rahimi ," A comprehensive investigation into the effect of water to cement ratio and powder content on mechanical properties of self-compacting concrete", Construction and Building Materials 57 ,69–80, (2014)

Ioan P., Geert S., Pieter D. and Traian O.,"Bond between powder type self-compacting concrete and steel reinforcement", Construction and Building Materials 41,824–833, (2013)

Ioannis S. and Konstantinos T.,"Effect of composition variations on bond properties of Self-Compacting Concrete specimens", Construction and Building Materials 41,252–262, (2013)

Ismaeel H. Albarwary," bond strength of concrete with the reinforcement bars polluted with oil", European Scientific Journal ,edition vol.9, No.6 ISSN: 1857 – 7881 , ISSN 1857- 7431, February (2013)

J. Cuenca , J. Rodriguez , M. Marin-Morales , Z. Sanchez-Roldan and M. Zamorano,"Effects of olive residue biomass fly ash as filler in self-compacting concrete", Construction and Building Materials 40,702–709, (2013)

Jinan, J. Alwash ," Drying Shrinkage Cracking Of Self Compacting Concrete", Journal of Babylon University/Pure and Applied Sciences,No.(5), Vol.:(18), (2010) Jingu K., Kunhwi K., Yun L. and John B.,“Modeling of fiber-reinforced cement composites: Discrete representation of fiber pullout”, International Journal of Solids and Structures 51, 1970–1979, (2014)

José C., Jorge B., Marco J., Joaquim B., Catarina S. and Vitor C.,“Bond behavior between glulam and GFRP’s by pullout tests”, Composites: Part B 43 ,1045–1055, (2012)

K. Ahmed et al. , “Effect of Rebar Cover and Development Length on Bond and Slip in High Strength Concrete”,Civil Engineering Department, University of Engineering & Technology, Lahore, Pakistan,Vol:2 Jan (2008)

K. Hossain , M. Lachemi , M. Sammour and M. Sonebi ,“Strength and fracture energy characteristics of self-consolidating concrete incorporating polyvinyl alcohol, steel and hybrid fibres”, Construction and Building Materials 45,20–29, (2013)

K. Iwaki et al,“ evaluation of bond behavior of reinforcing bars in concrete structures by acoustic emission”, Research Institute of Technology, Tobishima Corp., Kimagase 5472, Sekiyado, Chiba, 270-0222,Japan,Graduate School of Frontier Sciences, University of Tokyo Hongo 7-3-1, Bunkyo, Tokyo, 113-0033, Japan(2003)

Kay W.and Christopher C.,“ Material efficiency in the design of ultra-high performance concrete”,Department of Civil and Environmental Engineering, University of Connecticut, United States, Construction and Building Materials 86, 33–43, (2015)

Khalid M., Faris G., and Isam M. ,“ Behavior of Self-Compacting Concrete Using Different Sludge andWaste Materials”,International Journal of Chemical, Environmental & Biological Sciences,Vol: 2, Issue 3 ,ISSN 2320–4087 (Online) (2014)

Khayat, H. and Mitchell, D. ,“Self-Consolidating Concrete for Precast Prestressed Concrete Bridge Elements”, Final Report for NCHRP Project 18-12, Attachment D, D-192p, (2008)

Khayat, K.H., K. Manai, A. Trudel, “In situ mechanical properties of wall elements cast using self-consolidating concrete”, ACI Materials Journal, pp.491-500 (1997).

Konstantinos T., Ioannis S. and Christos P.,“Influence of water-to-binder ratio on top-bar effect and on bond variation across length in Self-Compacting Concrete specimens”, Cement & Concrete Composites 48,127–139, (2014)

Konstantinos T., Ioannis S. and Konstant O. ,“ Bond of self-compacting concrete incorporating silica fume: Top-bar effect, effects of rebar distance from casting point and of rebar-to-concrete relative displacements during setting”, Construction and Building Materials 73, 378–390, (2014)

Kuroiwa, S., “High Performance Concrete in Severe Environments”, ACI SP-140, pp.147-161 (1993).

L. Martinie and N. Roussel,“ Simple tools for fiber orientation prediction in industrial practice”, Université Paris Est., Laboratoire Central des Ponts et Chaussées, Paris, France, Cement and Concrete Research 41,993–1000, (2011)

M. A. Safan,“ Performance of Beams Made of Low-cost Self-compacting Concrete in an Aggressive Environment”, Acta Polytechnica Vol. 51 No. 5,(2011)

M. Hunger and H.J.H. Brouwers,“ Natural Stone Waste Powders Applied to SCC Mix Design”, Engineering Technology University of Twente, Enschede, The Netherlands, Vol. 14, No. 2, 131–140 (2008)

M. Reza E. , M. Lachemi and M. Reza Kianoush ,“ Top-bar effect of steel bars in self-consolidating concrete (SCC) ”,Cement & Concrete Composites 30, 52–60, (2008)

M. Valcuende and C. Parra ,“Bond behavior of reinforcement in self-compacting concretes”, Construction and Building Materials 23, 162–170, (2009)

M.A.S. Mohamed, E. Ghorbel and G. Wardeh,“Valorization of micro-cellulose fibers in self-compacting concrete”, Construction and Building Materials 24,2473–2480,(2010)

Mahmoud A. , Hatem M. and Ahmed F.,“Effect of tension lap splice on the behavior

Majid A., Xiaoyang L. and Nawawi C.,“Experimental investigations on bond strength between coconut fiber and concrete ”, Department of Civil and Environmental Engineering, The University of Auckland, New Zealand, Materials and Design 44,596–605, (2013)

Marco V.,“ Bond Strength between Corroded Steel Rebar and Concrete”, International Journal of Engineering and Technology, Vol: 4, No. 5, October (2012)

Maria T., G., B. and Souza S., F. ,“ Investigation of Bond Stress in Pull Out Specimens with High Strength Concrete”, Global Journals Inc. (USA),Online ISSN: 2249-4596 & Print ISSN: 0975-5861,(2013)

Mathias M. and Manfred k. , “Bond of steel and concrete under high loading rates”, International Conference, ISSN: 2311-9020; ISBN: 978-972-752-165-4, 30 June - 2 July (2014)

Matthew H. and Khalid N.,“Structural behaviour and durability of steel-reinforced structural Plain/Self-Compacting Rubberised Concrete (PRC/SCRC) ”, Construction and Building Materials 73 ,490–497, (2014)

Mohamed A. ,“Shear Strength of Self-compacting Concrete Containing Different Fillers and Coarse Aggregates”, Civil Engineering, Faculty of Engineering Menoufai University, EGYPT, ISSR Journals Vol. 2 (4) – December (2011)

Mohammad A., Rajesh D. and Allan S. ,“Post-yield bond behavior of deformed bars in high-strength self-compacting concrete”, Construction and Building Materials 44, 236–248(2013)

Mohammed S. , Richard D. and David, C., “Bond between Reinforcement and Concrete – Influence of Steel Corrosion”, Queen’s University, Belfast, PORTUGAL, April(2011)

Muhammad N.S. Hadi,“ Bond of High Strength Concrete with High Strength Reinforcing Steel”, The Open Civil Engineering Journal, vol:2, 143-147,(2008)

N. Ganesan , P. Indira and M. Sabeena,“Bond stress slip response of bars embedded in hybrid fiber reinforced high performance concrete”,Construction and Building Materials 50,108–115, (2014)

Nassim S., Mahfoud B., Nor A. and Christophe B.,“Mechanical properties of concrete-reinforced fibers and powders with crushed thermoses composites: The influence of fiber/matrix interaction", Construction and Building Materials 29, 332–338, (2012)

Natalie P., Ignasi P., Lars T. and Karin L.,"Pull-out of textile reinforcement in concrete", Construction and Building Materials 71 ,63–71, (2014)

Of high strength self-compacted concrete beams", Alexandria Engineering Journal,53, 319–328, (2014)

Okamura H., Ozawa K., and Ouchi M. ,"Self-compacting concrete Structural Concrete",Vol. 1, No. 1, pp. 3-17, March (2000)

Okamura, H, "Self-Compacting High-Performance Concrete", Concrete International, pp.50-54(1997).

Okan K., Khandaker H., Erdogan O., Mohamed L. and Emre S.,"Effect of metakaolin content on the properties self-consolidating lightweight concrete", Construction and Building Materials 31,320–325, (2012)

Oldrich Š., Giedrius Z., John E. B. and Henrik S. ," Influence of formwork surface on the orientation of steel fibres within self-compacting concrete and on the mechanical properties of cast structural elements",Cement & Concrete Composites 50,60–72, (2014)

Ozawa, K., "Development of high performance concrete based on the durability design of concrete structures", EASEC-2, Vol. 1, pp.445-450 (1989).

Peter H. , Veerle B. , Wouter C. , Geert S. and Pieter D.,"Structural behaviour of powder-type self-compacting concrete: Bond performance and shear capacity", Engineering Structures 48,121–132, (2013) Pieter, D., Geert,S. and Taerwe,L.,“ Bond Strength of Reinforcing Bars in Self-

Pop ,“Bond between powder type self-compacting concrete and steel reinforcement”, Construction and Building Materials 41 (2013) 824–833, JANUARY(2013)

Prof. R.M. Sawant et al. , “comprehensive study of high strength fiber reinforced concrete under pull out strength”, International Journal of Civil Engineering and Technology,ISSN 0976 – 6308 (Print),ISSN 0976 – 6316(Online), Volume 6, Issue 1, January (2015), pp. 14-20,January (2015)

reinforced concrete”, International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online), Vol. 4 (1), pp.72-81, January-March/ (2014)

Rodrigo L.,Joaquim B. and MiguelA., “Influence of casting condition on the anisotropy of the fracture properties of Steel Fiber Reinforced Self-Compacting Concrete (SFRSCC)”, Cement& Concrete Composites 59 ,60–76, (2015)

Rodrigo L., Joaquim B., Isabel V. and Miguel A.,“Development of sandwich panels combining fiber reinforced concrete layers and fiber reinforced polymer connectors. Part I: Conception and pull-out tests”, Composite Structures 105,446–459, (2013)

Rodrigo L., Joaquim B., Miguel A. and Isabel V.,“Development of sandwich panels combining fiber reinforced concrete layers and fiber reinforced polymer connectors. Part II: Evaluation of mechanical behavior”, Composite Structures 105,460–470, (2013)

Ruza, B., Dejan, V.,“Self-compacting concrete and itsApplication in contemporary architecturalPractice”, SPATIUM International Review, p. 28-34(2009)

S. Goel , S. Singh and P. Singh ,"Flexural fatigue strength and failure probability of Self Compacting Fiber Reinforced Concrete beams", Engineering Structures 40,131–140, (2012)

S. Goel and S.P. Singh,"Fatigue performance of plain and steel fiber reinforced self compacting concrete using S–N relationship", Engineering Structures 74, 65–73, (2014)

Sadegh A.,Changiz D. and Ali K.," Corrosion protection of the reinforcing steels in chloride-laden concrete environment through epoxy/polyaniline–camphorsulfonate nanocomposite coating", Corrosion Science 90,239–247, (2015)

Salem Alsanusi," Influence of Silica Fume on the Properties of Self Compacting Concrete", World Academy of Science, Engineering and Technology,Vol:7,05-23 (2013)

Sara C. and Gianpaolo R. ," Bond between Steel and Self-Consolidating Concrete:

Sara,Cattaneo and Gianpaolo,Rosati,"Bond between Steel and Self-Consolidating Concrete: Experiments and Modeling", ACI Structural Journal,July-August (2009)

Selctu R. and Yigit, A.,"The effect of limestone powder, fly ash and silica fume on the properties of self-compacting repair mortars", Civil Engineering Department, Dokuz Eylul University, 35160, Turkey, Vol. 34, Part 2, pp. 331–343 , April (2009)

self-compacting concrete", Advanced Concrete and Masonry Centre, University of Paisley,Cement and Concrete Research 35 ,1457–1462,(2005) Shruti S. and Abhijit M.,“ Ultrasonic guided waves for monitoring the setting process of concretes with varying workabilities ”,Construction and Building Materials 72 ,358–366, (2014)

Sirajul I., Hamdy A., Khaled S. and Hossein A.,“Bond characteristics of straight- and headed-end, ribbed-surface, GFRP bars embedded in high-strength concrete”, Construction and Building Materials 83 ,283–298, (2015)

Soroushian, P. and Choi, K.B.,“Local bond of deformed bars with different diameters in confined concrete”, ACI Str Jl, 86(02): 217-222,(1989)

St John, D. A., “Concrete Petrography”, A handbook of investigative techniques, Wiley & Sons, New York (1998).

Subramanian, S. and D. Chattopadhyay, “Experiments for mix proportioning of self-compacting concrete”, The Indian Concrete Journal, pp.13-20 (2002)

T. Ponikiewski and J. Gołaszewski,“The effect of high-calcium fly ash on selected properties of self-compacting concrete”, Department of Material Engineering and Building Processes, Silesian University of Technology, Gliwice, Poland , archives of civilandme chemical engineering 14 ,455 – 465, (2014)

T. Soetens and S. Matthys,“Different methods to model the post-cracking behaviour of hooked-end steel fiber reinforced concrete”, Construction and Building Materials 73,458–471, (2014)

T.A. Soylev and R. Franc¸ois ,“ Quality of steel–concrete interface and corrosion of reinforcing steel”,Cement and Concrete Research 33, 1407–1415, (2003) Trevor J. Looney et al. ,“ An Experimental Study on Bond Strength of Reinforcing Steel in Self-Consolidating Concrete”, International Journal of Concrete Structures and Materials, Vol.6, No.3, pp.187–197, ISSN 1976-0485 / EISSN 2234-1315, September (2012)

V.M.C. Cunha , J. Barros and J. Sena-Cruz ,“ An integrated approach for modeling the tensile behavior of steel fiber reinforced self-compacting concrete”, Cement and Concrete Research 41,64–76, (2011)

Vahid A., Sam H., Al G. and Konstantin S.,“Design and application of controlled low strength materials as a structural fill”, Construction and Building Materials 53,425–431, (2014)

Vitor C., Joaquim B. and José S. ,“A finite element model with discrete embedded elements for fibre reinforced composites”, Computers and Structures 94–95,22–33, (2012)

W. Zhu, J.C. Gibbs,“Use of different limestone and chalk powders in

Watcharapong W., Pailyn T., Athipong N. and Arnon C.,“Compressive strength and chloride resistance of self-compacting concrete containing high level fly ash and silica fume”, Materials and Design 64 ,261–269, (2014)

X.X. Zhang*, A.M. Abd Elazim, G. Ruiz, R.C. Yu,“ Fracture behavior of steel fiber-reinforced concrete at a wide range of loading rates”,International Journal of Impact Engineering 71, 89-96, (2014)

Yousif A., and Zhi Q.,“The Reinforcement Bond Strength Behavior under Different Corrosion Condition”, Journal of Applied Sciences, Engineering and Technology 5(7): 2346-2353(2013)

Zenon A. and Kypros P. , “Bond behavior of FRP Bars under direct pullout conditions”, paper published in Journal of Composites for Construction, 8 (2), pp. 173-181, (2004)