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EFFECT OF SILICA FUME AND STEEL FIBER ON THE MECHANICAL PROPERTIES OF THE CONCRETES PRODUCED WITH COLD BONDED FLY ASH AGGREGATES

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Effect of Silica Fume and Steel Fiber on the Mechanical Properties of the Concretes Produced with Cold bonded Fly Ash Aggregates

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Radhwan ALZEEBAREE

ABSTRACT

EFFECT OF SILICA FUME AND STEEL FIBER ON THE MECHANICAL PROPERTIES OF THE CONCRETES PRODUCED WITH COLD BONDED FLY ASH AGGREGATES

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This study presents an experimental research on the mechanical properties of steel fiber incorporated plain and silica fume (SF) concretes produced with cold bonded artificial fly ash aggregates (AFA). Two concrete series with water-to-binder (w/b) ratios of 0.35 and 0.55 were designed. SF incorporation was achieved by 10% replacement of the weight of cement by silica fume. Two types of hooked-end steel fibers with length/aspect ratios of 60/80 and 30/40 were utilized. AFA, produced from cold bonding pelletization of 90% class F fly ash and 10% Portland cement, were used as coarse aggregate in all of the concrete mixtures. The mechanical properties investigated were compressive strength; splitting tensile strength, modulus of rupture and bonding strength between rebar and concrete. The tests were carried out at the end of 28 day water curing. Analyses of variance of the experimental results were performed and the contributions of the significant factors on the mechanical characteristics of the concretes were determined for statistical evaluations. Moreover, correlation of the experimental data was carried out to monitor the interaction between mechanical properties and bonding strength of the concretes. The results demonstrated that incorporation of SF and utilization of different types of steel fiber reinforcements significantly affected the mechanical properties of the concretes regardless the w/b ratio.

Keywords: Cold bonding, Silica fume, Concrete, Mechanical properties, Bonding strength, Steel fiber.

ÖZET

SİLİS DUMANI VE ÇELİK LİFİN SOĞUK BAĞLAMA YÖNTEMİYLE ÜRETİLMİŞ UÇUCU KÜL AGREGASI İÇERENBETONLARIN MEKANİK ÖZELLİKLERİNE ETKİSİ

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Bu çalışmada, soğuk bağlama yöntemiyle üretilen yapay uçucu kül agregaları içeren yalın ve silis dumanlı çelik lif katkılı betonların mekanik özellikleri deneysel olarak incelenmiştir. Su bağlayıcı oranları 0,35 ve 0,55 olan iki beton serisi tasarlanmıştır. Silis dumanı, çimentonun ağırlığının %10'uyla yer değiştirilerek kullanılmıştır. Boy/narinlik oranı 60/80 ve 30/40 olan iki farklı tip kanca uçlu çelik tel kullanılmıştır. Bütün beton karışımlarında, %90'ı F sınıfı uçucu kül ve %10'u Portland çimentosu olan soğuk bağlı peletleme yöntemiyle üretilmiş yapay uçucu kül agregaları, kaba agrega olarak kullanıldı. Betonun mekanik özellikleri basınç dayanımı, yarmada çekme dayanımı, eğilmede çekme dayanımı ve donatı-beton arasındaki aderans dayanımı bakımından irdelenmiştir. Deneyler 28 günlük kür süresi sonunda gerçekleştirilmiştir. Deney sonuçların ützerinde varyans analizi yapılmış ve deneysel parametrelerin istatistiksel değerlendirmesi için betonların mekanik özellikleri üzerindeki etki faktörü belirlenmiştir. Ayrıca betonların aderans dayanımları ve mekanik özellikleri arasındaki etkileşimi görmek amacıyla deneysel verilerin korelasyonu yapılmıştır. Sonuçlar, su bağlayıcı oranı ne olursa olsun silis dumanı katkısı ve farklı tip çelik lif donatıları kullanılmasının, betonun mekanik özellikleri üzerinde önemli bir etkiye sahip olduğunu göstermiştir.

Anahtar Kelimeler: Soğuk bağlama, Silis dumanı, Beton, Mekanik özellikler, Aderans dayanımı, Çelik lif.

To my dear parents,

brothers, sisters, and

daughters

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LIST OF SYMBOLS/ ABREVIATIONS

SF	Silica Fume
AFA	Artificial Fly Ash Lightweight Aggregate
St	Steel Fiber
W/b	Water/Binder ratio
W/C	Water/Cement ratio
FA	Fly Ash
LWA	Light Weight Aggregate
GGBFS	Ground Granulated Blast-Furnace Slag
MK	Meta-Kaolin
MIP	Mercury Intrusion Porosimeter
RC	Reinforced Concrete
GLM-ANOVA	General Linear Model Analysis of Variance
ASTM	American System for Testing Materials
Vf	Volume Fraction of Fiber
L/d	Aspect ratio of Fibers
NWC	Normal Weight Concrete
LWC	Light Weight Concrete
LWAC	Light Weight Aggregate Concrete
CH	Calcium Hydroxide
ACC	Autoclaved Cellular Concrete
LWCA	Lightweight Coarse Aggregate

C-S-H	Calcium-Silica-Hydrated (Gel)
ACI	American Concrete Institute
SSD	Saturated Surface Dry Aggregate
OPC	Ordinary Portland Cement
V_{CA}	Volume of Coarse Aggregate
V_{TA}	Volume of Total Aggregate
FA-F	Fly Ash- Class F
SP	Super-Plasticizer
CLWC	Expanded Clay Light Weight Concrete
LWBC	Light Weight Bottom Ash Concrete
LWGC	Light Weight Granular Blast Furnace Slag Concrete
SLWAC	Sintered Fly Ash Light Weight Aggregate Concrete
FRC	Fiber Reinforced Concrete
NAC	Natural Aggregate Concrete
SEM	Scanning Election Microscopy
CSF	Compressed Silica Fume
LWVPC	Light Weight Volcanic Pumice Concrete
HPC	High Performance Concrete
HSLWC	High Strength Light Weight Concrete
HRWRA	High Range Water Reducing Admixture
RPC	Reactive Powder Concrete
Ꚍ	Bond Strength
δ	Compressive Strength

CHAPTER 1

INTRODUCTION

1.1 Background

Disposing industrial waste materials is one of the greatest environmental concerns. Concrete technology can offer some applications in recycling some industrial wastes, such as silica fume (SF), fly ash (FA), ground granulated blast furnace slag (GGBFS) etc. For several decades utilization of such minerals as a cement substitution material has been practiced by many researchers. However, utilization of industrial waste powder materials such as, FA and GGBFS in production of artificial aggregate has been commonly realized (Arslan and Baykal, 2006; Baykal and Doven, 2000; Bilgen et al., 2010; Dongxu et al., 2002; Cheeseman and Virdi, 2005; Gesoglu, 2004; Gesoglu et al., 2007; Joseph and Ramamurthy, 2009; Kayali, 2008; Gesoglu et al., 2012; Kockal, 2008). As a matter of the fact that the aggregates occupy about 65% to 75% of total concrete volume, it can be considered as an influential way to use such waste materials as aggregate in concrete. Artificial aggregates can be obtained through processing of different materials and utilizing methods like cold bonding pelletization (Gesoglu, 2004). Cold bonding is a kind of bonding method due to the ability of pozzolanic powder material to react with calcium hydroxide (CH) at conventional temperatures to produce a water resistant bonding material. Pelletized aggregates are left to cure for several days to produce an aggregate with proper strength to be used in concrete production (Kockal, 2008). Although Turkey produces large amounts of fly ash up to 15 million tons per year from a wide variety of industries only a limited percentage is utilized in the construction industry (TSI, 2010). Therefore, using FA in production of artificial lightweight aggregate might be a feasible way in recycling of this material. Cold bonding, autoclaving or sintering procedures are the most commonly applied techniques for manufacturing artificial aggregates (Arslan and Baykal, 2006; Baykal and Doven, 2000; Gesoglu, 2004; Gesoglu et al., 2007; Joseph and Ramamurthy, 2009). Although general trend for production of artificial aggregates is governed by sintering method, the energy saving concern has led the researchers to benefit from cold-bonding pelletization process for production of artificial aggregates.

Since artificial light weight aggregates (LWA) has relatively lower strength than natural aggregates, the concretes including LWA may have less mechanical properties than that of natural aggregate including ones (Kockal and Ozturan, 2011). In such cases, to improve the mechanical property of the concrete containing artificial aggregates, some mineral admixtures can be used as modifier. For example, silica fume is well known for its improvement in both durability and mechanical properties of concrete (Alexander and Magee, 1999; Al-Khaja, 1994; Khatri et al., 1997). So it has been used as a replacement material in the manufacture of high performance concrete (HPC). Bhanja and Sengupta (2005) carried out a wide experimental study above the w/b ratio between 0.26 and 0.42 and SF to binder ratios between 0 and 0.3. They determined in Compressive strength, split, and flexural tensile strengths at 28 days age. They reported that incorporation of SF increases the compressive strength, in addition to the tensile strengths of concrete. Poon et al. (2006) investigated on the pore structure of HPC with meta-kaolin (MK) and SF. To measure pore size distribution of the concrete, they used mercury intrusion porosimeter (MIP). They reported that a very dense microstructure of the paste, with a lower total porosity and finer pore size distribution resulted with the incorporation of MK in the cement pastes compared with the plain Portland cement pastes and SF blended cement pastes.

Improvement in mechanical properties of the concrete accompanies long term and safe service life of the structural performance of the reinforced concrete (RC) structures even under extreme loading cases. Performance of RC as a composite material depends on many different characteristics of its components (Ersoy et al., 2003). Due to the weakness of concrete in tension, it needs to be reinforced when used as structural element. The stress transfer results in bond stresses between the concrete and the steel bars. Bonding strength is the transfer of axial force from a reinforcing steel bar to the surrounding concrete results in the development of tangential stress components along the contact surface area (Pillai and Kirk, 1983).

For reinforced concrete as a composite material, it is necessary for the reinforcing steel to be conveniently bonded to the surrounding concrete. If there is a good bond there is little or no slip of the steel relative to concrete which means that stress is properly transferred across the steel-concrete (Warner et al., 1998).

In this study, effectiveness of SF on 28 day mechanical properties of concretes and with and without steel fiber was examined through an experimental program. The mechanical properties of the concretes were evaluated in terms of compressive, flexural and splitting tensile strength testing after 28 days age of curing. Moreover, being one of the most critical properties for pertinent structural behavior, adherence between reinforcing steel bar and concrete were evaluated by means of bonding strength test at that age. The concretes dealt with this study were produced by two different water/binder (w/b) ratios. For steel fiber reinforced concretes, two different kinds of steel fiber (St) with (length/aspect) ratios of 60/80 and 30/40 were utilized. The steel fibers were added to concrete with 0.25% and 0.75% of the volume of the concrete. The statistical analysis and calculation of the contributions of the independent factors on mechanical behavior of concretes were made by general linear model analysis of variance (GLM-ANOVA). Furthermore, the relation between mechanical properties and the bonding strength of the concretes were assessed through correlating the experimental data.

1.2 Research Significance

Because Middle East regions last years are subject to considerable and violently earthquake activities, investigation on the possible uses of lightweight aggregate concrete is getting common during the last decades. There is very little knowledge on the mechanical interaction ("bond") between reinforcing bars and lightweight aggregate concrete.

This paper is one of a great investigation project on estimating the mechanical properties effect of silica fume and steel fibers on structural lightweight aggregate concretes in order to determine the usability on reinforced concrete (RC). The goal of this investigation was to study the effects of silica fume and steel fibers on the mechanical properties of lightweight aggregate concrete and to compare these properties to ordinary lightweight aggregate concrete. The conventional pullout test setup basically followed the specification ASTM C234, but the nominal diameter of rebar was 16 mm instead of no.6 (19 mm) (Sancak, 2005; Sancak et al., 2008).

1.3 Outline of the Thesis

Chapter 1 Introduction: Aim and objectives of the thesis are introduced.

Chapter 2 Literature Review and Background: A literature review was conducted on the cracking in concrete. The previous studies on the use of fly ash for producing lightweight aggregate are investigated. The use of shrinkage reducing admixture and steel fibers in reducing shrinkage in concrete as well as reducing width of crack.

Chapter 3 Experimental Study: Materials, mixtures, casting, curing conditions, and test methods are described.

Chapter 4 Test Results and Discussions: Indication, evaluation, and discussion of test results are presented.

Chapter 5 Conclusions: Conclusions of the thesis are given.

CHAPTER 2

LITERATURE REVIEW

This chapter presents the history and recent development of lightweight aggregate concrete, pozolanic material concrete, bond strength in concrete, mechanism of bond strength in concrete, silica fume used as a pozolanic and mineral admixture in concrete, steel fiber reinforced concrete (SFRC) and the combined application of lightweight aggregates and steel fibers in the concrete with and without silica fume as well.

2.1 General

Cement based concretes have been long used for civil constructions like highways, buildings, and bridges. Conventionally, the components of cement based concretes contain cementitious material, water, aggregate and admixtures. Nevertheless, accidental degradation of reinforced concrete constructions has caused to the enhancement of durability of concrete structures. To improve concrete characteristics, especially tensile strength, abrasion resistance and energy-absorbing capability fiber have been supplemented in cement based concretes as 1960s (Gutierrez et al., 2005; Zhang et al., 2006; Song et al., 2005). The occupancy of fiber would refrain from the extension of inner cracks and assists to conveyance stress (Maalej et al., 1995; Swaddiwudhipong et al., 2006). FRC also displays an important increment in energy-absorption, so the sample with fiber has been greatly higher tensile strength than the sample without fiber (Kesner and Billington, 2005).

Nevertheless, the characteristics of FRC would be influenced by the kind, aspect ratio and volume fraction of fiber. Lesser fiber V_f is generally favored as far as substance expense and workability are troubled (Chen and Chung, 1996). The accepted Vf of fiber was about 2% in cement-based concretes has been mentioned by the earlier investigation (Naaman, 2003).

It was as well stated that the mix of SF and steel fiber would efficiently improve the compressive strength, splitting tensile strength, abrasion resistance and impact resistance (Eren et al., 1999) and be favorable for fiber distribution in cement based concretes (Chen et al., 1997; Chung, 2002). SF would improve the bonding strength between fiber and matrix (Fu and Chung, 1998) by reinforcing the transition zone (Yan et al., 1999). This research was directed to assess the influence of steel fiber on the mechanical characteristics of concretes with the silica fumes. Many regression examinations were also carried out on the test results to compute the effect of material variable quantities on the mechanical properties.

2.2 Difference between Normal Weight Concrete and Lightweight Aggregate Concrete

Differences between LWAC and NWC interest the mixing phase, hardening phase, tensile, failure modes et al.

In the mixing phase, the porous, water absorbing LWAs can influence the workability of the concrete (Neville et al., 1987) and the efficient water/binder ratio (ACI211.2, 1998). In the hardening phase, the proportionately ignoble specific heat and high isolating capability of LWAC will source a higher hydration temperature.

The water at first instant in the porous aggregate fragments may influence the moisture stage in the hardening procedure to a great extent. Volume variations happen with the variations in the stage of water in the pore technique in the early phase of hardening.

In the hardened concrete, the differences between LWAC and NWC are mostly expected to differences in the elastic modulus and strength of the aggregate, and especially to differences of the matrix aggregate transition zone. These differences conclude the grade of heterogeneity of concrete. The properties of the interfacial zone are concluded by the surface properties of the aggregate, in addition to the pore structure and the basic water content of the aggregates (Isserman and Bentur, 1996).

Some counteraction products, e.g. CH, relying on the pore structure of the aggregates, will even penetrate inside the pores of the aggregates. This is further acceptable in aggregates with higher absorption and larger pores (Isserman and Bentur, 1996).

The strength of many LWA is about the same as the strength of the hardened paste. The matrix aggregate transition zone is of a higher characteristic compared to the situation of NWC. The bleeding influence on aggregate surfaces is as well decreased expected to the decreased reaction of the LWA to vibration-energy through the compaction process of the concrete. It income that in many LWAC, the transition zone is not the weakest connection, generally, the LWA has even lesser modulus of elasticity than the mortar stage, generating the mortar to pull further stress. With equivalent modulus of elasticity for the mortar and LWA and, the stress will be further evenly dispensed in LWAC than in NWC. As a topic of reality, in this case, the transition zone will slightly be cramped by oblique compressive stress. The resulting confined oblique tensile stress will show in the mortar, and not in the transition zone (FIP, 1983).

The crack introduction of LWAC happens at a very high-stress degree expected to the elastic suitability of the stages. The strength and rupture toughness of LWA is significantly lesser than those of NWA of regular origin, and perhaps in spite of the mortar stage. The strength of LWA can be the strength upper limit of LWAC (Bremner and Holm, 1986; Chi and Huang, 2003).

2.3 Lightweight aggregate

2.3.1 Background

The use of fly ash (FA) is approximately 30% as various engineering property's specifications that are for ignoble technical programs such as in structure of fills and earthworks, walkway base, backfills, and sub base layer; middle technical programs such as in manufacturing blended cement, concrete tubes, pre-cast/ pre-stressed product's substances, LWC bricks/blocks, autoclaved aerated concrete and LWA. Presently, in India, the power zone relies on coal established thermal power stations, which produce a massive amount of fly ash and assessed to be about 110 million tonnes yearly (Baykal and Doven, 2000). LWC is manufactured in distinctive classifications established on aerated cellular concrete and LWACs. Utilizes of structural level LWC reduced substantially the dead-load of constructions and permits greater pre-cast elements to be held. For example, the Autoclaved cellular concrete (ACC), is a LWC material that can be produced utilizing 60 - 75% FA by mass of cement. With increasing interest over the extreme utilization of natural aggregates, artificial LWA manufactured as of environmental waste is a usable recent representative of constructional aggregate substance (Ahmaruzzaman, 2010).

Agglomeration system is one of the coarse systems periods manufacturing the LWA. In agglomeration system the pellets are created in two paths either by compaction and agitation granulation. The agitation system is not needed to any exterior power rather than revolving power. Increase the amount of water in the binder causes an increase in the cohesive strength of the pieces. To strengthen the green pellet sintering, autoclaving and cold bonding are three unlike procedures utilizes (Bijen, 1986). The partial replacement of NWC is 20% - 40% by the volume of LWA was calculated by Behera et al. (2004) with the difference of the compressive strength just 1%.

2.3.2 Peletizetion process

The pelletization procedure is utilized to production lightweight coarse aggregate (LWCA); some of the variables require to be pondered for the capability of the manufacture of pellet such as velocity of revolt of pelletizer disc, slope of pelletizer disc, wetness satisfaction and period of pelletization (Harikrishnan and Ramamurthy, 2006). The distinctive kinds of pelletizer instrument were utilized to manufacture the pellet such as disc or pan kind, drum kind, cone kind and mixer kind. With disc kind pelletizer the pellet proportion distribution is simpler to control than drum kind pelletizer. With mixer kind pelletizer, the small pieces are created at first and are following enlarged in piece volume by disc kind pelletization (shown in Figure 2.1, Bijen, 1986). The disc pelletizer dimension is 570 mm diameter and edge depth of the disc as 250 mm, it is established in a variable setting by modifying the gradient of the disc as 35 to 55° and to control for the revolve disc in perpendicularly a manner should be varying velocity as 35 to 55 rpm indicated in Figure 2.2 (Manikandan and Ramamurthy, 2007). To make the increment the strength of the pellet in a cold bonded system is as to increment the fly ash/cement ratio as 0.2 and above (by weight of cement) (Yang, 1997). Wetness content and slope of the disc variable affect the volume increase of pellets (Harikrishnan and Ramamurthy, 2006). The addition of the binding representatives is further significant for manufacture fly ash balls Sivakumar and Gomathi 43 Figure 2.2 Disc pelletizer instrument. And the best variety was established to be about 20% - 25% by the absolute weight of binders (Bijen, 1986). Initially, some percent of water is supplemented to the binder and then rained in a disc; residual water is sprayed through the revolving time because while revolving without water in the disc the fly ash powder leans to form pieces and does not increment the dispensation of fragment dimension. The pellets are created nearly in time of 20 min.

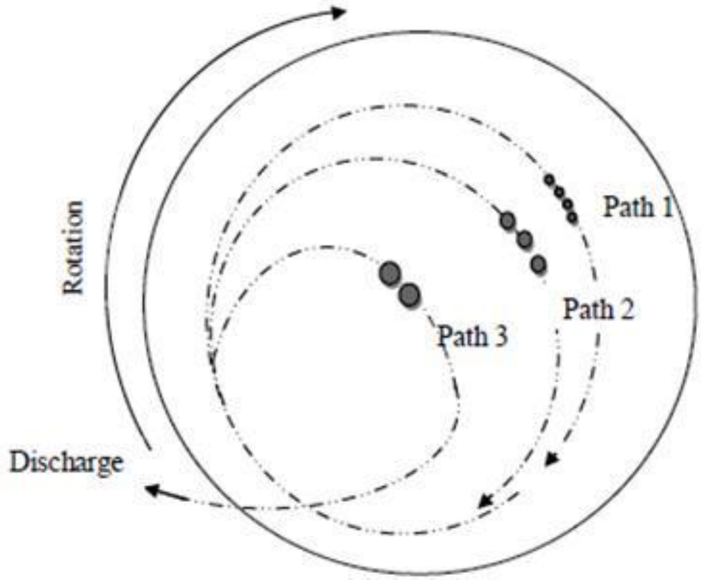


Figure 2.1 Growing path of pellets (Bijen, 1986)

Figure 2.2 Disc pelletizer machine (Bijen, 1986)

2.3.3 Hardening properties process of LWA

ASTM C 618 defined two great sections of fly ash, firstly, class-C and secondly called class-F classed established in the chemical constitution resulting from the various kinds of coal burning. Class-C fly ash is generally manufactured as of the burning of lignite and sub bituminous coal. The fly ash aggregates are permeable material and to enhance the strength of the pellet the binder material as cement, meta-kaolin, lime, glass powder, bentonite, kaolinite and ceramic powders are supplemented. (Geetha and Ramamurthy, 2011) stated that the clay binders as meta-kaolin and kaolinite impart higher fines price. The percent of binder component is obtained by the mass of fly ash. Hardening the pellets is over at various processes' specifically cold bonding, autoclaving and sintering. Cold-bonded fly ash aggregates are hardened at various curing procedures, namely normal water curing, steam and autoclaving curing. Autoclave and steam curing system is smaller efficient to enhance the characteristics of aggregate as compare to standard water curing system, between accelerated cured class c fly ash aggregate (FAA), expected to the dense micro-structure autoclaved aggregates has characteristics closer to the standard water cured aggregate. The curing system is further significant to improve the aggregate strength. Consequently, for high early strength, a standard water curing system can be adopted and autoclaving may be adopted (Manikandan and Ramamurthy, 2008).

An examination by Topcu and Uygunoglu (2007) indicate that a higher strength of the aggregate can be attained at 8 - 10 h in autoclave curing.

Sintering procedure can be explained as burning the cold bonded pellet in a muffle furnace at temperature variety between 800 – 1200 °C. Therefore, sintered fly ash LWA manufacture is further available while replacing the NWA to LWA, as the mineral particles in the binder contact with each other to construct the crystalline construction (C-S-H) and results in higher strength of the aggregate (Verma et al., 1998).

2.3.4 Mix design of LWAC

The mix design of LWACs is deferent than NWC mix design. Because of the aggregates are permeable and effects in satisfaction of additional water for getting further workability. Generally established in the manufacture of the higher strength matrix to the low w/c ratio for the softer aggregate, the mix designs are conceptions. Therefore, in a LWAC's mix design further complex for supplementing of water, LWA is a permeable aggregate, so we require additional water in the concrete. However, in NWC, the sum of mixtures that are essential to decide the optimum constitution can be decreased to a lowest (Grubl, 1979). An examination by Sari and Pasamehmetoglu (2005) determined that gradations of aggregate by various aggregate grading dimension dispensations are desired to enhance the engineering characteristics in the concrete mix design.

As equated to the ACI 211.11 system (Chao-Lung and Meng-Feng, 2005). The self-consolidating characteristics of LWACs can be acquired by an identified mix design algorithm which provides stiffer strength, excellent durability and flow ability. The designs of LWAs are accompanied in two systems; total hard mass estimation in addition to lose mass estimation (Wang et al., 2005). In mixture proportion, the LWA is blended in various degree times completely saturated situation, dry situation and relatively saturation situation. The LWA is used as saturated surface dry (SSD) before inclusion of the concrete mix design. LWAs were plunged in water of 24 h to enhance the workability of concrete mixtures. An investigation by Wang et al. (2005) stated that the choice of the sand-aggregate ratio is 28 to 52% in the mix design, which can affect the compressive strength and control the workability of concrete mixtures.

A study by Kockal and Oztoran (2011), they reported that the amount of the components can be chosen the mass of coarse aggregate to complete mass of the aggregate percentage as 0.6; established on the cold-bonded FAA the amount of cement content as 551 kg/m^3 larger than the sintered FAA as about 548 kg/m^3. The strength of concrete is same to the efficient w/b ratio which is selected as 0.26. Both types of LWACs showed the stiffer compressive strength. Furthermore, Yun et al. (2004) stated on LWCs, including the bottom ash and the sintered fly ash in the concrete should improve the permeability; at replacing 30% of ordinary Portland cement (OPC) by fly ash, to enhance the permeability of LWCs. Inclusion of admixture in the LWCs is to improve the elastic modulus and strength. As Shannag (2011) reported that the inclusion of SF by 5 - 15% in the LWCs can enhance the strength characteristics while, at replacing 10% of OPC by FA in concrete can reduce the strength as compared to the concrete mix designs that seen in Table 2.1.

Table 2.1 Mix proportion of LWAC ingredients studied from various literatures

Author	Concrete type	W/b ratio	Cement content (kg/m3)	Fine aggregate content (kg/m3)	Fine aggregate content (kg/m3)	V_{CA}/V_{TA} ratio	Light weight aggregate content (kg/m3)	AEA (%)	Admixture (%)	Admixture (%)
				Natural sand	Crushed sand				FA-F	SP
Yannick et al. 2006	LWAC	0.27	475.6	674.4	-		546.6	-	158.7	
		0.34	335.3	728.9	-	0.6	612.5		110.6	-
		0.28	391.2	734	-		540		107	
Kockal and Ozturan 2011	CLWC	0.26	551	318	318		592			
	LWBC		548	316	317	0.6	567	0.2	-	1.1
	LWGC		549	317	317		580			
Wasserman and Bentur 1997	SLWAC	0.4	440	49%	49%	0.51	51%	-	-	-

2.3.5 Strength properties

The lime, cement and bentonite are utilized like a binder in 10, 20 and 30% by mass of fly ash for pelletization process. It is as well noticed that the decrease in water absorption of sintered fly ash aggregate and the enhancement in the 10% small size rate. To test strength of LWA 10% fineness is used. To enhance the strength of LWA the bentonite is supplemented, the lime is for increasing the ball-ability and cement is to provide minimum strength for LWA. Thus, the inclusion of bentonite approximately 20% provides an optimum strength for LWA (Ramamurthy and Harikrishnan, 2006)

The compressive strength of the steel fiber reinforced is lesser than polypropylene fiber reinforced by 7 MPa (Kayali et al., 2003). FRC improves the tensile strength with low modulus of elasticity and lowering the shrinkage cracking in LWAC (Kayali et al., 1999). The LWA produced utilizing pelletizing procedure provides a smooth top surface for LWA. The sintered fly ash LWAs that is not involved pelletizing were crushed to provide a coarse surface and improving the compressive strength about 66 - 76 MPa (Kayali, 2008).

Expanded clay LWA contains higher porosity in the interfacial zone which may indicate a significant influence on the permeability of LWC. The pre-wetting period of expanded clay LWA was essentially influenced the strength and workability of the concrete (Lo et al., 1999). The pore structure of the sintered pulverized fuel ash LWA is studied by Swamy and Lambert (1981) approaching variety of the pore dimension as of 200 μm down to smaller than 1μm by all the volume was evenly dispensed during the pellet and provides the best bond between the pellets and matrix of cement.

Lo et al. (2006) utilized the high analysis visual microscope and picture examination software program to determine the pore dimension dispensation in the cement paste and the pore zone proportion and the interfacial zone of concrete that water cured at 28 days. A soft region of further permeable between the aggregate and cement matrix is the interfacial zone, great water absorption varieties as of 8.9 to 11%, which cause larger pore proportion like 14.4 as well as 21.7% at the interfacial zone were indicated at an experimental result of LWA.

Consequently, LWA is further permeable as of the external layer and it current thick transition zone for the LWA lacking any external layer. So that expected to the mechanical interconnecting between LWA and the cement matrix, the LWA provides best bond developed (Min-Hong and Gjorv, 1990). The benefits of utilizing silica fume for supplementing in LWC is to enhance the mechanical characteristics, but harm of shrinkage performance is smaller equated to NWC (Gesoglu et al., 2004)

2.3.6 Micro-structural properties of fly ash lightweight aggregate

The mechanical characteristics and durability of concrete affect by its compounds and the interfacial zone between them. In NWC, the interface between the aggregate/cement pastes is the weakest part of the micro-structural system and the area where cracks start, compare to strongest constituent because it is a normal aggregate (Min-Hong and Gjorv, 1990). However, the LWACs have unlike than the interface between the cement pastes, and aggregate is difficult and it's changing to the normal aggregate concrete (NAC). The particles are able of absorbing water, which produced near matrix; this kind of aggregate is permeable in nature. The porosity can change from 25 to 75% of Lytag aggregate relying on the production procedure utilized (Swamy and Lambert, 1981). Especially cement-matrix and aggregate interface performed on many further studies that work to recognize the inner and surface construction of LWA (Shondeep et al., 1992). For assigned micro-mechanical system considered the ultimate bonding between the aggregate and cement matrix (Chung-Chia and Ran, 1998).

In general sintered fly ash LWA was manufactured at polymer and temperature handling so that to enhance LWA strength, pozzolanic reaction and absorption as per to their characteristics of aggregate by variation to the micro-structure. Scanning election microscopy (SEM) are examination to observe further suit dispensation of low pore dimension, and to notice the larger expansion in the sintered fly ash LWA at the heat-treated LWA about 1200 – 1300 °C (Weasserman and Bentur, 1997). For reinforcing the interface zone a significant character is acts at mechanical interconnecting (Shondeep et al., 1992). The influence of LWA utilizing is dry and saturated LWAs on the interior interfacial zone microstructure. The thickness of the internal interfacial zone surrounding the normal aggregate is 35 μ over than the dry and saturated LWA as 10 μ and 15 μ respectively (Amir et al., 2005).

2.3 Bond strength

One of the mainly significant characteristics in reinforced concrete constructions is the bond characteristic between reinforcing steel bar and concrete. The bond strength of steel and concrete is the mix of friction, adhesion, and assistance of the ribs in deformed steel. The initial characteristic started by the applied load is the adhesion process. It is slightly negligible ignition interlock of paste into weaknesses on the steel bar top surface and slightly a potential chemical interaction between surfaces (Cosenza and Zandonini, 1999; Lungren, 1999). Another two processes, friction and rib support, leave into activity when adhesion fails and some proportional move starts between concrete and steel bars. After that, this period important since slip may be noticed, as well as the structure and delay of cracks.

There are a massive knowledge with respect to bond strength behavior between reinforcing steel bar, and NWAC's as well as some pattern equation advanced by a sum of investigators (Gjørv et al., 1990; Valcuende and Parra, 2009; Ožbolt et al., 2002; Lundgren, 1999; Kayali and Yeomans, 2000; Harajli et al., 2002; Banholzer et al., 2005). Also the influence of the concrete strength, development length in concrete, steel bar diameter, cover thickness of concrete and spacing of crack on the bond strength was explained by (Elfgren and Noghabai, 2002).

Some researches were satisfied in terms of bond strength between reinforcing bars and concrete with an artificial LWA, such as (Mor, 1992; Orangun 1967; Kayali and Yeomans, 2000; Hassan et al., 2010). Field's performance has exhibited acceptable performance LWC with strength varieties between 20 and 35 MPa with aspect to bond strength and embedded length. LWC's have lower bond splitting capabilities as well as a lesser post elastic strain capability than NWC, because of the lower particle strength. Unless tensile splitting strengths are defined, ACI 318 makes the embedded lengths for LWC to be enlarged by a factor of 1.3 over the lengths desired for NWC (Holm and Bremner, 2000).

Zhang and Gjorv (1990) investigated that the interface between the LWA and cement pastes is narrow and described by a mechanical interlocking in the mix by a chemical interaction in the shape of pozzolanic effect. Mehta (1986) reported that depending on the surface structure of aggregate the character and micro-structure of the transition zone change, the type of aggregate, pore structure of aggregate, the porosity of the cement paste, and the bleeding of water in the aggregate. In addition to previous, Gjørv et al. (1990) investigated that the morphology and microstructure of the transition zone are influenced, when the compressed silica fume (CSF) is added to the concrete, so that both porosity and thickness of the transition zone are decreased. Mor (1992) described the influence of CSF as follows: (i) decreased better orientation of calcium hydroxide (CH) crystals at the transition zone; (ii) compaction of the transition zone expected to pozzolanic response between CH and CSF; and (iii) decreased agglomeration of free water to the interface during casting of samples, when CSF is supplemented to the concrete mixture the adhesion is much enhanced, and LWA concrete uses the full adhesion, much increasing its individual bond strength.

The silica fume is a pozzolanic material. SF has important effects on the characteristics of the subsequent materials used as an admixture in a concrete mixture. These effects concern to the strength, tensile, modulus of elasticity, air void contend, permeability, shrinkage, abrasion resistance, and bonding strength with reinforcing steel bars, chemical attack resistance, corrosion reduction of embedded steel reinforcement and alkali silica reactivity resistance. In addition, inclusion of SF lowers the workability of the mixture (Xu and Chung, 2000).

Hossain (2008) reported on the bond properties of plain lightweight volcanic pumice concrete (LWVPC) and NWC and compared to other deformed reinforcing bars. The mainly significant effect was in which the bond strength of deformed bars in NWC was greater when compared by those of LWVPC, according to this writer. Regulated bond strength of NWC samples was established to be varieties between 1.08 and 1.14 times greater than LWVPC. This can be pondered as general for a LWC.

2.3.1 The Bond Mechanism

In reinforced concrete structure, effective and certain force move inside the concrete and surrounding the reinforcement are needed for optimum design. The move of forces from the reinforcement to the surrounding concrete happens for a deformed bar as shown in Figure 2.3 by Al-Amoudi et al. (2006) and Al-Amoudi et al. (2004)

- Chemical adhesion occurs between the steel bar and concrete;
- Frictional stresses beginning as of the coarseness of the interface, stresses diagonal to the bar surface, and corresponding slip between the steel bar and surrounding concrete; and
- Mechanical bearing of the bar deformations versus the concrete surface.

Later primary slip of the steel bar, mainly of the stress is conveyed by bearing. Friction, nevertheless, particularly among the concrete and the bar deformations (ribs) acts like an important character in the stress move, as established by epoxy layers, which lesser the factor of friction and effect in lesser bond capabilities. Friction also acts like a significant character for smooth steel bars (with no deformations), by slip-induced friction resulting as of the transverse stresses at the bar surface produced by little varieties in bar shape and minor, anyway a more important, surface coarseness of the bar on bond strength. Smooth bars with properly ignoble allowed bond stress were utilized for several years for reinforced concrete in North America and are yet utilized in some zones of the world (ACI-234, 1992).

When a deformed bar move by respect to the surrounding concrete, bearing stress on the ribs and friction stress on the ribs and drum of the steel bar are mobilized, while surface adhesion is lost. The values of the friction stress are raised at the compressive bearing stress on the ribs. The stresses on the bar surface are stable by compressive and shear stresses on the concrete connection surfaces, which are determined into tensile stresses that can effect in cracking in planes that are both vertical with parallel to the reinforcement, similarly shown in Figure 2.4(a) and 2.4(b). The cracks shown in Figure 2.4(a), can effect in the structure of a pointed failing surface for steel bars that contract as of concrete and are set in tension. They differently act simply a lesser character in the bearing and evolution of reinforcement. The diagonal cracks indicated in Figure 2.4(b) form if the concrete cover or bars spacing is adequately little, lead to splitting cracks, as in Figure 2.4(c) (ACI-234, 1992).

If the concrete cover, spacing between the bar, or diagonal reinforcement is adequate to delay or prevent a splitting failure; the technique will fail by shearing together with a surface at the upper of the ribs surrounding the bars, resulting in a “pullout” failing, as indicated in Figure 2.4(d). Like slip rises, friction on the drum of the reinforcing bar is decreased, leaving the stresses at the connection stresses between the ribs and the surrounding concrete as the essential process of stress transfer. It is shared, for both splitting and pull out failings, to study crushed concrete in a zone next to the bearing faces of some of the deformations. If anchorage to the concrete is sufficient, the stress in the reinforcement may come to be high enough to produce an even strain to harden the bar. Experiments have established that bond failings can take place at the bar when the maximum load exceeds the tensile strength of the steel bar (ACI-234, 1992).

As of these easy qualitative characterizations, it is potential to state that bond resistance is influenced by:

- The mechanical characteristics of the concrete (related to tensile and bearing strength);

- The magnitude of the concrete surrounding the steel bars (associated with concrete cover and spacing of bar parameters);
- The occupancy of labour in the shape of diagonal reinforcement, which can deferment as well as control crack extension;
- The surface situation of the steel bar (rough or smooth); and
- The geometry of the steel bar (deformation height, spacing, width of concrete surrounding the bars, and surface angle) (ACI-234, 1992).

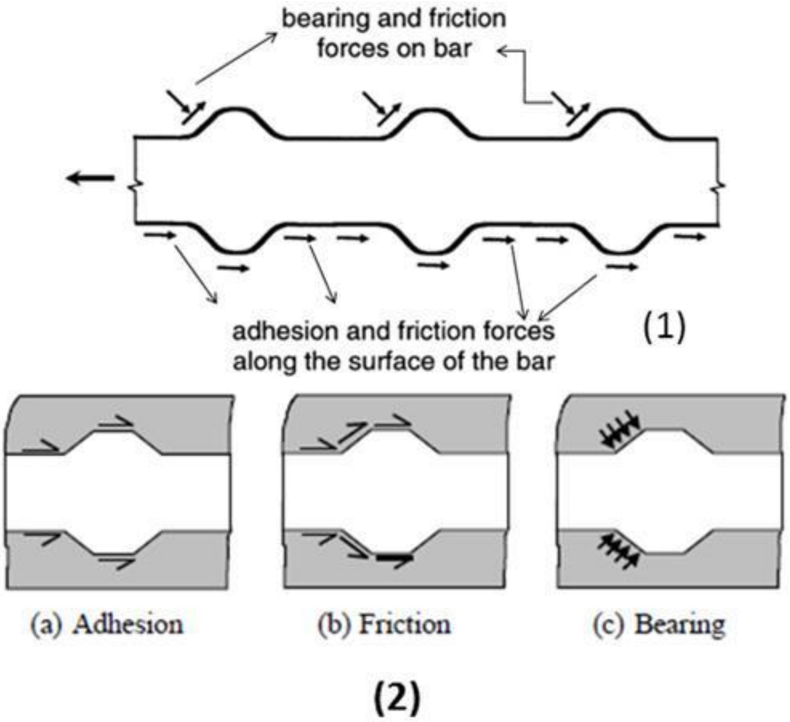


Figure 2.3 Perfect strength conveyances processes, enhanced from ACI (1992)

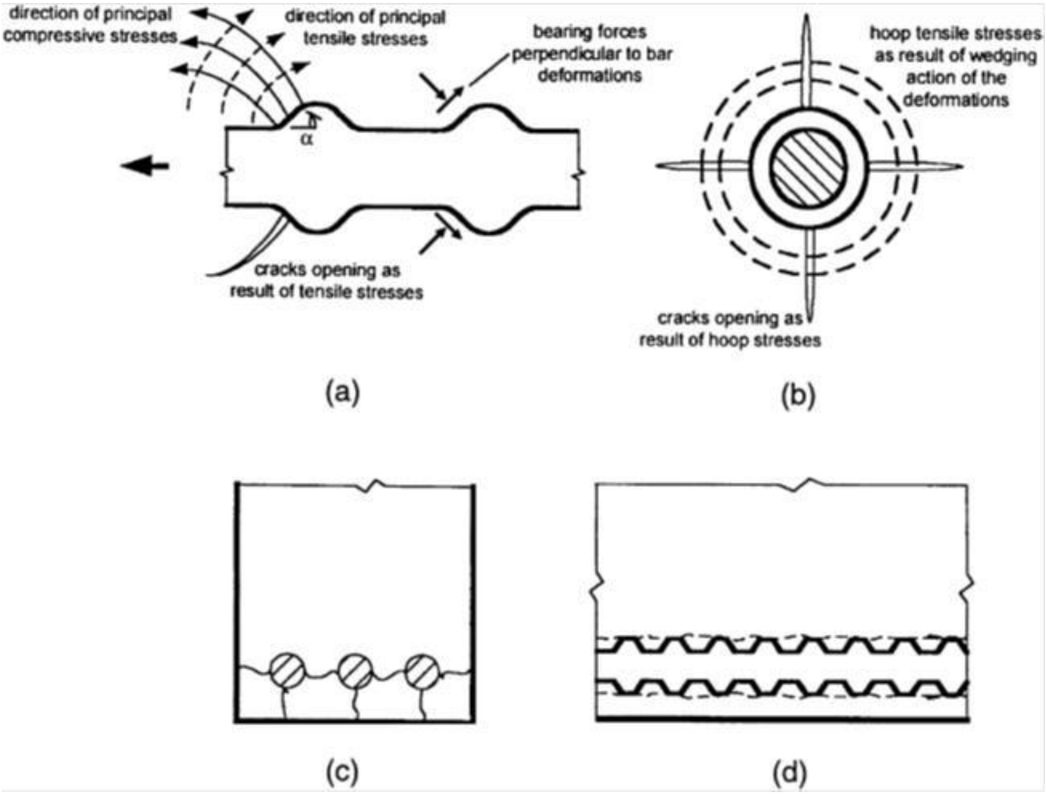


Figure 2.4 Cracking and damage processes in bond: (a) side observation of a coarse bar with deformation surface angle; (b) end observation indicated in structure of splitting cracks aligned to the steel bar; (c) end observation of associate show splitting cracks between steel bars and through the concrete cover; and (d) side observation of associate show shear crack and local concrete crushing expected to steel bar pullout ACI (1992)

2.5 Silica Fume (SF)

2.5.1 Background

Silica fume (SF) is a result of the producing procedure in the ferrosilicon production. Results of the manufacture of the ferrosilicon alloys having silicon constituents of 75% or else further include 85–95% non-crystalline silica and silicon metallic constituent. The producing of silicon from high-purity quartz glass by heat over the 2 000 ^{o}C manufactures SiO2 vapors, which oxidizes and compress in the low-heat zone to small fragments. Considerably smaller silica component from the result of the manufacture of ferrosilicon alloy containing 50% silicon contains. Thus, the type of alloy actuality manufactured associated to SiO2 component of the silica fume (Table 2.2) (ACI-234, 1992).

Silica fume is described in ACI as "as a result of manufacture of essential silicon or alloys is very fine non-crystalline silica manufactured in electric automobile curve furnaces, including silicon." It can display both cementitious and pozzolanic characteristics. SF is generally a grey colored powder, slightly like to Portland cement (PC) or some fly ashes (Silica Fume Association, 2005).

SF has been well-known to improving the mechanical characteristics to a large extent as mineral admixtures. It is possible by utilizing SF together with superplasticizers (SP) to attain compressive strengths of about 100 – 150 MPa in the research laboratory. The SF will be ready for use in concrete after is composed in greatly big sieves in the bughouse and later constructed. As well as the use of SF in concrete enhance its durability by decrease the permeability, due to a decrease in pore structure; it is effects in a larger resistance to sulfate attack by decreasing CH content. Which as well increase the ability of silica fume concrete in preventing inserted steel as of corrosion. Diagrammatic sketch of silica fume manufacture is indicated in figure 2.5 (Silica Fume Association, 2005).

Table 2.2 Silica fume content of SiO2 manufactured from unlike sources (ACI-234 1995)

Types of alloy	SF content of SIO2 (%)
ferrosilicon 50%	61-84
ferrosilicon 75%	84-91
Silicon metal	87-98

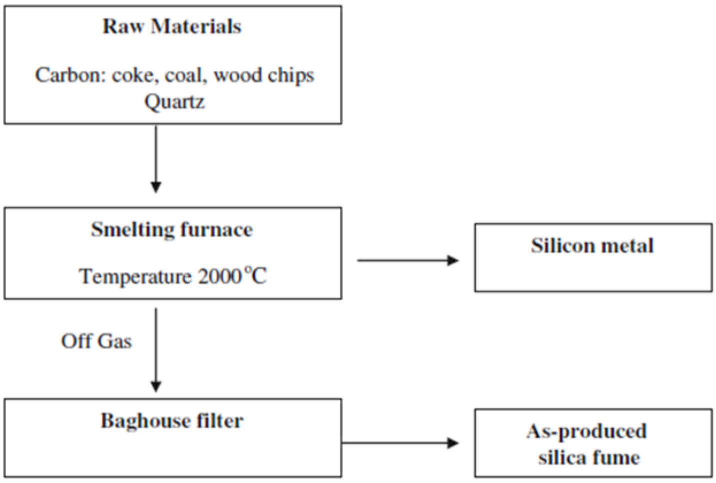


Figure 2.5 Diagrammatic plan of silica fume manufacture (Silica Fume Association, 2005)

2.5.2 Mechanism of silica fume Reaction

Hence silica fume excessive fineness and greatly high unformed silicon dioxide component, it is a very reactive pozzolanic material. Starts to act chemically in concrete similar the Portland cement, it exchanges CH. This CH act with the silica fume to form extra binder substance called C-S-H (Gel), which is similar to the C-S-H produced by Portland cement. This extra binder provides silica-fume concrete its enhanced characteristics (Silica Fume Association, 2005).

2.5.2.1 Matrix Densification and Pore-size Improvement:

By the presence of silica fume in the Portland cement concrete compounds it is possible to decrease in the magnitude of great pores at all ages. It essentially fill inside openings between fragments as it known that sand as fine aggregate supplies the openings between fragments of coarse aggregates, and cement pieces supply the openings between fine aggregates fragments and because of which it acts as filler expected to its fineness (Silica Fume Association, 2005).

2.5.2.2 Reaction of silica fume with Free Lime

Which, can be called as ‘‘Pozzolanic Reaction’’, silica fume acts with CH result decreasing amount of CH component as well as forming strength causing by cementitious products. Since CH crystals in Portland cement pastes are representatives of weakness, while CH generates cracks in concrete affecting its strength, durability and other characteristics (Silica Fume Association, 2005).

2.5.2.3 Interfacial Enhancement Cement Paste/Aggregate

In concrete, by the properties of the interfacial zone among the aggregate pieces and cement paste an important character in the bond between cement and aggregate is performed. Silica fume inclusion affects in interfacial stage in mortars and the density of it by reducing the orientation of the CH. By the inclusion of SF compared with mortar including just ordinary Portland cement, the density lowers and decreases in grade of orientation of CH in transition stage. Since the improvement in interfacial, thus it enhanced the mechanical characteristics and durability. Process not only associated to chemical structure of C–S–H at interface, but in addition to the micro-structure changes (CH) porosity, orientation, and thickness of the transition zone as well (Silica Fume Association, 2005).

2.5.3 Effect of Silica Fume (SF) on workability of Concrete

Clear reduce in water needs in concretes including high attention of silica fume and water reducer admixtures are stated by Sellevold and Redjy (1983). The distribution of cement and SF particles causes by the inclusion of water reducer admixtures or and decreases the attention of connection points among the various particles; subsequent in fewer water requirements to obtain a given workability.

Alshamsi et al. (1993) navigated that the inclusion of micro silica on concretes to cause a reduction in workability. To assert a constant slump such as influence can byproduct in higher water demand. Water reducing admixtures should be added by weight of micro-silica, in order to keep water demand equivalent to that of plain concrete. Higher silica fume replacement percentages, greater the superplasticizer addition needed and the greater the water demand to assert the standard workability is indicated in Table 2.3. It is well known that workability decreased with physical characteristics of micro-silica, chiefly expected to finer particles that causes higher water request. As shown in Table 2.5 the workability of the concrete mix (9) including mineral admixture is substantially enhanced by utilizing chemical admixture. The fine fraction volume of silica fume in the quantity exceeding 5% as of the weight of cement substantially rises and the water demand of the binder, so the mix of a superplasticizer and silica fume is suitable.

Table 2.3 Mix proportions for standard workability (Alshamsi et al., 1993)

Mix Name	OPC	Silica fume	Water	Admixture (ml)
Plain	100	0	27.5	0
5% SF	95	5	30	0
10% SF	90	10	32	0
15% SF	85	15	37.5	0
20% SF	80	20	43	0
4%SF+3% SP	95	4	27.5	3
10% SF+5% SP	90	10	27.5	5
15% SF+6% SP	85	15	27.5	6.5
20% SF+8% SP	80	20	27.5	8

The water required decreased with incorporating of 10% SF in a lean concrete (100 kg/m^3) of cement. In normal construction concrete, the water request is raised even with 5% SF inclusion, to assert constant slump. SF up to 10% is supplemented as an admixture and use of superplasticizer (SP) to assert required slump found necessary for manufacturing very high strength and durable concrete. An extra 1 l/m^3 of water should be utilized for every 1 kg/m^3 of SF inclusion, when no SP is utilized, to assert a constant grade of fluidity (Al-Khayat and Aitcin, 1993).

2.5.4 Influence of Silica Fume (SF) on the Mechanical Properties of Concrete

2.5.4.1 Compressive Strength

An important variation in the compressive strength of the mixture is obtained, when it included SF. This is primarily expected to improved aggregate paste bond and micro-structure enhancement.

The strength of SF concrete is larger than that of SF paste which they applied to the variation in the function of the aggregate in concrete that was stated by Bentur et al. (1987). In SF concrete, by reinforcing the bond between the cement paste and aggregate and a smaller porous in the interfacial zone and forming further homogenous micro-structure are the attendance of silica fume eliminates to enhance weak connection in concrete. However, in cement concrete, the aggregate roles as inert filler but expected to the attendance of weak transition zone. Therefore, taking into account that the strength of cement paste is less than the strength of aggregate, and silica fume concrete is stronger than silica fume cement paste.

The compressive strength of HPC, including SF was investigated by mazloom et al. (2004). The w/cm ratio being 0.35, and SF content was 0, 6, 10, and 15% by weight of cement. Table 2.4 indicated the results from this study. From the table, it can be observed that (1) silica fume improve compressive strength of concrete mixes was negligible later the age of 90 days. (2) The silica fume concrete was 21% at the age of 28 days was stronger than plain concrete. Furthermore, the compressive strength of plain concrete and concrete mixes including various percentages of silica fume at the age of 400 days were the same.

Table 2.4 Compressive strength improvement with age (Mazloom et al., 2004)

Mix #	SF (%)	Compressive strengths (Mpa)						
		7 days	14 days	28 days	42 days	90 days	360 days	400 days
1	0	46	52	58	62	64	73	74
2	6	50.5	58	65	69	71	73	73
3	10	52	61	67.5	71	74	73	73
4	15	53	63	70	73	76	75	76

2.5.4.2 Tensile Strength

The splitting tensile strength of SF concretes up to the age of 182 days was stated by Hooton (1993) as shown in (Table 2.5). It can be observed that split tensile strength lowered with increasing replacement of SF by the amount of cement. Additionally, it was seen that the splitting tensile strength was not enhanced for SF concrete mixes except at 28 days.

The splitting tensile of SFRC with SF was studied by Köksal et al. (2008). They utilized cold drawn steel fibers with end hooked. With fibers aspect ratios (l/d) were 65 and 80 and fibers volume fractions V_f were 0.5 and 1%. SF replacement was 0, 5, 10, and 15% by the weight of cement. They establish that by increasing the SF and steel fiber contents a substantial rise in the splitting tensile strength of the concrete took place. The rises in the splitting tensile strengths of the SF concrete without steel fibers were determined for the 5, 10 and 15% silica fume as 9.7, 54 and 87.9%, respectively.

Table 2.5 Variation of Splitting tensile strength of concrete (Hooton, 1993)

Age of Test	Mixes of concrete			
	Plain	5% silica fume	10% silica fume	15% silica fume
28	5.2	6.3	6.2	4.6
91	6.8	6.7	6.2	5.6
182	7.1	6.2	6.5	5.6

2.5.4.3 Flexural Strength

The effect of SF on the flexural strength of HPC was studied by Bhanja and Sengupta (2005). Five mixes of concrete prepared, at SF replacement by weight of cement were made with water to cementitious ratios of 0.26, 0.30, 0.34, 0.38 and 0.42. The varieties of flexural strength with SF replacement percentage at various water/cementitious ratios are indicated in Figure 2.6. The percentages of silica fume were 0, 5, 10, 15, 20 and 25% of the complete cementitious materials. They determined that a clear influence on the flexural strength found by the addition of SF in comparison with splitting tensile strength. Furthermore, it was establish that by an increase in the SF replacement percentage there was a stable improve in the flexural tensile strength values. For flexural strengths, even very high additions of SF considerably enhance the flexural strengths of concrete.

The flexural strength of concrete including hooked ends steel fibers and SF was estimated by Köksal et al. (2008). With fibers aspect ratios (l/d) were 65 and 80 and fibers volume fractions V_f were 0.5 and 1%. SF was added to concrete as of 0, 5, 10 and 15% by weight of cement. a significant enhance in the flexural strengths of the concrete were noticed by the addition of SF and steel fibers.

Furthermore, they establish that the increase in V_f of steel fibers from 0.5% to 1% enhance the flexural tensile strengths of concretes for each of the SF content. The improves in the flexural strengths of the concrete without steel fibers for the 5, 10 and 15% silica fumes were 7, 42.1 and 64.9%, respectively.

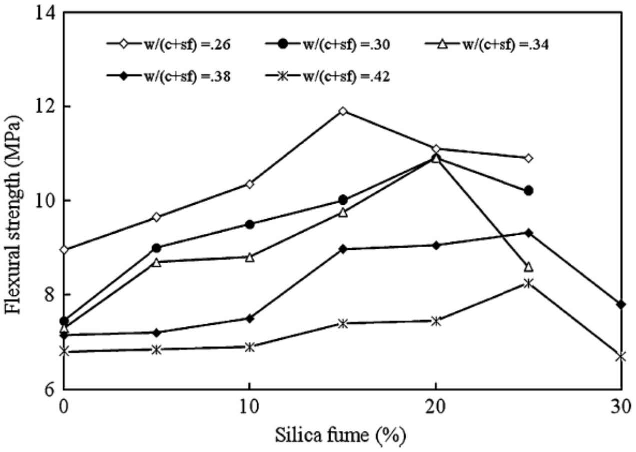


Figure 2.6 Correlation between percentage replacement of silica fume by weight of cement and 28-day flexural tensile strength (Bhanja and Sengupta, 2005)

2.6 Steel fiber reinforced concrete (SFRC)

2.6.1 Introduction

A composite material prepared with Portland cement, aggregate, and including separate discontinuous fibers described as fiber reinforced concrete (FRC). Nowadays, plain concrete is a brittle material, with a low strain capability, and a low tensile strength, which causes of supplementing such fibers to concrete. To bridge the cracks that create gives some post-cracking (ductility) is the character of randomly distributes dis-continuous fibers. If the fibers are adequately bonded to material, adequately strong, and allow the fiber reinforced concrete to transport substantial stresses above a reasonably great strain capacity for the post cracking phase (ACI Committee-544, 2006).

There are, of course, another ways "and probably cheaper" of improving the strength of concrete. Improve the toughness of the concrete is the actual contribution of the fibers, under any model of loading. That is, the fibers give a great amount of energy absorption in post-peak part of the load verses deflection curve and tend to improve the strain at maximum load (ACI Committee-544, 2006).

Fibers reinforcement show efficiently as inflexible additions in the concrete matrix, when they are in the form of short separate fibers. Physically, fiber reinforcement have thus the same arrangement of size as aggregate additions; therefore, steel fiber reinforcement cannot be considered as a direct replacement of longitudinal reinforcement in reinforced and pre-stressed constructional members. Though, because of the inherent substance characteristics of fiber concrete, the plan of a tensile skin of fiber concrete or the attendance of fibers in the body of the concrete can be due to enhance the resistance of conventionally reinforced constructional members to deflection, cracking and other usability conditions (Fanella and Naaman 1985).

It is nowadays successfully started that excellent resistance to cracking, and crack extension is one of the significant characteristics of SFRC. The clear result of all these is to impart to the fiber composite noticeable post–cracking ductility, which is unheard of in ordinary concrete. As a result of this capability to capture cracks, fiber composites obtain raised extensibility and tensile strength, both at first crack and at last, special under flexural loading; and the fibers are capable to support the matrix together even later extensive cracking. The change as of a brittle to a ductile kind of material would rise the fiber's capability to stand frequently applied, shock or impact loading and improve considerably the energy absorption properties to the fiber composite (Johnston, 1974).

2.6.2 Technology for producing of SFRC

Generally, SFRC can be manufactured using same plain concrete practice, although obviously, some significant differences that establish. The primary trouble is to obtain the needed enhancements in mechanical action to insert an adequate volume of consistently distributed, while keeping adequate workability in the fresh mix to allow suitable mixing, placing and finishing. In addition to, a high aspect ratio (l/d) adversely influences the workability of the fresh mixture. Usually, the difficulties of both uniform distribution and workability reduce by reducing fiber length and volume. The performance of the hardened concrete is improved further with a larger fiber's aspect ratio, because it enhances the bond between fiber-matrix (ACI Committee-544, 2006).

Using normal concrete apparatus, SFRC can be placed sufficiently. Since the fibers tend to inhibit the flow, it looks to be very hard; however, when vibrated, the material will flow easily inside the frameworks. It should be notable that to enhance the workability only with great attention water should be supplemented to SFRC mixes, because above a w/c ratio of about 0.5, extra water may increase the slump of the SFRC without increasing its workability and place capability under vibration. Similarly, for plain concrete, the finishing actions by SFRC are basically the same, although maybe further attention must be taken with regard to handiwork (ACI Committee-544, 2006).

2.6.3 Mechanical Properties of Steel Fiber Reinforced Concrete (SFRC)

The post-crack process and crack controlling of SFRC results in the enhancement of all characteristics related with cracking, such as strength (tensile strength, torsional strength, flexural strength, bearing strength, and shear strength), stiffness, and the resistant to freeze-thaw damage, ductility energy absorption, impact, thermal loading and fatigue. There are three main effects of the crack controlling characteristic of fibers on the action of concrete composite (Barr, 1987)

a. Fibers delay the beginning of flexural cracking. The final strain may be as great as 20 to 50 times compare to that of plain concrete, since the increment in tensile strain at the initial crack being as much as 100 percent.

b. A well-defined post-cracking action to the composite can be imparted by the fibers.

c. The crack-arrest property and significance increment in ductility imparts a larger energy-absorbing capability to the composite previous to failure.

2.6.3.1 Compressive Strength

An inclusion of up to 1.5% of fibers by volume of concrete rises the compressive strength as of 0 to 15% was investigated by (Johnston, 1974; Dixon and Mayfield, 1971). Figure 2.9 indicate a gradual slope in the dropping part of the FRC stress-strain curve shows enhanced spalling resistance, ductility and toughness (Johnston, 1974).

The influence of steel fibers on the compressive strength of concrete is varying. Reported increases for the concrete variety as of negligible in mainly situations to 23% for concrete, including 2% by volume of fiber with l/d = 100, within 19-mm maximum-size aggregate, and experimented with 150 x 300 mm cylinders (Williamson, 1974). For mortar mixes, they stated improve in compressive strength varieties as of negligible to slight (Fanella and Naaman 1985).

Standard stress strain curves for SFRC in compression are indicated in Figure 2.9 (Johnston, 1974). While Fanella and Naaman (1985) show the curves for steel fiber reinforced mortar that indicated in Figures 2.7 and 2.8. In these curves, the grade of the dropping part is less steep than that of plain samples without fibers can be notable, and a considerable increment in the strain at the peak stress. This is typical of significantly greater toughness, where toughness can be measured as of the area below the curves, and it is a gauge of capability to absorb energy through deformation. The enhanced toughness in compression informed by fibers is effective in avoiding quick failure below static loading, in addition to absorbing energy below dynamic loading.

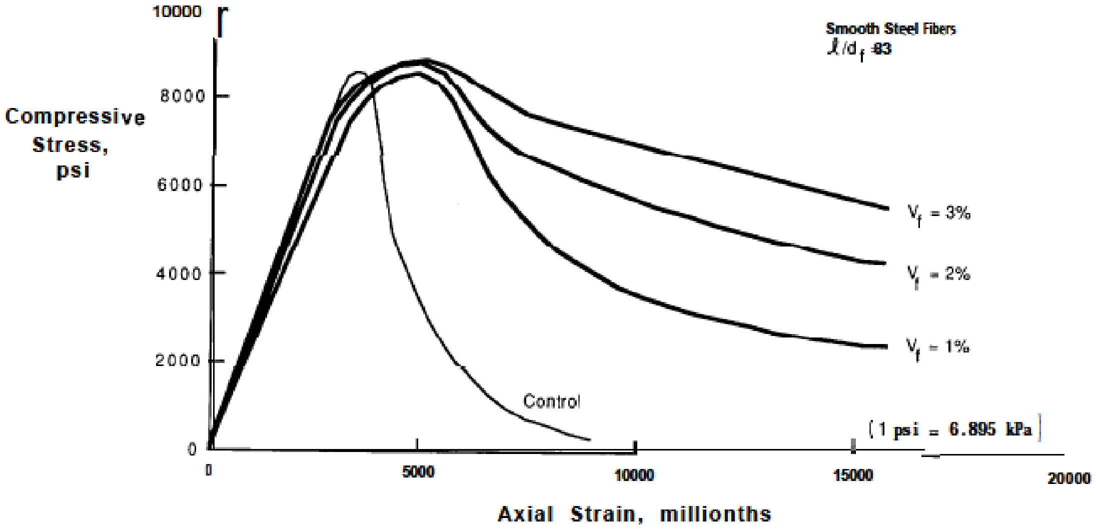


Figure 2.7 Stress-Strain curves in compression for SFRC (Fanella and Naaman, 1985)

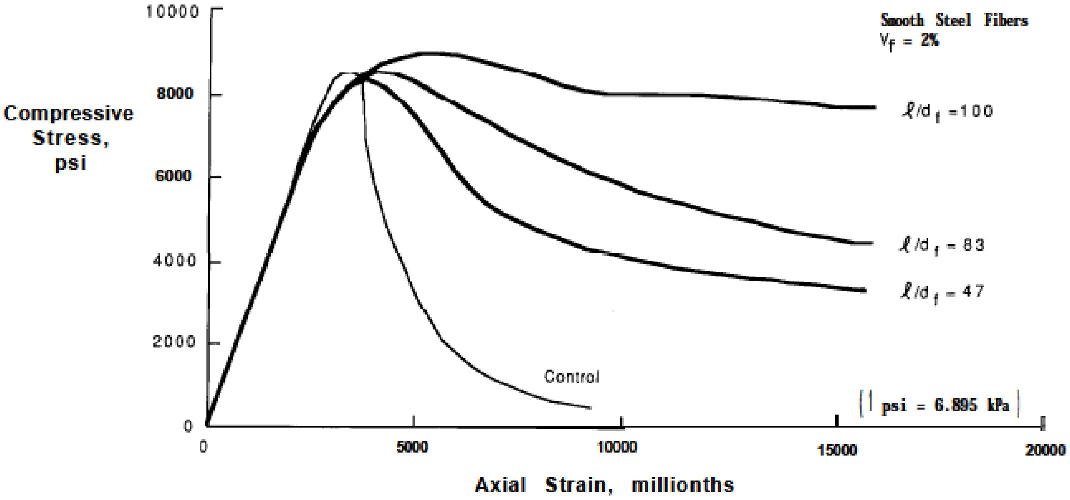


Figure 2.8 Effect of the aspect ratio (l/d) of fibers on the stress-strain curve of SFRC (Fanella and Naaman, 1985)

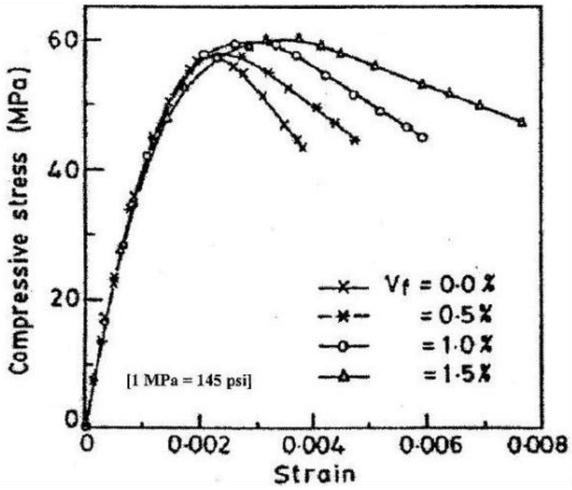


Figure 2.9: Effects of Steel Fibers Content on Compressive Stress-Strain Curve of FRC (Padmarajaiah and Ramaswamy, 2002)

2.6.3.2 Shear Strength

A previous researcher such as (Narayanan and Darwish, 1987; Barr, 1987; Oh et al., 1999; Noghabai, 2000), they indicate that fibers considerably improve the shear strength of concrete. Narayanan and Darwish (1987) investigated that FRC; including 1 % volume of fibers can improve the ultimate shear strength up to 170%. Steel fibers have been indicated by Williamson (1978) and Noghabai (2000) to be an efficient represents to completely replace conventional diagonal shear reinforcement.

Very by using a single type of fiber, a mix of fibers with different aspect ratios studied by Noghabai (2000) stated that it could be further effective in increasing the mechanical performance of FRC. The improved performance of FRC over its unreinforced equivalent comes as of its enhanced capability to absorb energy through and later break dawn.

2.6.3.3 Flexural strength

The addition of steel fibers on the concrete enhanced flexural strength is greatly larger than for compression and direct tension. There are generally two flexural strength standards are stated. First, called the first-crack-flexural strength, agrees to the load at which the load-deformation-curve leaves as of linearity as Point A on Figure 2.10. The second generally named the ultimate-flexural-strength agrees to the maximum load attained as Point C on Figure 2.10. Utilizing the formula for modulus of fracture specified in ASTM-C-78, strengths are measured as of the comparable load, while the strain distributions and linear stress on which the formula is based to no longer assign later the matrix has cracked.

Process for measuring ultimate tensile flexural strengths and first crack, as produced in ACI 544.2R and ASTM C 1018, are established on testing 100 x 100 x 350 mm prisms under third-point load for excellence control. Another sizes and shapes provide higher or lesser strengths, the percentage of fiber length to the minimum cross-sectional measurement of the experiment sample, and relying on span length, width and depth of cross section.

It is potential; though, to compare the results attained in various analysis formations to values for typical beams experienced under third-point-load, even when center-point-load is full that studied by Johnston (1982a). This is essential when aiming to compare the performance results of a specific design depth, to the performance results of standard 100 x 100 x 350 mm beams. The specifications relating to cross-sectional-dimension to design thickness of FRC and to fiber length in ASTM C 1018 report that, for normal thickness of sections or mass concrete applications, the minimum cross-sectional-dimension shall be at minimum three times the nominal maximum aggregate size and the fiber length.

In general ultimate flexural tensile strength increases compare to the result of fiber volume fraction V_f and aspect ratio (l/d). There are small effects on static strength characteristics when the addition of fiber less than 0.5 % by volume of concrete of low aspect ratio fibers. Johnston (1980) stated that hooked fibers, have prepared flexural strength improves over mixes without fibers of as much as 100%. The selection of fiber kind and the volume fraction of the fiber kind utilized are much affected on post cracking load deformation properties. The cost-effectiveness of a specific fiber kind and amount combination should therefore be assessed by original testing.

Johnston (1980) stated that high flexural strengths were most easily obtained in mortars. Standard rates for mortars (w/c ratio ranged between 0.45 and 0.55) are in the variety of (6.5 to 10) MPa for fiber volume fraction 1.5 relying on the l/d and the kind of fiber, and may arrive (13 MPa) for fibers volume fraction 2.5 %. The addition of a superplasticizing admixture may improve strengths above the rate gotten without the admixture if the w/c ratio is decreased. Fibers with end anchorage, surface deformed fibers, and crimped fibers obtain strengths over those for smooth fibers of the same volume percentages, or let similar strengths to be obtained with lesser fiber percentages (Ramakrishnan and Coyle, 1983).

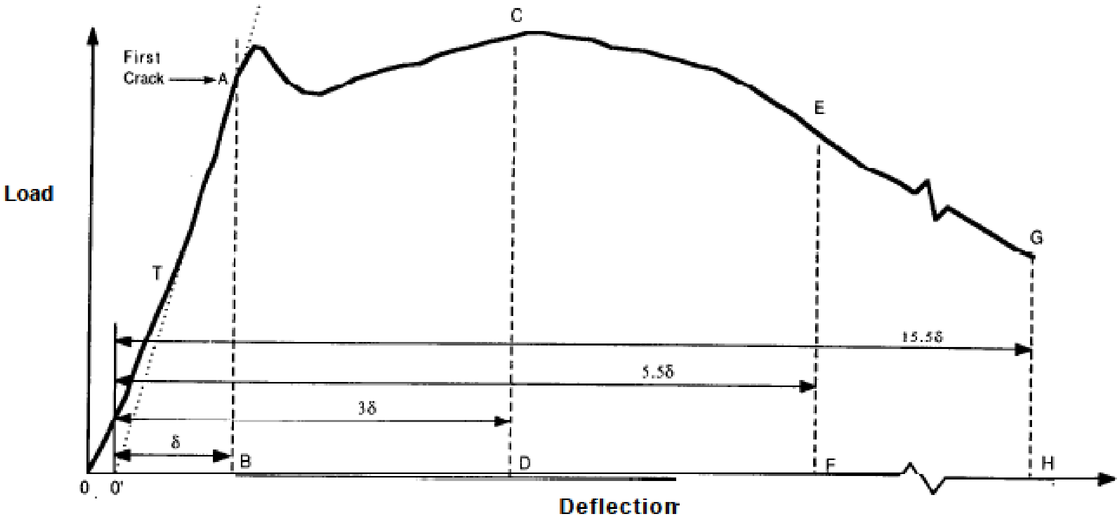


Figure 2.10 Significant properties of the load-deflection curve (ASTM C 1018)

2.7 Combination of silica fumes and steel fibers in concrete

It is in general approved that establishing different kinds of fibers, particularly steel fiber, into the mixes can improve the ductility of high-strength concrete (Lu and Hsu, 2006; Nili and Afroughsabet, 2010).

For all that the strength, volume fractions V_f and orientation of the fibers are causes affected the performance of FRC; this affected significantly by the grade of fiber distribution (Lataste et al., 2008; Sahmaran et al., 2005). The fiber distribution may be adjusted by the admixture, such as SF, that is utilized together with the fiber that was indicated as a test result by Chung (2005). In addition, because of silica fumes pozzolanic reaction, the consequences shown that the inclusion of SF enhanced the interfacial zone, which is recognized as the weakest zone in the concrete (KÖksal et al., 2008; Ozer and Ozkul, 2004). So, SF enhanced the concrete in two shapes that it may be described: first by fiber distribution and second pozzolanic properties. The act of inclusion of steel fiber in HSC that was prepared with SF was studied by Eren and Çelik (1997). They indicated that the compressive strength of the concrete is determined by the fiber volume and fiber aspect ratio. Though, since the fiber is distributed in the concrete to monitor the failure procedures by crossing the cracks and produce crack formation and coalescence further difficult, the fibers' efficiency in improving the characteristics of the brittle matrix results was clearly (Yazici et al., 2007, Woo et al., 2005).

ACI Committee-544 (2006) and Balaguru et al. (1992) prepare a compressive evaluation of literature associated to SF and Steel Fiber concrete. It stated that the inclusion of steel fibers in the concrete matrix enhances all mechanical characteristics of concrete matrix, and it contained standards for design, mixing, placing and finishing of SFRC.

SFRC under compression and Stress-strain curve for SFRC in compression was concluded by Nataraja et al. (1998). To quantify the influence of fiber on the compressive strength of concrete in relations to fiber reinforcing variable, they have suggested an equation. The compressive strength in their model ranging between 30 and 50 MPa, with a fiber aspect ratio of low as 55 and high as 82 and volume fraction of fibers 0%, 0.5%, 0.75% and 1% were utilized. The certain strength rates have been given with in all the patterns and thus are valid for a specific w/cm ratio and sample variable. In all the patterns just a specific w/cm ratio with differing fiber content was utilized.

Song et al. (2004) do a test on the mechanical properties of high-strength steel fiber reinforced concrete (HSSFRC). They have been obvious by addition of steel fibers, with low tensile strength and strain capabilities of high strength concrete possible to overcome. The steel fiber was supplemented by the volume fraction (V_f) of 0.5%, 1.0%, 1.5% and 2.0%.The compressive strength of steel fiber concrete arrived at a greatest approximate 15.3%enhancement above the HSC at 1.5% V_f of steel fiber. The flexural and split tensile strength enhanced at 2.0% V_f of steel fiber 126.6 and %98.3%.

Palanisamay et al. (2008) prepare an investigation on influence of GGBFS and SF on mechanical characteristic of Concrete Composites. With percentages replacement of SF of 5, 10, 15, and 20% by weight of cement and 70 MPa concrete. The best percentages replacement of SF was by 10 % replacement that indicated compressive, flexural strength and split tensile improved by 8%, 4.1% and 22% than plain concrete. The compressive strength, flexural strengths and split tensile strength were carried out at the age of 28 days on 25 mixtures and equated with the plain concrete mixture.

Katkhud et al. (2009) do a test on the effects of SF on compressive, split and flexure strengths on the high strength lightweight concrete (HSLWC). They carried out at varies constant w/b ratio keeping another mix design variable quantities constant by replacing cement with various percentages of SF. The SF was supplemented by 0%, 5%, 10%, 15%, 20% and 25% for various w/b starting from 0.26 to 0.42. Compressive, flexural and split tensile strengths were concluded at 28 days for all mixtures. They indicated that the compressive, split and flexural tensile strengths improved with SF addition, however the best replacement of SF is not constant since it depends on the w/b of the mixture. Established on the results, a correlation between compressive strength, split and flexure tensile strengths of SF concrete was advanced utilizing statistical systems.

Wei et al. (2008) prepared a study on the influence of steel fiber on the mechanical characteristics of concrete composites including SF. They calculated the mechanical characteristics of concrete composites. Test variable quantities contained w/cm, inclusion of silica fume and V_f of steel fiber. Tests on splitting tensile strength, compressive strength, direct tensile strength, abrasion resistance and drop weight were carried out at 28 days age, and the results were studied statistically. According to the results, the planned direct tensile testing system was a proper system to calculate the tensile strength of fiber concrete composites. It was observed that silica fume in the composites would assist getting the uniform fiber distribution in the concrete and enhance strength and the bonding between fiber and matrix producing as of additional condensed C- S-H (gel), while the inclusion of fibers given best performance for the concrete composites. The mix of steel fibers and silica fume together can much improve the mechanical characteristics of concrete composites.

Other than, a many regression examination was performed to compare compressive strength, direct tensile strength, impact number and abrasion coefficient with w/cm ratio, silica fume replacement and steel fiber volume fraction.

Shakir et al. (2005) stated a report on the influence of steel fibers on the mechanical properties of HPC. They indicated that the influence of steel fiber's content and the combined influence of high range water reducing agent (HRWRA) and rice husk ash (RHA) on the mechanical characteristics of the prepared matrix. The test results indicated the utilizing steel fibers in HPC conducted to a substantial enhancement in mechanical characteristics of concrete. The results show that the inclusion of steel fibers to HPC above 1% volume fraction by 6% (HRWRA) with 8% (RHA) percentage replacement by weight of cement, improves the compressive strength considerably. Moreover, the results specified that the inclusion of 1.5% volume fraction of steel fibers by 6% (HRWRA) with 8% (RHA) improves the splitting and flexural tensile strengths significant. At 28 days, the compressive, splitting and flexural strengths were improved to 11.57%, 63.86%, and 32.93% further than HPC without addition of steel fibers, respectively. Pawade et al. (2011) determined that the effect of Silica fume in improvement of compressive strength, flexural strength of steel fiber's concrete and their association. They studied on concrete expected to the influence of silica fume on Portland pozzolona cement with and without steel fibers.

Since the high-strength causes to increased brittleness of concrete, (Hsu et al., 1994; Webb, 1993) stated that FR should be considered for increasing tensile strength of concrete. This is further directly required when LWA is concerned (Valle et al., 1994; Imam and Vandewalle, 1996; Tomosawa, 1996). The advantages of fiber reinforcement in LWAC have been stated further than 25 years by Ritchie and Kayali (1975). The large increment in the utilizing of HSC, the environmental and commercial advantages of LWC and the capability to manufacture LWHSC with suitable constructional characters have repaired the importance in utilizing fibers as a required reinforcement versus brittle failing. However, in spite of the benefits that have been stated in this zone (Balaguru and Ramakrishnan, 1987; Theodorakapoulos and Swamy, 1989; Hanus et al., 1993), greatly further investigation is still required. This is particularly because of the variety of the sources from which LWA may be gotten. Additional to that is the variety of the kinds of fibers and the several varieties that are attainable inside every kind.

CHAPTER 3

EXPERIMENTAL DETAILS

3.1 Materials

3.1.1 Portland cement and fly ash

CEM I 42.5 R type Portland cement having specific gravity of 3.14 and Blaine fineness of 326 m^2/kg was utilized for both manufacturing AFA aggregates and preparing the concrete test specimens used in determination of mechanical properties. Table 3.1 shows the chemical composition of the cement.

Class F fly ash (FA) conforming to ASTM C 618 was utilized in this study, for manufacturing cold-bonded artificial fly ash aggregates (AFA). It was provided as of thermal power plant, named Ceyhan Sugözü, placed in Turkey. FA used in this study has a specific surface 287 m^2/kg and a specific gravity of 2.25. Table 3.1 presents the chemical and some physical characteristics of the fly ash used.

Table 3.1 Chemical compositions and physical properties of Portland cement and mineral admixtures

Chemical analysis	Portland cement	Silica fume (SF)	Fly ash (FA)
CaO	62.58	0.45	4.24
SiO2	20.25	90.36	56.2
Al2O3	5.31	0.71	20.17
Fe2O3	4.04	1.31	6.69
K2O	0.92	1.52	1.89
Na2O	0.22	0.45	0.58
Loss of ignition	3.02	3.11	1.78
Physical Properties			
Specific gravity	3.15	2.2	2.25
Blaine Fineness [m2/kg]	3260	21080	287

3.1.2 Silica fume (SF)

A commercial grade silica fume (SF) obtained from Norway was used as a mineral admixture in concrete production. SF has a specific surface are of 21080 m^2/kg and specific gravity of 2.2 g/cm^3. Table 3.1 presents chemical analysis and some physical properties of SF.

3.1.3 Superplasticizer (SP)

Sulphonated naphthalene formaldehyde based high-range-water-reducing-admixture (HRWRA) with specific gravity of 1.19 was employed to achieve slump value of 14±2 cm for the ease of handling, placing, and finishing in all concrete mixtures. The superplasticizer was adjusted at the time of mixing to realize the specified slump. Table 3.2 indicates the properties of SP.

Table 3.2 Properties of Super Plasticizer

Property	Superplasticizer
Name	Daracem 200
Color	Dark Brown
State	Liquid
Specific Gravity [kg/lt]	1,19
Chemical	Sulfonated Naphthalene Formaldehyde
Freezing Point	-4

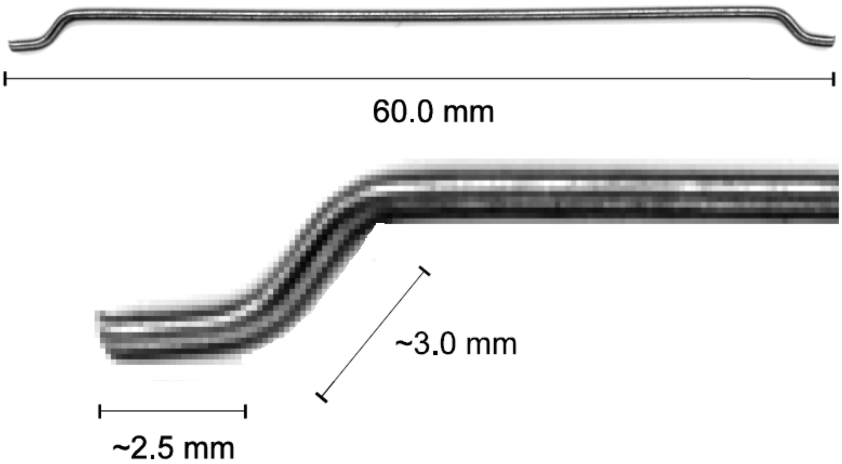
3.1.4 Steel fibers

Two types of commercially available hooked end steel fibers (Dramix 60/80 and Kemerix 30/40) were used for production of steel fiber reinforced concretes. The geometrical properties and aspect ratios of the steel fibers are given in Figures 3.1 and 3.2 and Table 3.3.

Table 3.3 Properties of steel fibers

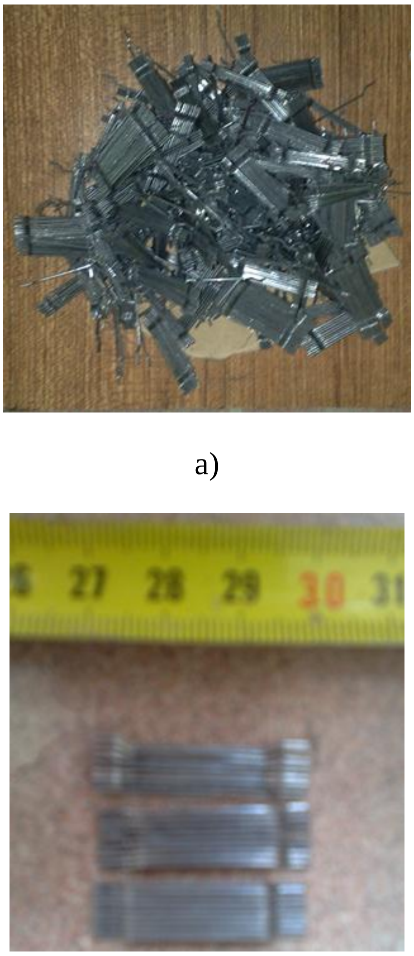
Designation of the steel fibre	Diameter D (mm)	Length L (mm)	Aspect ratio (L/D)
St1	0.75	60	80
St2	0.75	30	40

a)



b)

Figure 3.1 Photograph and dimensions of the DRAMIX$^{®}$ ZC 60/.80 fiber and its end part



a)

b)

Figure 3.2 Photograph and dimensions of the KEMERIX® ZC 30/.40 fiber

3.1.5 Ribbed steel bars

Reinforcing ribbed steel bars having 16 mm diameter and minimum yield strength of 420 MPa were utilized for preparing the reinforced concrete specimens to be used for testing the bonding strength.

3.1.6 Aggregates

3.1.6.1 Artificial fly ash aggregate (AFA)

In the first stage of the experimental program artificial fly ash aggregates (AFA) were manufactured through the cold bonding peeletization procejure of fly ash (FA) and Portland cement (PC) in a tilted pan as shown in Figure 3.3 at an ambient temperature. For this, 10% PC and 90% FA were mixed in powder form in the pelletizer shown in Figure 3.3. After the dry powder mixture of about (10-13) kg was fed into the pan, the disc was rotated at a constant velocity to assure the consistency of the mixture as shown in Figure 3.4. The total of sprayed water used during pelletization process has been determined as the coagulant to form spherical pellets with the motion of rolling disc (Arslan and Baykal, 2006; Baykal and Doven, 2000; Gesoglu, 2004; Gesoglu et al., 2007; Doven, 1998). The optimum water content required for each type of powder was determined according to (ASTM D2216–10).

Then, the water was sprayed on the mixture with a quantity of 22 % by weight. The formation of pellets occurred between 10-12 minutes in trial productions. The total pelletization time was determined as 20 minutes for the compaction of fresh pellets as shown in Figure 3.5. Finally, they were kept in sealed plastic bags as shown in Figure 3.6 for 28 days in a curing room in which the temperature and relative humidity were 21^{o}C and 70%, respectively. The curing method adopted in this study is a practical and simple method to fit the laboratory conditions. At the finale of the curing age, hardened LWA were sieved into portions from 4 to 16 mm sizes to be used as coarse aggregate in concrete production as shown in Figure 3.7. Further details of cold bonding pelletization were presented elsewhere by the authors (Gesoglu et al., 2012).

Specific gravity and water absorption tests were carried out as per ASTM C127 to determine physical properties of the AFA. Moreover, crushing strength test was performed as per BS 812, part110. Practically, individual pellets were placed between two parallel plates and loaded diametrically until failure occurred. Crushing test was accompanied on hardened aggregate of different sizes between 6 and 14 mm by using a 28 kN capacity load-ring. A number of representative agglomerates were statistically tested and the average of the results was defined as crushing strength or generally named as crushing value. Figure 3.8 shows the crushing strength test configuration and strength values of the cold bonded FAA produced in this study. Additionally, water absorption and saturated surface dry (SSD) specific gravity values of the AFAs were determined as 12.7% and 1.92, respectively.

Figure 3.3 General view of the pelletization disc

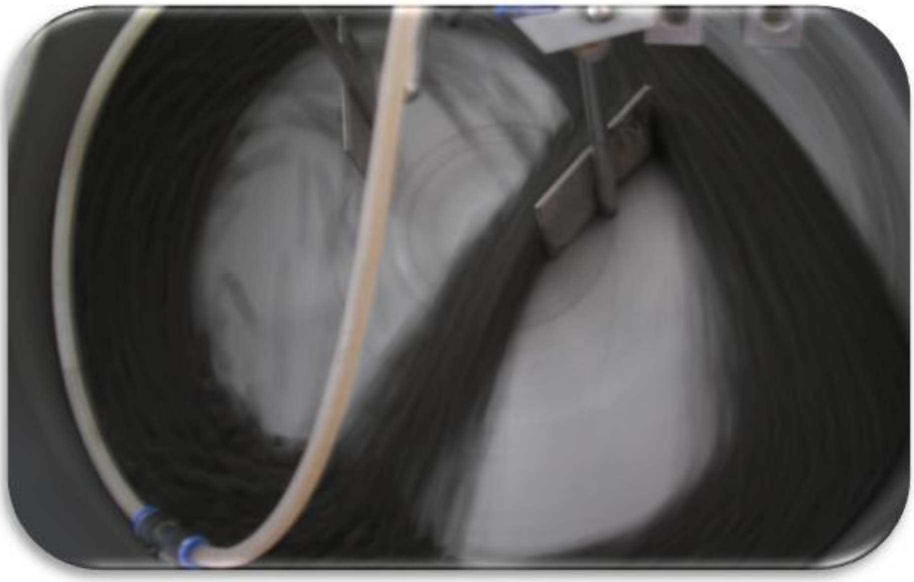


Figure 3.4 Materials poured in pelletization disk

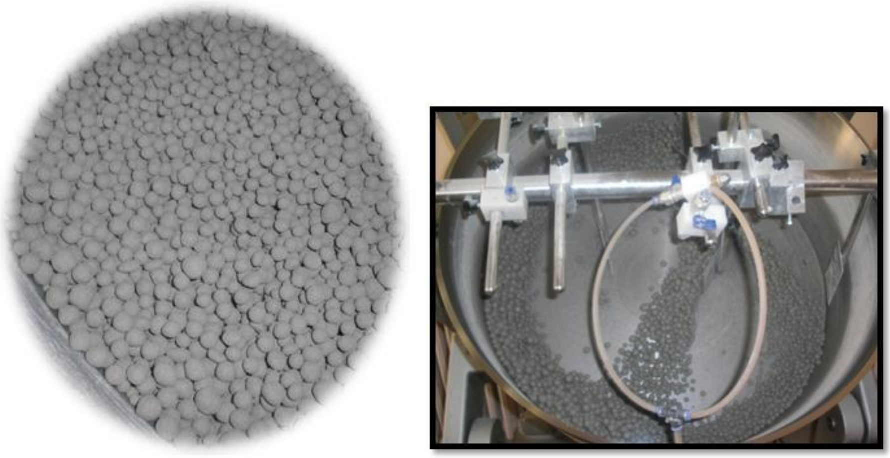
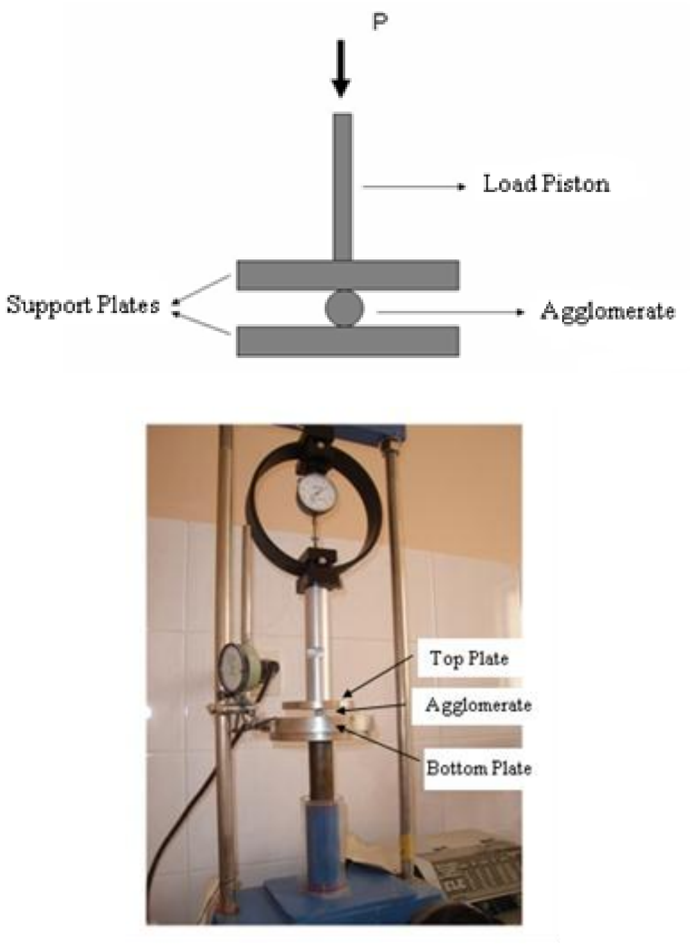


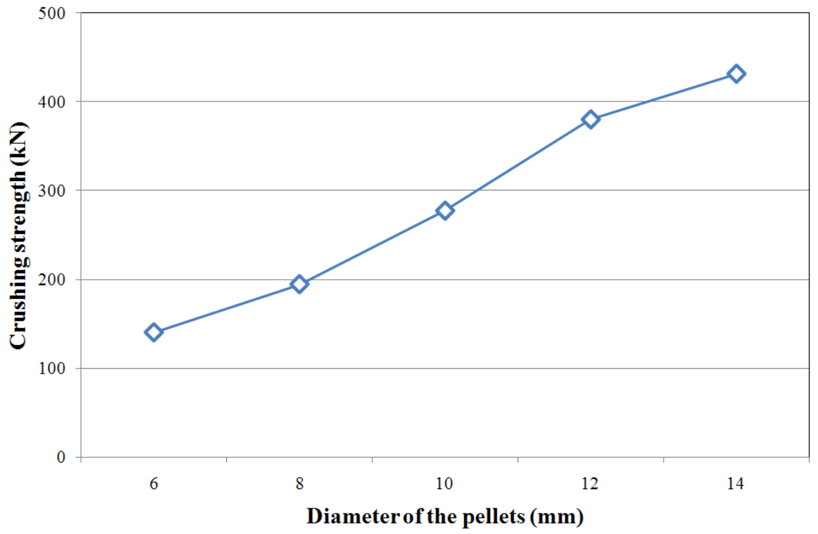
Figure 3.5 Spherical pellets formation after approximately 20 minutes

Figure 3.6 Air curing of fresh aggregates by keeping in sealed plastic bags

Figure 3.7 Hardened aggregate sieved by (16, and 4) mm sieve



a)



b)

Figure 3.8 Variation of crushing strength value for hardened LWA and test apparatuse

3.1.6.2 Natural fine aggregate

A mix of river sand and crushed limestone sand was used as a fine aggregate in this study. Fine aggregates were achieved from local sources. Table 3.4 presents the properties of fine aggregates.

Table 3.4 Sieve analysis and physical properties of natural fine aggregate

Sieve size (mm)	**Fine aggregate (%)**	
	River sand	Crushed sand
31.5	100	100
16.0	100	100
8.0	99.7	100
4.0	94.5	99.2
2.0	58.7	62.9
1.0	38.2	43.7
0.50	24.9	33.9
0.25	5.40	22.6
Fineness modulus	2.79	2.38
Specific gravity (gm/cm$^{3)}$	2.60	2.45

3.2 Mix proportioning and casting of concrete

Cold bonded artificial fly ash aggregates (AFA) were used as coarse aggregates for all of the concrete mixtures. Concrete mixtures of two series with w/b of 0.35 and 0.55 were designed to produce plain and SF incorporated concretes. SF modified concretes were produced with 10% replacement of the cement with SF by the weight. For production of steel fiber (St) reinforced concretes, each type of steel fibers (St1 and St2) were added to the concrete by 0.25% and 0.75% of the total concrete volume. Therefore, 20 different types of concrete mixtures were produced for examining the mechanical properties of the concretes. Table 3.5 gives the details of the concrete mixtures.

The designations of each mix were made according to SF incorporation, type of steel fiber, and volume fraction of steel fiber. For example, SF10-75St1 code stands for the concrete incorporated with 10% SF and 0.75% steel fiber type I (St1)

A special technique was followed for batching, mixing, and casting of concrete to decrease the quick slump loss due to the high water absorption of LWA. Concrete mixtures were designed to have a 140±20-mm slump for easy mixing molding and finishing as shown in (figure 3.10) which was obtained by using a superplasticizer. Lightweight coarse aggregates (LWCA) were first immersed in water for 30 minute to get saturation and then put on a lower sized sieve for an additional 30 minute for the seepage of excessive surface water as shown in (figure 3.9 a, and b). All concretes were mixed in a research laboratory pan mixer. First, the saturated-surface-dry LWCA were mixed with the Portland cement and SF (if it used). Then, the natural fine aggregate was added into the mixer. Lastly, the water containing the superplasticizer was added slowly to this mixture, Then, Steel fibers were added (if it used) which was continued to be mixed for approximately 4 minute. Slump and density were then measured. Later, the mix was poured into the steel molds in two layers, each of which being vibrated for a couple of seconds. Freshly poured concrete specimens were covered with plastic sheet and kept in laboratory at 21±2 ^{o}C for 24 hours. Then, the specimens were demoulded and transferred to a water tank for curing up to 28 day.

a)

b)

Figure 3.9 View of production of LWAC's

a)

b)

Figure 3.10 Slump test for two w/b ratios mixtures in LWAC's

Table 3.5 Concrete mix design

Mix ID	w/b ratio	Water	Cement	Silica fume	Fine Aggregate		Coarse Aggregate	Steel Fiber		S.P*
					Natural sand	Crushed sand	AFA (4-16 mm)	St1	St2	
Control I	0.35	157.5	450	0	566.9	199.2	766.1	0	0	8.5
SF0-25St1		157.5	450	0	566.9	199.2	766.1	19.6	0	10.5
SF0-25St2		157.5	450	0	566.9	199.2	766.1	0	19.6	12.5
SF0-75St1		157.5	450	0	566.9	199.2	766.1	58.9	0	11.5
SF0-75St2		157.5	450	0	566.9	199.2	766.1	0	58.9	14
Control II		157.5	405	45	561.9	197.4	759.3	0	0	8.75
SF10-25St1		157.5	405	45	561.9	197.4	759.3	19.6	0	10.8
SF10-25St2		157.5	405	45	561.9	197.4	759.3	0	19.6	12.5
SF10-75St1		157.5	405	45	561.9	197.4	759.3	58.9	0	11.8
SF10-75St2		157.5	405	45	561.9	197.4	759.3	0	58.9	14.8
Control I	0.55	192.5	350	0	656.3	281.25	562.5	0	0	0.5
SF0-25St1		192.5	350	0	656.3	281.25	562.5	19.6	0	1.5
SF0-25St2		192.5	350	0	656.3	281.25	562.5	0	19.6	1.75
SF0-75St1		192.5	350	0	656.3	281.25	562.5	58.9	0	3
SF0-75St2		192.5	350	0	656.3	281.25	562.5	0	58.9	3.25
Control II		192.5	315	35	653.9	280.22	560.4	0	0	1
SF10-25St1		192.5	315	35	653.9	280.22	560.4	19.6	0	1.75
SF10-25St2		192.5	315	35	653.9	280.22	560.4	0	19.6	2.5
SF10-75St1		192.5	315	35	653.9	280.22	560.4	58.9	0	3.5
S10-75St2		192.5	315	35	653.9	280.22	560.4	0	58.9	4

3.3 Details of test specimens

The concrete specimens having various dimensions were used for testing. Cubic specimens having 150x150x150 mm were utilized for compressive strength. For three point flexural tensile strength testing, prismatic specimens with 100x100x500 mm dimensions were used to ensure 450 mm span length for testing. Splitting tensile strength of the concrete was measured from cylindrical specimens having Φ150x300 mm dimensions. Bonding strength between concrete and reinforcement were tested on cubic reinforced concrete specimen. In order to have a smooth surface to provide uniform load distribution, the top surface of the pullout specimens were capped with gypsum coating. The details and dimensions of the pullout test specimen are illustrated in Figure 3.11.

For each test, three specimens were used. Each experimental parameter was determined by averaging the results obtained from those specimens. All of the tests were performed at the end of 28 day curing period.

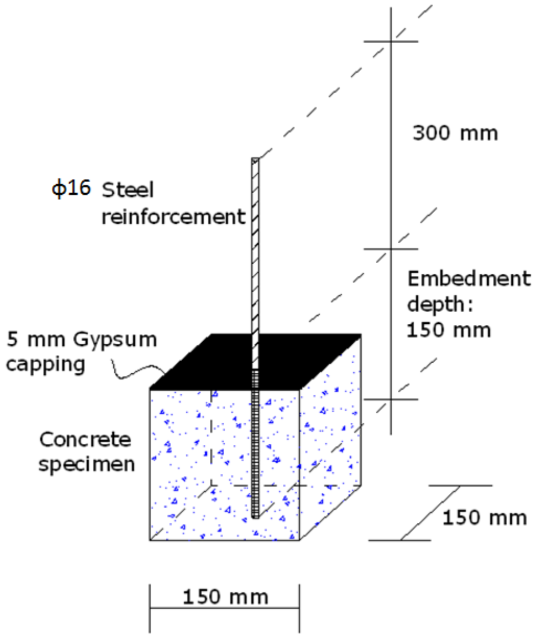


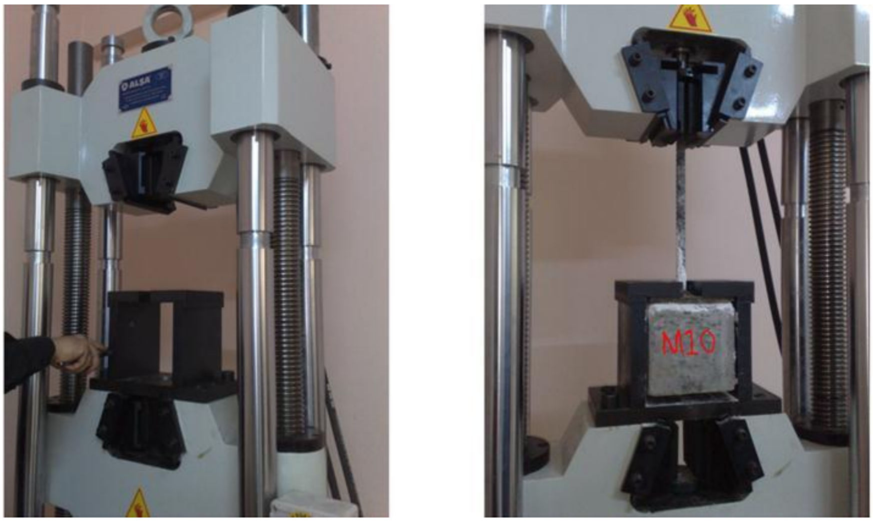
Figure 3.11 Details of the bonding strength test specimen

3.4 Test Methods

The compression test conforming to ASTM C39 was carried out on the specimens by a 3000 KN capacity testing machine. Three-point flexural tensile strength conforming to ASTM C293 was applied to the prismatic specimens through 100 kN capacity bending frame. Splitting tensile strength was carried out according to the specification per ASTM C496. Bonding strength of the concretes was determined in accordance with RILEM RC6. The bonding strength, τ, is calculated by dividing the tensile force by the surface area of the steel bar embedded in concrete (Eqn. 1). For this test, specially modified test apparatus was installed to 600 kN capacity universal testing machine (Figure 3.12).

$$\tau = \frac{F}{\pi \times d \times L} \qquad \text{(Eqn. 1)}$$

Where F is the tensile load at failure (N), d and L are the diameter (mm) and embedment length (mm) of the reinforcing steel bar, respectively. In this study, d and L are 16 mm and 150 mm, respectively.



a) b)

Figure 3.12 Photographic view of the pullout test device a) installing the test apparatus b) testing the specimen

CHAPTER 4

EXPERIMENTAL RESULT AND DISCUSIONS

4.1 Fresh concrete properties

All concrete mixes designed to have slumps within 140±20 mm (Figure 3.10), which was attained by using different quantities of a superpasticizer (SP). The mixes were of cohesive consistency. The fresh density of the mixes ranged between 2152 and 2060 kg/m^3 as shown in Table 3.5. Concrete fresh densities appear to be rather high for lightweight concretes. Therefore, these concretes may be considered as semi-lightweight concretes. This might be recognized to three causes. First, water-binder ratios were low, and the cement content was high. Second, specific gravity (SG) of the FA was slightly high resulting in AFA having a SG of 1.92, which was marginally high for use in lightweight concretes. Lastly, the third cause was the use of fine aggregate as natural sand, which formed all the mixes to exceed the limitation of ACI as much as the density of the concrete was concerned. Though, similar results were stated in earlier researchers (Chang et al., 1996; Yang et al., 1997; Mor et al., 1992). Air contents of the concrete mixtures were calculated through determining the total compositions, and the values were in the range of 1.5–2.5%. On the other hand the addition of SF decrease the slump value and need to more amount of (SP) than plain concrete because very fine spherical silica fume atoms increase the grading of the binder by filling the openings between the relatively coarser cement atoms and increase amount of the free water. Although this useful result, the high surface area of SF atoms to be wetted causes high water necessity and lower durability without a superplasticizer (SP) admixture (Al-Khayat and Aitcin, 1992). In these cases, use of superplasticizer allowed to obtain the wanted slump with much lower water contents, as seen in Table 3.5. However the addition of steel fibers increase requirement of water and then increase the amount of SP, because the steel fibers with a longer shape have the higher specific surfaces than aggregate of the same volume. Depends on the type and content of fibers used, the degree to which workability decreases, on the matrix in which they are embedded and the properties of the constituents of the matrix on their own. Difficult to distribute uniformly with a high volume fraction of fibers is; however to attain best benefits of the fibers should be with a good distribution, (Sedran and Larrad, 1999).

4.2 Compressive Strength

Figure 4.1 and Table 4.1 shows the variation in compressive strength of the plain and SF incorporated concretes with the change in the amount of fiber reinforcement and w/b ratio. The plain concretes' compressive strength values ranged between 27-31 MPa and 43-47 MPa for w/b ratios of 0.35 and 0.55, while SF incorporated ones had compressive strength values between 31-35 MPa for the former and 47-50 MPa for the latter, respectively. The compressive strength test results proved that incorporation of SF had significant enhancement on the compressive strength of the concretes. Similar results regarding the improvement of compressive strength of concretes can be found in the studies of previous authors (Al-Khaja, 1994; Bhanja and Sengupta, 2005; Poon et al., 2006; Güneyisi et al., 2012; Ding and Li, 2002; Nili and Afroughsabet, 2012). For example, in the study of Güneyisi et al. (2012) concretes incorporated with 5% and 15% replacement level of SF yielded relatively higher strength than that of plain concretes at different w/b ratios. As it can be seen from Figure 4.1, increasing the amount of steel fiber resulted in slight rise of the compressive strength of the concretes without depending on the incorporation of SF and w/b ratio. Nili and Afroughsabet (2012) reported that 28 day compressive strengths of plain concrete produced with w/b ratio of 0.46 were 41.3 MPa, 46.4 MPa, and 47.3 MPa for steel fiber V_f of 0%, 0.5%, and 1.0%, respectively. Moreover, the influence of aspect ratio can also clearly be seen from Figure 4.1. The higher the aspect ratio, the higher the increase in compressive strength was observed, especially for SF incorporated ones. For instance, the plain concretes produced with water-binder ratio of 0.35 and steel fiber volume fraction of 0.75% had 46.5 MPa and 45.9 MPa for St 1 and St 2, respectively. However, SF included concretes with the same parameters had 49.2 MPa and 48.9 MPa for St 1 and St 2, respectively.

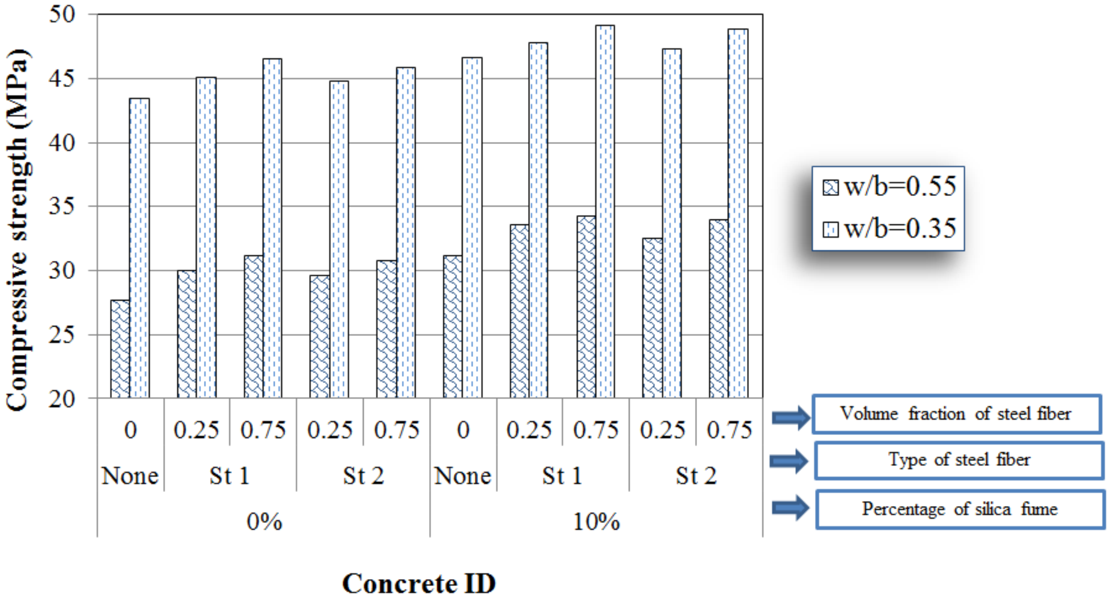


Figure 4.1 Variation in compressive strength for both w/b for different concrete mixes

Table 4.1 Variation of compressive strength, bond strength, flexural tensile strength, and splitting tensile strength of different mixtures

w/b= 0.55					w/b= 0.35				
mixes	Compressive strength MPa	Flexural strength MPa	Bond strength MPa	Split strength MPa	mixes	Compressive strength MPa	Flexural strength MPa	Bond strength MPa	Split strength MPa
Control I	27.73	3.38	7.89	2.57	Control I	43.52	3.69	8.39	2.92
SF0-25St1	30.01	3.76	8.84	2.91	SF0-25St1	45.14	5.01	9.68	4.00
SF0-75St1	31.16	6.31	10.50	3.40	SF0-75St1	46.53	8.07	13.10	4.83
SF0-25St2	29.63	3.56	8.73	2.76	SF0-25St2	44.87	4.55	9.56	3.56
SF0-75St2	30.78	5.34	9.37	3.17	SF0-75St2	45.91	6.75	11.42	4.24
Control II	31.19	3.62	8.32	2.78	Control II	46.67	3.97	8.81	3.29
SF10-25St1	33.60	4.34	9.11	3.06	SF10-25St1	47.85	6.07	10.97	4.19
SF10-75St1	34.33	7.23	11.50	3.75	SF10-75St1	49.16	9.21	14.32	5.24
SF10-25St2	32.24	3.94	8.81	2.90	SF10-25St2	47.34	4.93	10.44	3.76
SF10-75St2	34.02	5.97	10.07	3.31	S10-75St2	48.89	7.42	12.23	4.62

4.3 Tensile strength

The tensile strength of plain and SF incorporated concretes were evaluated in terms of splitting tensile strength and three point modulus of rupture. The test results of splitting and flexural strength tests are given in Table 4.1 and Figures 4.2 and 4.3, respectively, to reveal the effectiveness of steel fiber reinforcement and silica fume. The results revealed that steel fiber incorporation provided significant increase in splitting tensile strength capacity of plain concretes by 65% and 32% for w/b ratios of 0.35 and 0.55, respectively. However, SF incorporated ones exhibited 60 % and 35 % for those w/b ratios. Kayalı et al. (2003) reported that the main and major contribution of the steel fibers was due to the increase of tensile strain capacity of the concrete. The similar trend was also observed for flexural strength of the concretes. The maximum flexural strength values of 9.20 and 7.22 MPa were observed for concretes coded SF10-75St1 for w/b ratios of 0.35 and 0.55 respectively, compared to plain concretes 3.69 and 3.38 MPa, respectively. Without depending on the type of steel fiber, the modulus of rupture results of concretes incorporated with 0.25% volume fraction of steel fiber appeared to be very close to each other. Another noticeable finding from the tensile strength testing is that the contribution of St1 was observed to be better than that of St2. This situation may be attributed to the distribution of the steel reinforcement within the cement matrix. In the study of Nanni (1998) it was reported that, tensile strength can significantly increase when steel fiber was added to the concrete due to the crack arrest effect of the fibers.

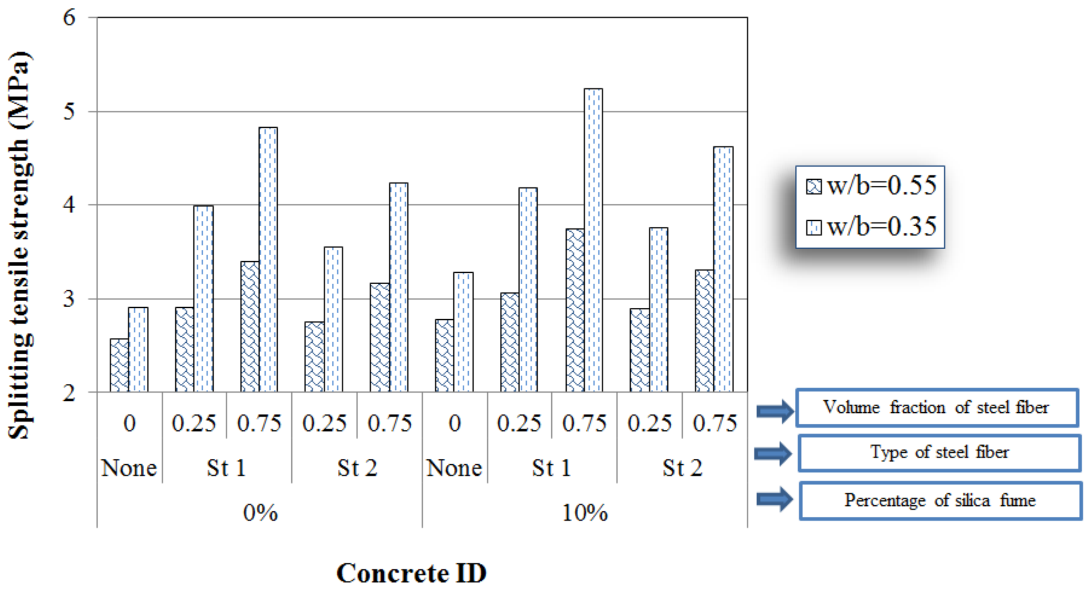


Figure 4.2 Influence of silica fume (SF) and steel fibers (St) content for both w/b ratios on splitting tensile strength of LWACs

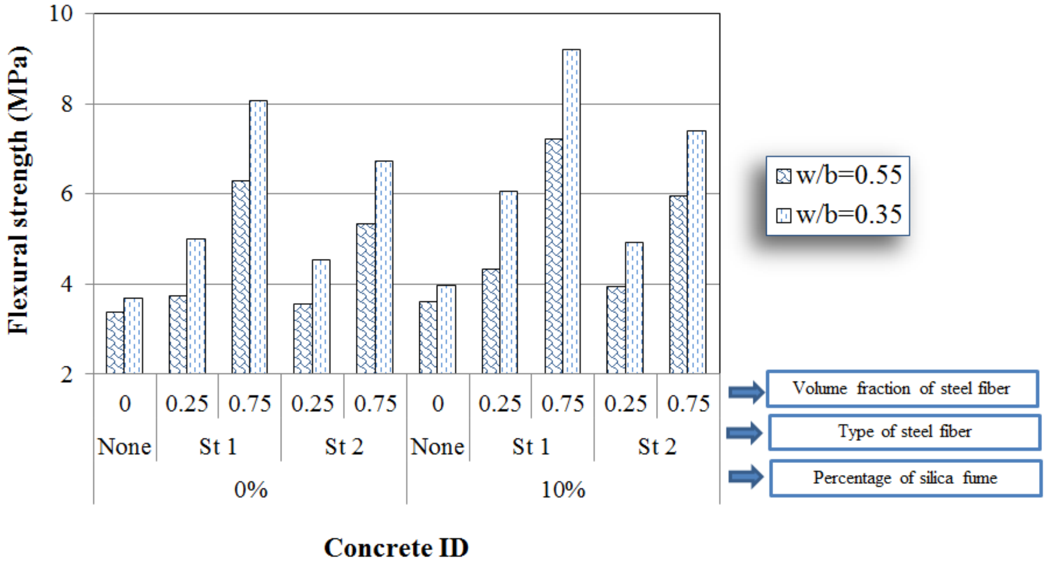


Figure 4.3 Influence of silica fume (SF) and steel fibers (St) content for both w/b ratios on flexural strength of LWACs

4.4 Bonding strength

Bonding strength of the concrete mixes with the change in the amount of the steel fiber reinforcement and incorporation of SF is depicted in Figure 4.4 and Table 4.1. The figure showed that the increase in the volume fraction of steel fiber resulted in considerable change in the bonding strength. However, likewise tensile strength development, the bonding strength values at 0.25% volume fraction of steel fiber seemed to have close values, regardless the incorporation of SF. Nonetheless, incorporation of SF imparted additional performance in terms of bonding strength.

For example, at w/b ratio of 0.35, the highest bonding strength for SF modified concretes was observed as 14.3 MPa, while the minimum value for plain concrete was observed as 8.4 MPa. Therefore, 70% enhancement in bonding strength capacity was accomplished by combined incorporation of SF and steel fibers. The similar trend was also observed for the concrete group with w/b ratio of 0.55. Baran et al. (2012) reported that steel fibers enhance the pull-out resistance of strands through controlling the crack propagation inside concrete blocks. They stated that, by this technique, the level of limitation at the component concrete interface was increased, which resulted in enhancements the resistance in both friction and mechanical bond components. Their results also revealed that further than 30% increase was achieved in pull out strength due to fiber reinforcement.

The studies regarding the bond strength between rebar and concrete generally focus on the concretes produced with natural aggregates. However, the previous results presented for silica fume incorporated steel fiber reinforced concretes may highlight the effectiveness of utilization of this mineral admixture on the concretes including artificial aggregates. For example, in the study of Chan and Chu (2004), the influence of SF and steel fiber on the bond properties of matrix of reactive powder concrete (RPC) were studied. They achieved pullout tests in their experimental program, with the SF content as the primary variable. They specified that the addition of SF in RPC matrix significantly improved the bond between fiber and matrix. Abu-Lebdeh et al. (2011) also revealed that the quality of matrix has prominent importance on the bonding and tensile strain capacity of steel fibers in HSC. Consequently, owing to its superior enhancement in cement matrix as a result of pore size refinement by microfilling effect and pozzolanic reactivity (Poon et al., 2006), SF provided improvement in the pullout capacity of the reinforced concretes.

Photographic views of the pullout specimens tested in the current study are given in Figure 4.5. As can be seen, after failure, the reinforcing steel bars were separated from the concretes without steel fiber, whereas steel fiber reinforced concretes did not release the steel bars.

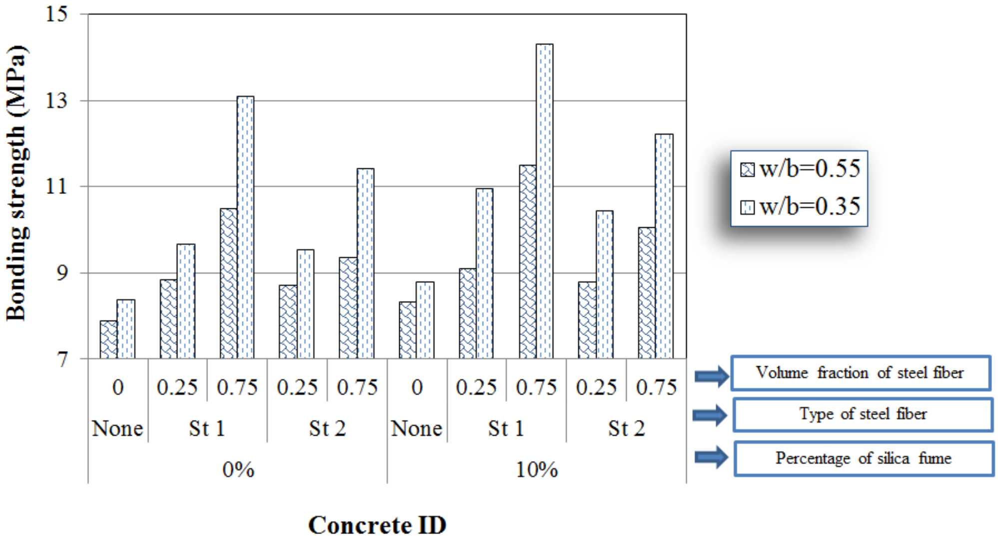


Figure 4.4 Influence of silica fume (SF) and steel fibers (St) content for both w/b ratios on bonding strength of LWACs

a) b)

Figure 4.5 Typical failure patterns of concretes a) without steel fiber and b) with steel fiber

4.5 Statistical evaluation of the test results

A general linear model analysis of variance (GLM-ANOVA) was conducted at a 0.05 level of significance to evaluate the difference in the tested properties of the fiber reinforced concretes in a quantitative manner. For this, bonding strength, compressive strength, splitting and flexural tensile strength of the concretes were given as the dependent variables while the type and volume fraction (V_f) of the steel fibers used, incorporation of SF and w/b ratio were the factors. A statistical analysis was achieved to specify the statistically significant (p-level<0.05) factors. The influences of the factors on the measured test results are also presented in Table 4.2.

The column below the percent contribution provides an indication about the degree of effectiveness of the independent factors on the measured response such that the higher the contribution, the effectiveness of the factors to that particular response was higher. Similarly, if the percent contribution is low, the contribution of the factors to that particular response is less. Table 4.2 observes that all of the independent variables had significant effect on the mechanical properties of fiber reinforced concretes. When observing the contribution levels of the factors, it was noticed that the most important parameter in variation of the compressive strength and splitting tensile strength of the fiber reinforced concretes is w/b ratio. As it was proved from the experimental results, type and amount of steel reinforcement had very little effect on the compressive strength. However, the influence of increased volume fraction steel fibers was observed to be the most dominant factor at bonding strength and flexural strength of the fiber reinforced concretes. Besides, the utilization of SF was also proved to be effective on all of the mechanical properties of fiber reinforced concretes.

Table 4.2 Statistical analysis of the test results

Dependent Variable	Independent variable	Sequential Sum of Squares	Computed F	P Value	Significance	Contribution (%)
Compressive strength	w/b ratio	894.16	16544.05	0.000	YES	95.5
	SF replacement	35.1	649.43	0.000	YES	3.7
	Type of steel fibre	0.9	16.68	0.002	YES	0.1
	Steel fiber volume fraction	6.0	111.02	0.000	YES	0.6
	Error	0.6	-	-	-	0.1
	Total	936.75	-	-	-	-
Bonding strength	w/b ratio	13.64	39.30	0.000	YES	34.1
	SF replacement	2.43	6.99	0.023	YES	6.1
	Type of steel fibre	3.4	9.80	0.010	YES	8.5
	Steel fiber volume fraction	16.73	48.19	0.000	YES	41.8
	Error	3.82	-	-	-	9.5
	Total	40.02	-	-	-	-
Flexural strength	w/b ratio	8.36	70.92	0.000	YES	20.6
	SF replacement	2.08	17.60	0.001	YES	5.1
	Type of steel fibre	3.54	30.01	0.000	YES	8.7
	Steel fiber volume fraction	25.34	215.07	0.000	YES	62.4
	Error	1.29	-	-	-	3.2
	Total	40.61	-	-	-	-
Splitting tensile strength	w/b ratio	5.27	206.15	0.000	YES	64.2
	SF replacement	0.25	9.65	0.010	YES	3.0
	Type of steel fibre	0.58	22.7	0.001	YES	7.1
	Steel fiber volume fraction	1.83	71.4	0.000	YES	22.3
	Error	0.28	-	-	-	3.4
	Total	8.21	-	-	-	-

4.6 Correlation between mechanical properties

Correlating the experimental data is one of the most common practices among the researchers for assessment of the findings reported. Theoretically, the main elements controlling the mechanical properties of concrete are the relative volume fractions of paste matrix and aggregate, as well as their quality. As mentioned earlier higher compressive strength reflects enhanced mechanical behavior. In order to evaluate the bonding strength between reinforcement and concrete, correlating other mechanical properties with this parameter was considered to be critical. For this, correlation between bonding strength and other mechanical properties for both w/b contents is respectively presented in Figures 4.6-4.8. Based on the facts presented above to specify the possible correlation between the mechanical characteristics of plain and SF concretes with and without steel reinforcement, the correlation coefficients (R^2) were calculated and presented on those figures as well. The data used for these figures cover the entire test results obtained. Figures 4.7 and 4.8 revealed that the best correlation was achieved by polynomial curve fitting for splitting and flexural strength while for compressive strength exponential curve fitting yielded the highest correlation, without depending on the w/b ratio. As a result of the noticeable differences and uniformity for the measured values between bonding and tensile strengths, the strongest correlation was observed to take place between these parameters. The highest correlation was observed between splitting tensile strength vs. bonding strength (R^2=0.97) while the weakest was observed between compressive vs. bonding strength. This may be due to the irregularity of the scatter of the data for bonding vs. compressive strength or presence of steel fibers that may affect more on bonding and tensile strength than compressive strength.

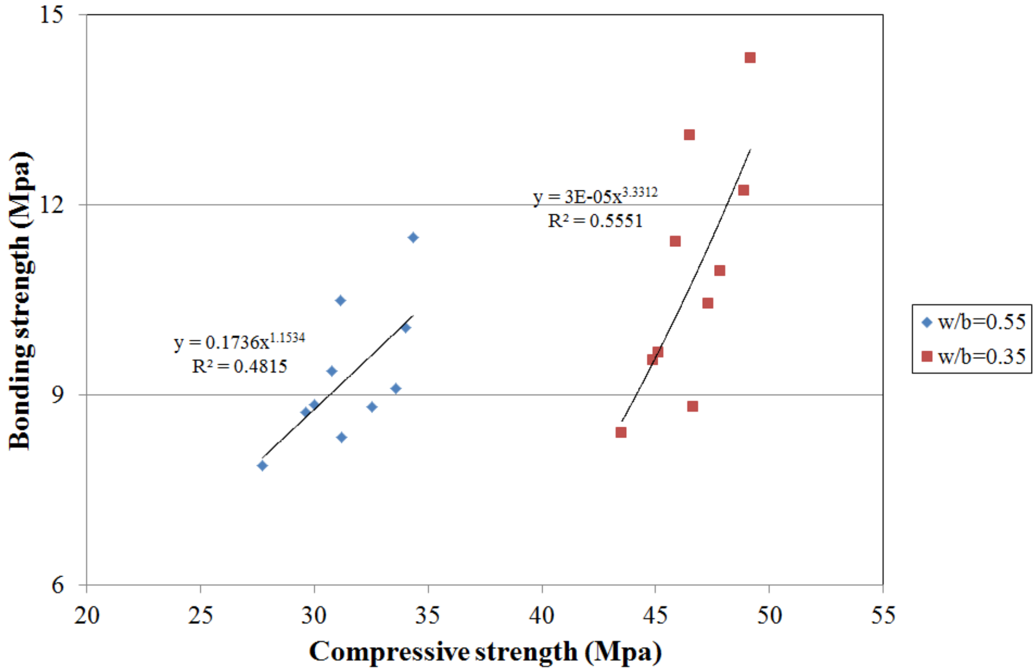


Figure 4.6 Correlation between bond strength and compressive strength

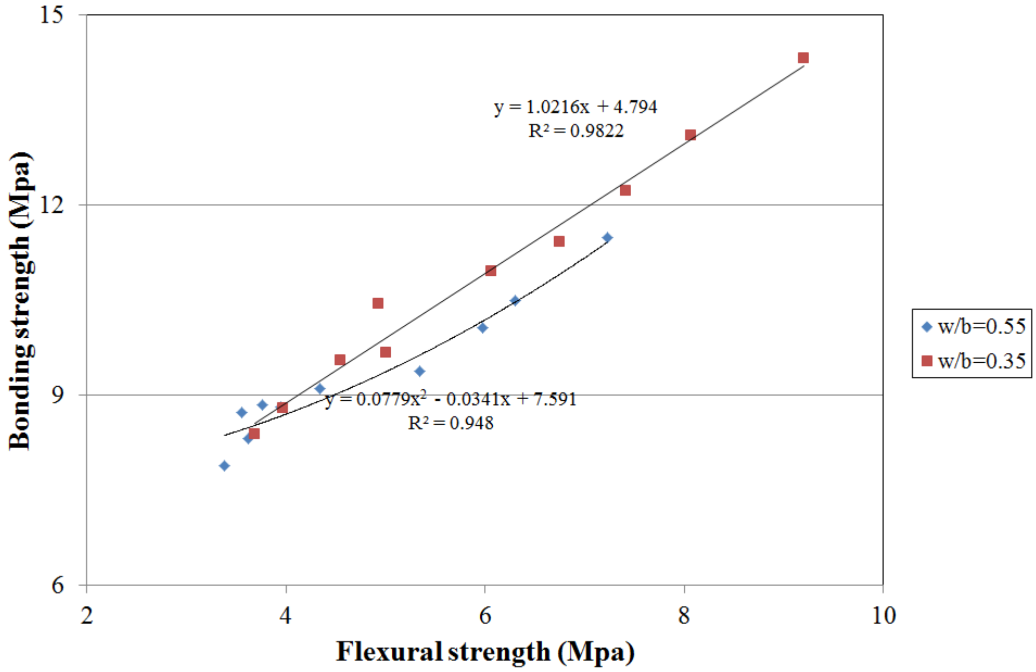


Figure 4.7 Correlation between bond strength and flexural strength

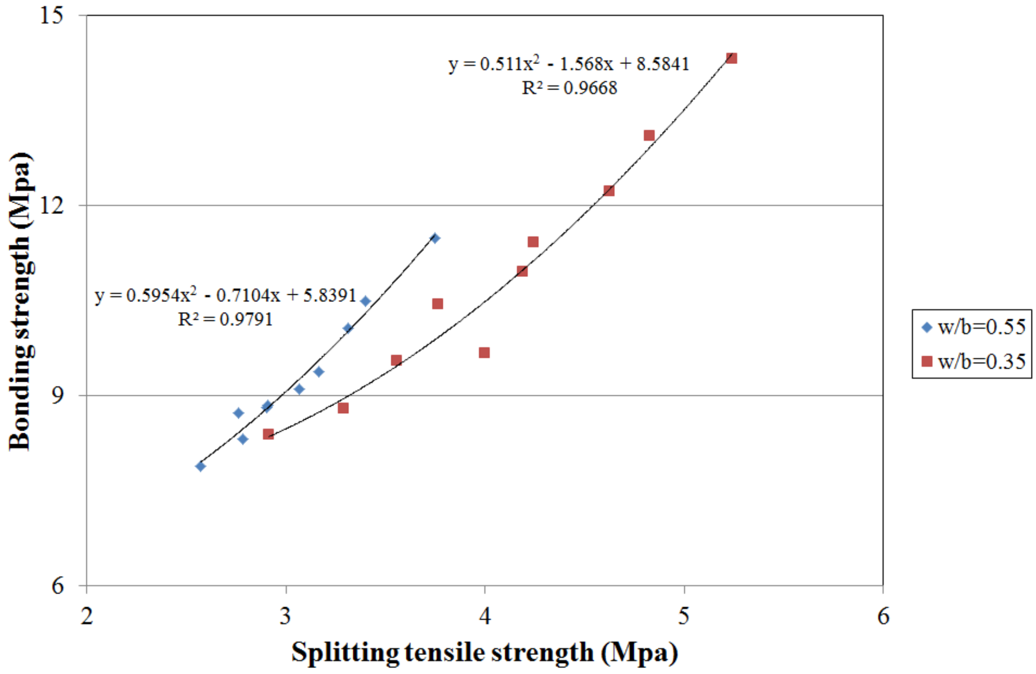


Figure 4.8 Correlation between bond strength and splitting tensile strength

CHAPTER 5

CONCLUSIONS

In accordance with the experimental results presented herein, the following conclusions can be drawn:

- The production of concretes with artificial cold bonded fly ash aggregates having proper mechanical properties was proved to be possible through incorporation of silica fume and steel fibers.

- Use of SF as a replacement material provided improved mechanical properties of concretes when compared to plain ones for both w/b ratios. The highest compressive strength values were measured as 49.2 and 34.3 MPa for concrete groups with w/b ratios of 0.35 and 0.55, respectively. The inclusion of steel fibers also contributed to the compressive strength. The long fibers (St1) provided higher compressive strength development than St2 incorporated concretes with increase in volume fraction. The level of improvement was more pronounced for SF concretes than plain ones.

- Addition of steel fibers demonstrated remarkable improvement in bonding and tensile strength capacities of the concretes investigated. The steel fibers with higher length/aspect ratio (St1) contributed in further improvement in bonding and tensile strength capacities than St2 did. However when considering the compressive strength, there were only slight differences between St1 and St2 incorporated concretes. This difference in the behavior of steel fiber reinforced concretes may be attributed to the dispersion and orientation of the steel fibers within the concrete.

- Addition of 0.75% volume fraction of the steel fiber to concrete proved to be much more effective than 0.25% addition, without depending on type of steel fiber and incorporation of SF.

- Statistical analysis revealed that w/b ratio, type and amount of steel fiber and incorporation of SF are all influential factors at varying levels on mechanical properties of the concretes. Especially, for bonding and flexural strength the amount of the steel fiber had the greatest effect. Besides, incorporation of SF was statistically proved to be influential on the mechanical properties of concretes.

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APPENDIX-A-

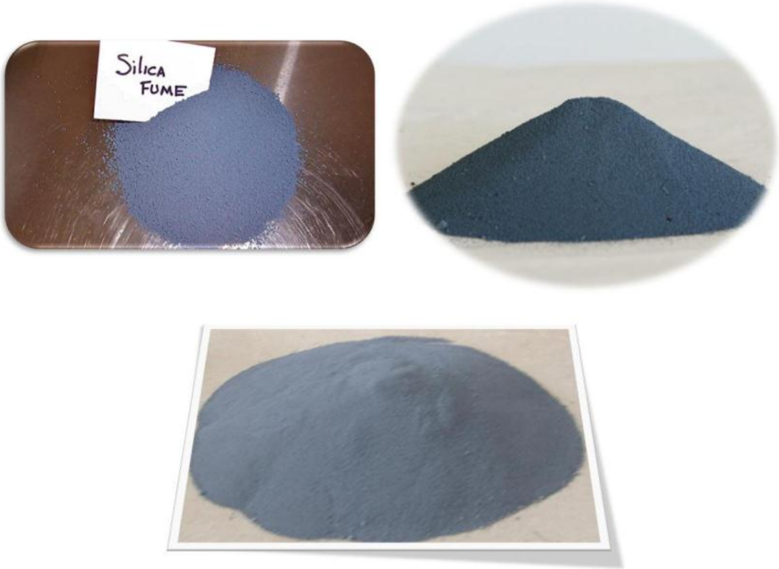

Figure A.1 Silica fume used in test

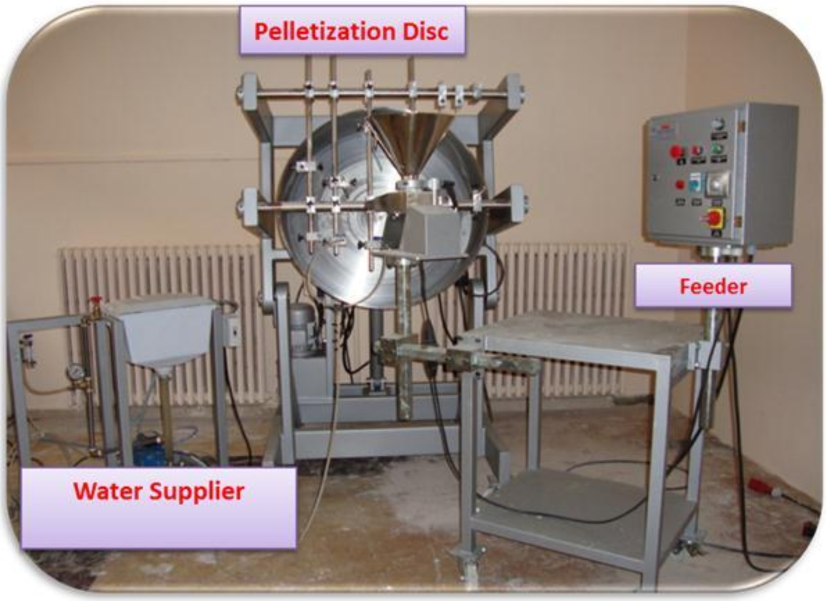

Figure A.2 General view if pelletization disc

Figure A.3 Side view of pelletization disc

Figure A.4 Formation of fresh aggregate in pelletization process

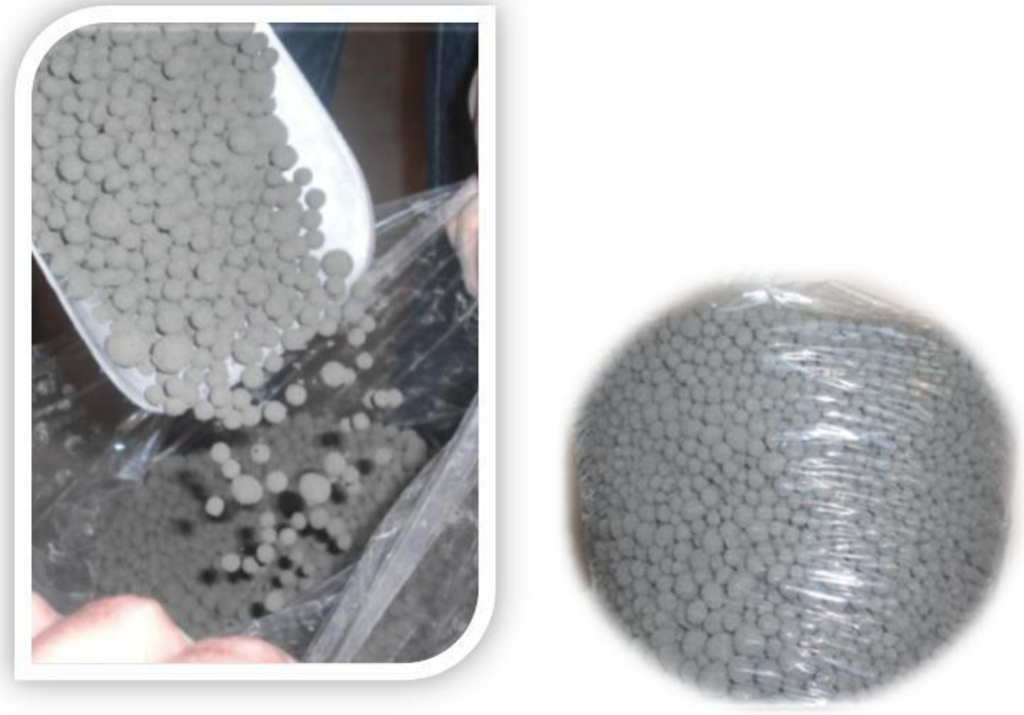

Figure A.5 Self-curing of fresh aggregate by kept it in sealed bags

Figure A.6 Hardened aggregate sieved and ready for mixes

Figure A.7 Aggregate immersed in water for 30 min. to get SSD aggregate

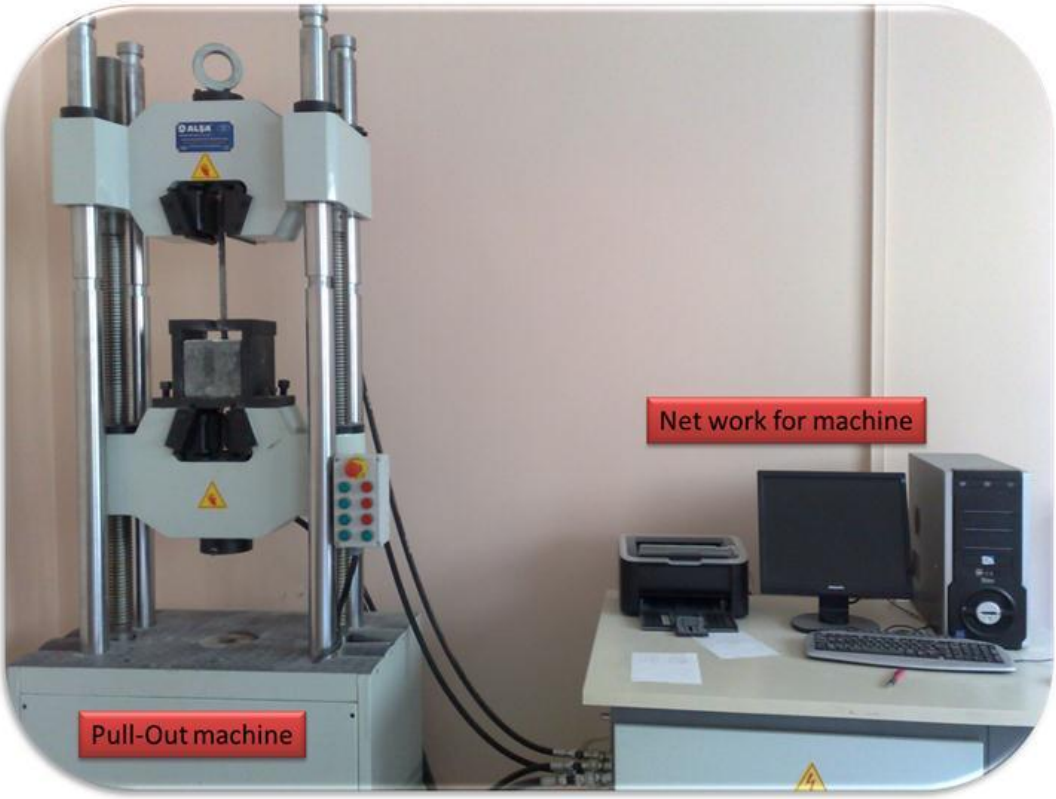

Figure A.8 Fully automatic digital pull out machine

Figure A.9 Cubic specimen under compressive test

Figure A.10 Flexural specimens after testing for plain and steel fibers mixes

Figure A.11 Pull out specimens before testing for plain and steel fibers mixes

Figure A.12 Pull out specimens after testing for plain and steel fibers mixes