UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES

FRESH PROPERTIES OF SELF COMPACTING CONCRETES INCORPORATING MULTI-SYSTEM MINERAL ADMIXTURES

M. Sc. THESIS
IN
CIVIL ENGINEERING

BY
MUSTAFA ERKAN KOCABAĞ
August 2010

Fresh Properties of Self Compacting Concretes Incorporating Multi-System Mineral Admixtures

M.Sc. Thesis
in
Civil Engineering
University of Gaziantep

Supervisor
Assoc. Prof. Dr. Erhan GÜNEYİSİ

by
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August 2010

T.C.
UNIVERSITY OF GAZİANTEP
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CIVIL ENGINEERING

Name of the thesis: Fresh Properties of Self Compacting Concrete Incorporating Multi-System Mineral Admixtures
Name of the student: Mustafa Erkan KOCABAĞ
Exam date: 13.08.2010

Approval of the Graduate School of Natural and Applied Sciences

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To my father and mother
Ömer Ali ve Münevver

ABSTRACT

FRESH PROPERTIES OF SELF COMPACTING CONCRETES INCORPORATING MULTI-SYSTEM MINERAL ADMIXTURES

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M.Sc. in Civil Eng.
Supervisor: Assoc. Prof. Dr. Erhan GÜNEYİSİ
August 2010, 62 Pages

In this study, the effect of using different kinds of mineral admixtures at varying levels on the fresh properties of self-compacting concrete (SCC) was investigated experimentally. Blended concrete mixtures contained various combinations of fly ash (FA), marble powder (MP), and limestone filler (LF) while control mixture incorporated only Portland cement as binder material. All mixtures were produced at a constant water-to-binder ratio of 0.35 and total binder of 520 kg/m^3. Generally, two different series of concrete mixtures, namely, binary and ternary blends of mixtures were designed. The fresh properties of the produced self-compacting concretes were observed through slump flow diameter, slump flow time, V-funnel flow time, L-box height ratio, initial and final setting times, and viscosity. The test results revealed that it was possible to produce self-compacting concrete with binary and ternary blends of FA, MP, and LF. However, the effects of mineral admixtures on the fresh characteristics of self-compacting concrete were very remarkable.

Key Words: Self Compacting Concrete, Marble Powder, Fly Ash, Limestone Filler, Fresh Properties, Viscosity

ÖZET

ÇOKLU SİSTEM MİNERAL KATKILI KENDİLİĞİNDEN YERLEŞEN BETONLARIN TAZE ÖZELLİKLERİ

KOCABAĞ, Mustafa Erkan
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Ağustos 2010, 62 sayfa

Bu tez çalışmasında, değişik tip ve oranlarda mineral katkı kullanımının kendiliğinden yerleşen betonun (KYB) taze özellikleri üzerindeki etkisi deneysel olarak araştırılmıştır. Karışım betonu bağlayıcı madde olarak değişik kombinasyonlarda uçucu kül, mermer tozu ve kalker filleri içerirken kontrol betonu karışımına yalnızca portland çimentosu katılmıştır. Bütün karışımlar su-bağlayıcı oranı 0,35 ve toplam bağlayıcı miktarı 520 kg/m^3 olarak üretilmiştir. Genel olarak, iki farklı seri beton karışımı yani, ikili ve üçlü karışımın dizaynı yapılmıştır. Üretilen kendiliğinden yerleşen betonun taze özellikleri yayılma çapı, yayılma süresi, V-hunisi akma süresi, L-kutusu yükseklik oranı, priz başlangıç ve bitiş süreleri ve viskozite üzerinden gözlenmiştir. Deneylerden elde edilen sonuçlara göre, ikili ve üçlü uçucu kül, mermer tozu ve kalker filleri karışımlarından kendiliğinden yerleşen beton üretmenin mümkün olduğu gözlenmiştir. Bununla birlikte, kullanılan mineral katkıların kendiliğinden yerleşen betonun taze özellikleri üzerinde oldukça etkili olduğu görülmüştür.

Anahtar Kelimeler: Kendiliğinde Yerleşen Beton (KYB), Mermer Tozu, Uçucu Kül, Kalker Filleri, Taze Özellikler, Viskozite

ACKNOWLEDGEMENT

I owe special thanks to my supervisor, Assoc. Prof. Dr. Erhan Güneyisi, for his help and endless encouragement throughout this study.

I would like to thank Assoc. Prof. Dr. Mehmet Gesoğlu and Kasım Mermerdaş for their contributions.

Thanks are also due to Vakıf Kiriş, Veysel Bayram and Hatice Öznur Öz for their assistance with laboratory work.

Finally, I would like to thank my father, mother, sister and brother (Ömer Ali, Münevver, Havva Nesrin, Mustafa Kemal Kocabağ) for their continuous support and encouragement.

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LIST OF SYMBOLS / ABBREVATIONS

$\dot{\gamma}$	Shear Strain Rate
τ	Shear Stress
μ	Viscosity
τ_0	Yield Stress
t	Flow Time
t_v	V-Funnel Flow Time
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
FA	Fly Ash
KYB	Kendiliğinden Yerleşen Beton
LF	Limestone Filler
MD	Marble Dust
MP	Marble Powder
PC	Portland Cement
SCC	Self Compacting Concrete
SCRC	Self Compacting Rubberized Concrete
SEM	Scanning Electron Microscope
SF	Slump Flow
SP	Superplasticizer
TS EN	Turkish Standard European Norm

1. CHAPTER: INTRODUCTION

1.1 General

Self-compacting concrete (SCC) has emerged in Japan in the late 1980s as a material that can flow under its own weight, completely filling formwork, and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogenous and has the same engineering properties and durability as traditional concrete (Nehdi et al., 2004). The purpose of SCC concept is to decrease the risk due to the human factor, to enable economic efficiency, less human work, more freedom to designers and constructors, to lower noise level on the construction site.

The common practice to produce SCC is to limit the coarse aggregate content associated with its maximum size and to use the lower water-binder ratios together with appropriate superplasticizers (Okamura and Ozawa, 1995).

In order to achieve a SCC of high fluidity and to prevent the segregation and bleeding during transportation and placing, the formulators have employed a high volume of Portland cement and chemical admixtures (Lachemi et al., 2004). In some cases, the saving in labor cost might offset the increased cost. But the use of mineral admixtures such as fly ash, ground granulated blast furnace slag, marble powder, limestone filler, etc. reduced the material cost of the self –compacting concretes and also improved fresh and hardened properties of the concretes. Using mineral admixtures especially in SCC necessitates further attention. On incorporation of such materials, certain properties of the concretes may be enhanced whereas others may worsen relative to the plain Portland cement concrete.

Fly ash, for example, improves workability but decreases early strength (Cabrera, 1986). The negative effects may be remedied by the combined use of the mineral admixtures.

1.2 Research Objective

The objective of this thesis is to investigate the effects of using different types of mineral admixtures as a partial replacement of portland cement on fresh properties of self-compacting concretes. For this, the binary (two components) and ternary (three components) cementitious blends of portland cement, fly ash, marble powder, and limestone filler were used in the production of self-compacting concretes. A constant replacement level of 30% by weight of total binder content was taken into account for fly ash. However, the various levels of (5, 10, and 20%) were assigned for marble powder and limestone filler.

A total of 14 SCC mixtures were designed at a water-to-binder ratio of 0.35 and a total binder of 520 kg/m^3. Slump flow, L-box height ratio, V-funnel flow time, viscosity, and setting properties were determined as for the fresh properties.

1.3 Outline of Thesis

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

2. Chapter - Litereature review and backgroud: A literature review and a general background information of SCC are investigated. In this chapter, properties of fresh SCC, rheology of concrete, and effects of mineral admixtures on fresh properties of concrete are discussed.

3. Chapter - Experimental study: The experimental program, test procedures, materials, minerals, mixtures, and curing conditions are described.

4. Chapter - Test results and discussion: The test results of the experimental studies, the effects of mineral and chemical admixture on the fresh properties of SCC are explained.

5. Chapter - Conclusions: The conclusions of thesis are given.

2. CHAPTER: LITERATURE REVIEW AND BACKGROUND

2.1 General

The following literature review focuses on the definition and properties of self compacting concretes. And also, the properties and formation of mineral admixtures, especially for fly ash, marble powder, and limestone filler are presented. Moreover, the effects of mineral admixtures on the fresh properties of SCCs are discussed.

2.2 Self Compacting Concrete (SCC)

2.2.1 Definitions

Self-compacting concrete (SCC) is a form of concrete that is able to flow under its own weight and completely fills the formwork even in the presence of dense reinforcement, without the need of any vibration, whilst maintaining homogeneity (EFNARC, 2002). Yahia et al. (2005) defined SCC as ‘‘concrete that can exhibit high deformability and can flow into place under its own weight without any external consolidation and with limited signs of segregation’’.

2.2.2 Rheology of SCC

The rheological properties of concrete are important for the construction industry because concrete is usually put into place in its plastic form. Characteristic phenomena of liquid and gas to immediately deform when subjected to small shearing stress is called ‘‘flow’’. The study of flow process that deals with relations between stress and strain and their time dependent derivative is called ‘’rheology’’ (Ozawa et al., 1989). In practice, rheology is concerned with materials whose flow properties are more complicated then of a simple fluid or ideal elastic solid (Tattersall et al., 1983).

Without any vibration, concrete is viscoplastic. To make it flow, strong shearing forces are necessary to break the bonds between grains, and that is where the initial yield value of concrete originates from. The vibration process periodically breaks the bonds, and tends to decrease the initial yield value. Whether the floe is facilitated by local shear or vibration, the apparent viscosity is decreased. The admixtures which are called the superplasticizers cause an important decrease in initial yield value without any external mechanical action (Bouzoubaa et al., 2001).

The flow properties of materials are often determined through shear stress-rate of shear plots (Figure 2.1). For a Newtonian liquid, the shear stress divided by the rate of shear is constant and called the coefficient of viscosity (μ) which is used as a physical characteristic of material. The rheology of fresh concrete, however, is often described by the Bingham model. A Bingham fluid is characterized by the shape and the location of its flow curve at shear stress versus shear strain rate diagram. According to this model, fresh concrete must overcome a limiting stress (yield stress, τ_0) before it can flow (Equation 2.2). Once the concrete starts to flow, shear stress increases linearly with an increase in strain rate as defined by plastic viscosity (Figure 2.2). Therefore, in order to fully describe the rheological properties of fresh concrete by Bingham model two parameters, namely the plastic viscosity and the yield stress are necessary (Ozawa et al., 1989).

If a shear force is applied to a liquid as shown in Figure 2.3, a velocity gradient is induced in the liquid. The proportionality factor between the force and the gradient is called the viscosity. The velocity gradient is equal to the shear rate $\dot{\gamma}$.

$$F/A = \tau = \eta\ \dot{\gamma} \tag{2.1}$$

$$\tau = \tau_0 + \eta\ \dot{\gamma} \tag{2.2}$$

Where;

$\dot{\gamma}$	Shear Strain Rate
τ	Shear Stress
τ_0	Yield Stress

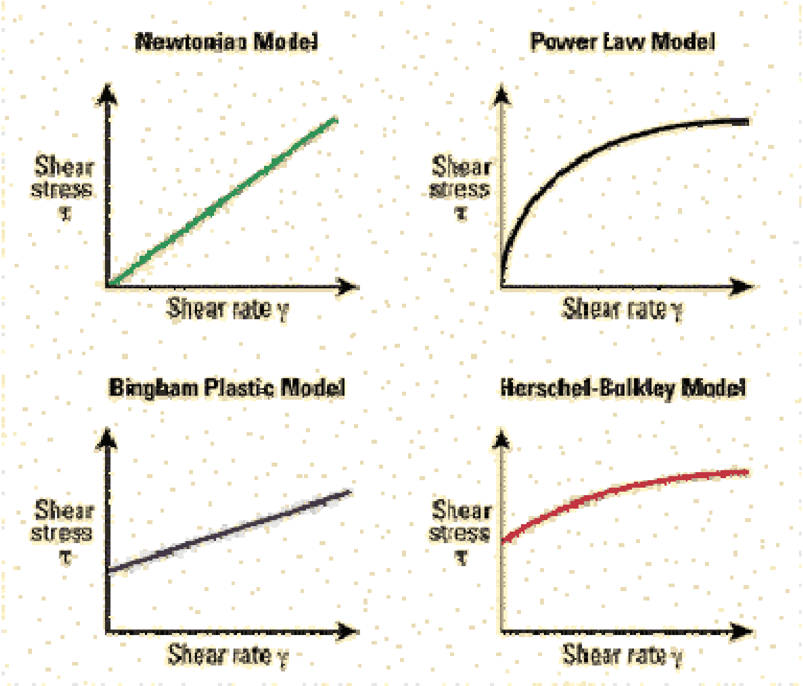


Figure 2.1 Rheological Models (www.glossary.oilfield.slb.com)

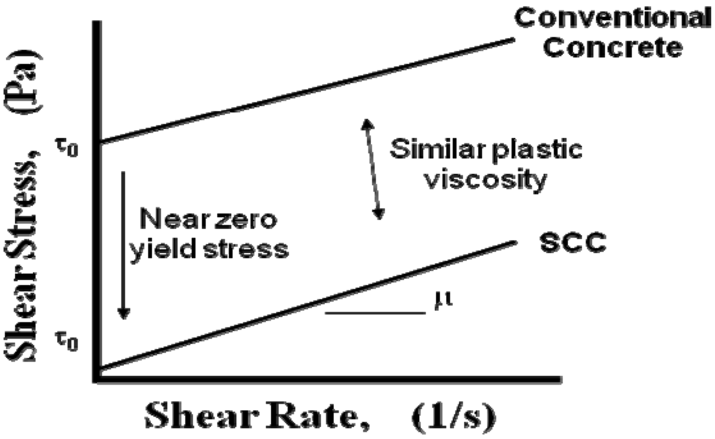


Figure 2.2 Comparison of conventional concrete to SCC (Grube and Rickert, 1999)

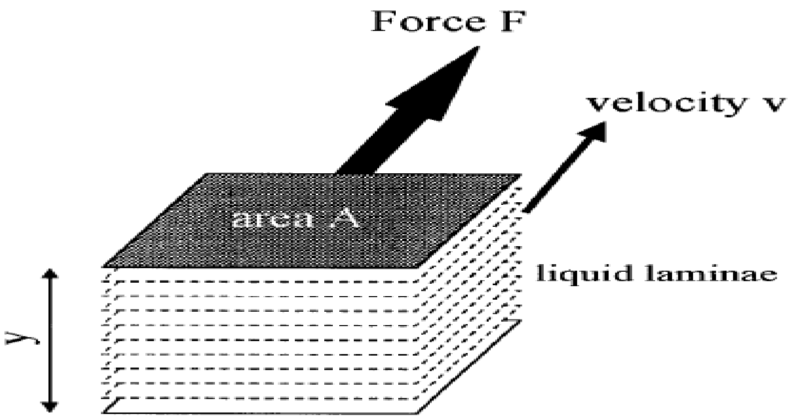


Figure 2.3 Newton's equation of viscous flow (Ferraris, 1999)

The rheological properties of fresh concrete are determined by the so-called rheometers which measure the shear stress at varying shear rates. Unfortunately the inherent properties of concrete make it impossible to use the rheometers designed for neat fluids without any solid particles. Therefore, there isn't a consensus on the rheological properties of SCC that are available in the market (NIST, 1999). In a comprehensive study by NIST, a series of twelve concrete mixtures was tested by five rheometers. The mixtures had slumps ranging from 90 mm to 235 mm, but more importantly, they had a wide range of combinations of yield stress and plastic viscosity. It was found that the rheometers gave different values of the Bingham constants of yield stress and plastic viscosity, even for those instruments that give these directly in fundamental units (NIST, 1999).

Compared to conventional concrete, SCC exhibits:

- Significantly lower yield stress (near zero): allows concrete to flow under its own mass
- Similar plastic viscosity: ensures segregation resistance
- Plastic viscosity must not be too high or too low
    - Too high: concrete is sticky and difficult to pump and place
    - Too low: concrete is susceptible to segregation

2.2.3 Workability Requirements of SCC

Workability is defined in terms of the amount of mechanical work, or energy, required to produce full compaction of the concrete without segregation. Because of the high content of powder, SCC may show more plastic shrinkage or creep than ordinary concrete mixes. These aspects should therefore be considered during designing and specifying SCC. The workability of SCC is higher than the highest class of consistence described within EN 206 and can be characterized by the following properties (EFNARC, 2002):

- Filling ability
- Passing ability
- Segregation resistance

Filling ability: SCC must flow freely under its own weight, both horizontally and vertically, and to completely fill every corner of the formwork without leaving voids.

Passing ability: SCC must flow freely between the congested reinforcement bars and cover reinforcement without segregating, and without having the need of applying any external forces like vibrator.

Segregation resistance: SCC must keep homogeneity while flowing and during placement. There should be no separation of aggregate from paste or water from solids, and no tendency for coarse aggregate to sink downwards through the fresh concrete mass under gravity (EFNARC, 2005).

If the expected workability requirements have been achieved from the produced concretes, the following most important advantages can be obtained (Okamura, 1999):

- Faster construction
- Reduction in site manpower
- Easier placing
- Improved durability
- Thinner concrete sections

- Greater freedom in design
- Better surface finishes
- Reduce noise levels, absence of vibration
- Safer working environment

Table 2.1 List of test methods for workability properties of SCC (EFNARC, 2002)

No	Method	Property
1	Slump Flow by Abrams Cone	Filling ability
2	T_{50} Time Slump Flow	Filling ability
3	J-Ring	Passing ability
4	V-Funnel	Filling ability
5	V-Funnel at $T_{5 \text{ minutes}}$	Segregation resistance
6	L-Box	Passing ability
7	U-Box	Passing ability
8	Fill-Box	Passing ability
9	GTM Screen Stability Test	Segregation resistance
10	Orimet	Filling ability

2.2.3.1 Test Methods for Achieving Workability of SCC

2.2.3.1.1 Slump Flow Test and T_{50} Time Test

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan (Japan Society of Civil Engineers, 1992) for use in assessment of underwater concrete. The test method is based on the test method for determining the slump described in EN 1235-2. The diameter of the concrete circle is a measure for the filling ability of the concrete. This is a simple, rapid test procedure, though two people are needed if the T_{50} time is to be measured.

It can be used on site, though the size of the base plate is somewhat unwieldy and level ground is essential. It is the most commonly used test, and gives a good assessment of filling ability. It gives no indication of the ability of the concrete to pass between reinforcement without blocking, but may give some indication of resistance to segregation. It can be argued that the completely free flow, unrestrained by any boundaries, is not representative of what happens in practice in concrete construction, but the test can be profitably be used to assess the consistency of supply of ready-mixed concrete to a site from load to load. (EFNARC, 2002)

Slump flow and T_{50} time is a test to asses the flowability and the flow rate of SCC in the absence of obstructions. The result is an indication of the filling ability of SCC, and the T_{50} time is a measure of the speed of flow and hence the viscosity. The fresh concrete is poured into a cone. When the cone is upwards the time from commencing upward movement the cone to when the concrete has flowed to a diameter of 500 mm is measured; this is the T_{50} time. The largest diameter of the slow spread of the concrete and the diameter of the spread at right angles to it are then measured and the mean is the slump-flow, Figure 2.4 (Grdic et al., 2008).

The higher the slump flow (SF) value, the greater its ability to fill formwork under its own weight. A value of at least 650 mm is required for SCC. There is no generally accepted advice on what are reasonable tolerances about a specified value, though ± 50 mm, as with the related flow table test, might be appropriate. The T_{50} time is a secondary indication of flow. A lower time indicates greater flowability. The Brite EuRam research suggested that a time of 3-7 seconds is acceptable for civil engineering applications, and 2-5 seconds for housing applications. In case of severe segregation most coarse aggregate will remain in the centre of the pool of concrete and mortar and cement paste at the concrete periphery. In case of minor segregation a border of mortar without coarse aggregate can occur at the edge of the pool of concrete. If none of these phenomena appear it is no assurance that segregation will not occur since this is a time related aspect that can occur after a longer period (EFNARC, 2002). Slump flow classes are shown in the Table 2.2 (The European Guidelines for SCC, 2005). Advantages and disadvantages of slump flow test are also shown in Table 2.3.

Table 2.2 Slump flow classes (The European Guidelines for SCC, 2005)

Class	Slump-flow in mm
SF1	550 to 650
SF2	660 to 750
SF3	760 to 850

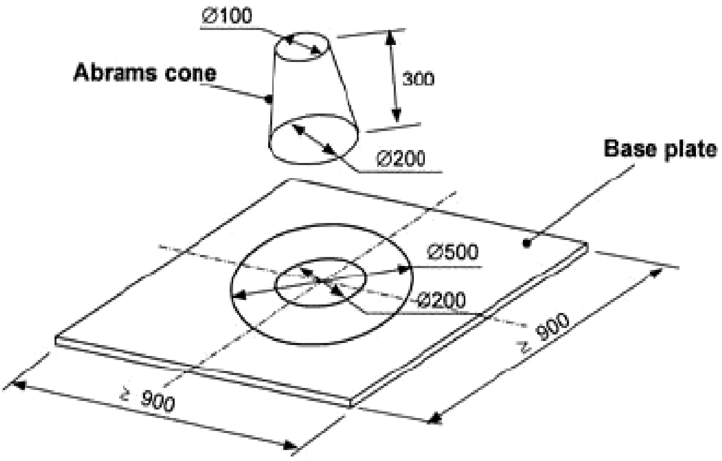


Figure 2.4 Apparatus for the slump flow test (Grdic et al., 2008)

Table 2.3 Advantages and disadvantages of slump flow test method (Bartos, 2005)

Test method	Advantages	Disadvantages
Slump flow test **(S and T_{50})** **Lab: Yes** **Site: Yes** **Rating: A**	• Easy and familiar • Good indication of filling ability • Very good correlation with rheology (S with yield stress; T_{50} with p. viscosity) • Sensitive to water content • Can be done with 1 operator only • Suitable for compliance testing • Good indication of flowing ability • Visual assessment possible for severe segregation	• Need stiff and flat base plate • Very sensitive to moisture condition of the base plate • Only tells part of story about filling ability • T_{50} not easy to measure for very fluid mixes • Usually needs 2 operators • Operator sensitive • Can not detect moderate segregation

2.2.3.1.2 V-Funnel Test

The test was developed in Japan and used by Ozawa et al. (1995). The equipment consists of a V-shaped funnel, shown in Fig. 2.5. An alternative type of V-funnel, the O funnel, with a circular section is also used in Japan. The described V-funnel test is used to determine the filling ability (flowability) of the concrete with a maximum aggregate size of 20 mm. The funnel is filled with about 12 liter of concrete and the time taken for it to flow through the apparatus measured. After this the funnel can be refilled concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly. Though the test is designed to measure flowability, the result is affected by concrete properties other than flow. The inverted cone shape will cause any liability of the concrete to block to be reflected in the result – if, for example there is too much coarse aggregate. High flow time can also be associated with low deformability due to a high paste viscosity, and with high inter-particle friction. While the apparatus is simple, the effect of the angle of the funnel and the wall effect on the flow of concrete is not clear (EFNARC, 2002).

The procedure is to clean the funnel and bottom gate, then dampen all the inside surface including the gate. Close the gate and pour the sample of concrete into the funnel, without any agitation or rodding, then strike off the top with the straight edge so that the concrete is with the top of the funnel. Place the container under the funnel in order to retain the concrete to be passed. After a delay of (10±2) sec from filling the funnel, open the gate and measure the time t_v, to 0.1 sec, from opening the gate to when is possible to see vertically through funnel into the container below for the first time. t_v is the V-funnel flow time. V-funnel is shown in Figure 2.5 (Grdic et al., 2008). Viscosity classes are shown in the Table 2.4 (EFNARC, 2005).

Table 2.4 Viscosity classes (EFNARC, 2005)

Class	T_{500}, s	V-funnel time in s
VS1/VF1	≤ 2	≤ 8
VS2/VF2	> 2	9 to 25

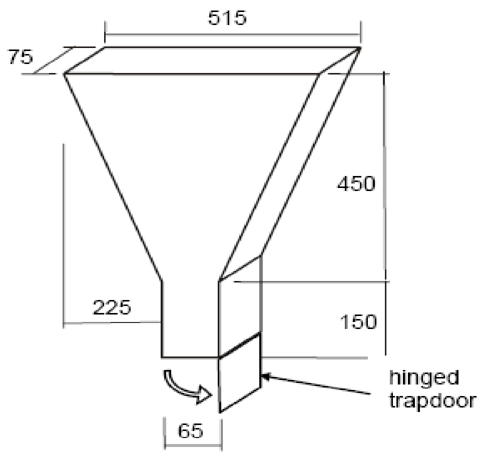


Figure 2.5 V-Funnel apparatus (Grdic et al., 2008)

This test measures the ease of flow of the concrete; shorter flow times indicate greater flowability. For SCC a flow time of 10 seconds is considered appropriate. The inverted cone shape restricts flow, and prolonged flow times may give some indication of the susceptibility of the mix to blocking. After 5 minutes of settling, segregation of concrete will show a less continuous flow with an increase in flow time (EFNARC, 2002).

Table 2.5 Advantages and disadvantages of V-funnel test method (Bartos , 2005)

Test method	Advantages	Disadvantages
V-funnel test (t_v) **Lab : Yes** **Site: ?** **Rating: B**	• Reasonably good correlation with plastic viscosity • Indication of filling ability • Widely used, particularly in Japan • Possible to detect severe blocking	• Physically difficult to perform • Unknown practical limits for results • Usually needs 2 operators • Visual assessment impossible

2.2.3.1.3 L-Box Test

This test, based on a Japanese design for underwater concrete, has been described by Petersson et al. (1996). The test assesses the flow of the concrete, and also the extent to which it is subject to blocking by reinforcement.

The apparatus is shown in Figure 2.6. The apparatus consists of a rectangular-section box in the shape of an ‘L’, with a vertical and horizontal section, separated by a moveable gate, in front of which vertical lengths of reinforcement bar are fitted. The vertical section is filled with concrete, then the gate lifted to let the concrete flow into the horizontal section. When the flow has stopped, the height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H_2/H_1 in the Figure 2.6). It indicates the slope of the concrete when at rest. This is an indication passing ability, or the degree to which the passage of concrete through the bars is restricted. The passing ability PA is calculated from the following equation.

$$PA = H_2/H_1 \tag{2.3}$$

The horizontal section of the box can be marked at 200 mm and 400 mm from the gate and the times taken to reach these points measured. These are known as the T_{200} and T_{400} times and are an indication for the filling ability. The sections of bar can be of different diameters and spaced at different intervals: in accordance with normal reinforcement considerations, 3x the maximum aggregate size might be appropriate. The bars can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete.

This is a widely used test, suitable for laboratory, and perhaps site use. It assesses filling and passing ability of SCC, and serious lack of stability (segregation) can be detected visually. Segregation may also be detected by subsequently sawing and inspecting sections of the concrete in the horizontal section (EFNARC, 2002). Passing ability classes are shown in Table 2.6 (EFNARC, 2005).

Table 2.6 Passing ability classes (EFNARC, 2005)

Class	Passing ability
PA1	≥ 0.80 with 2 rebars
PA2	≥ 0.80 with 3 rebars

Advantages and disadvantages of L-box test method are shown in Table 2.7.

Table 2.7 Advantages and disadvantages of L-box test method (Bartos, 2005)

Test method	Advantages	Disadvantages
L-box test **(P_L or B_L)** **Lab : Yes** **Site: No** **Rating: A**	• Familiar and widely used • Good indication of passing ability • Can use any materials to construct • Good correlation with slump flow • Single measurement (h_2) possible	• Values may be irrelevant at high slump flow • Difficult to use on site and to clean • Essential that it be level • Relatively long time to prepare and test

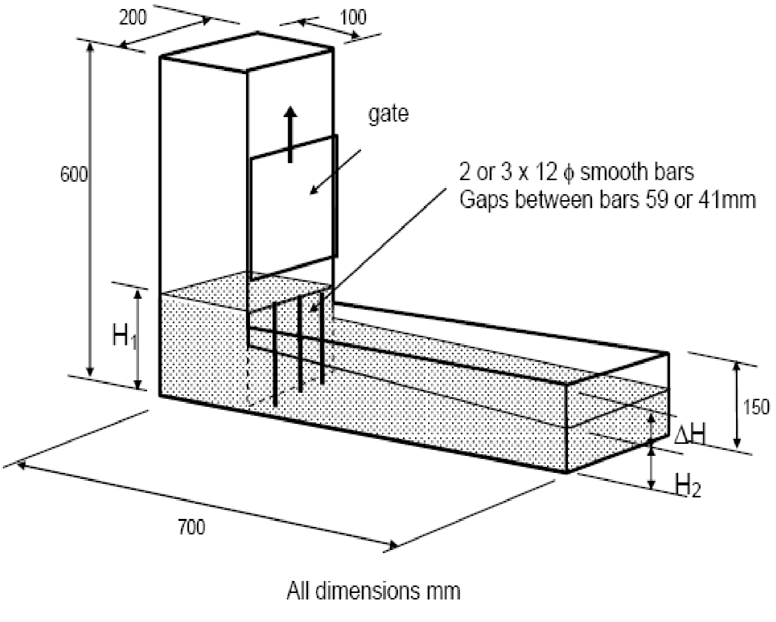


Figure 2.6 L-box apparatus (EFNARC, 2005)

2.2.3.1.4 J-Ring Test

The principle of the J-ring test may be Japanese, but no references are known. The J-ring test itself has been developed at the University of Paisley. The test is used to determine the passing ability of the concrete. The equipment consists of a rectangular section (30mm x 25mm) open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar (Figure 2.7). These sections of bar can be of different diameters and spaced at different intervals: in accordance with normal reinforcement considerations, 3x the maximum aggregate size might be appropriate. The diameter of the ring of vertical bars is 300 mm, and the height 100 mm. The J-ring can be used in conjunction with the slump flow, the orimet test, or eventually even the V-funnel. These combinations test the flowing ability and (the contribution of the J-ring) the passing ability of the concrete. The orimet time and/or slump flow spread are measured as usual to assess flow characteristics. The J-ring bars can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete. After the test, the difference in height between the concrete inside and that just outside the J-ring is measured. This is an indication of passing ability, or the degree to which the passage of concrete through the bars is restricted (EFNARC, 2002).

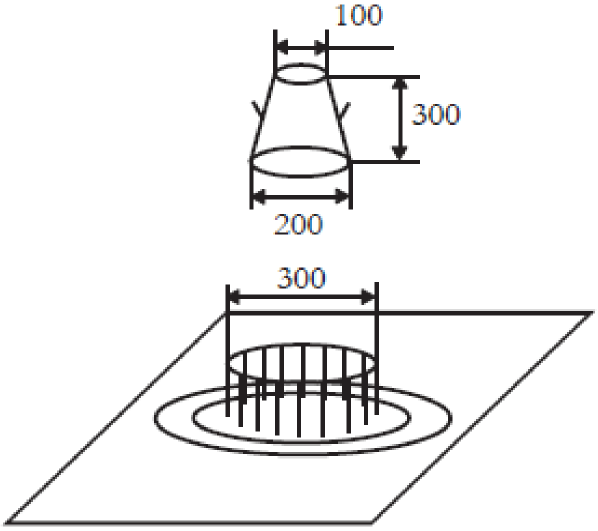


Figure 2.7 J-ring test apparatus (EFNARC, 2002)

Table 2.8 Advantages and disadvantages of J-ring test method (Bartos, 2005)

Test method	Advantages	Disadvantages
J-ring test **(S_J, $T50_J$ and B_J)** **Lab : Yes** **Site: Yes** **Rating: A**	• Easy, portable • Use with slump flow • S_J correlates with filling ability • B_J as good indication of passing ability • Visual assessment possible for blocking and severe segregation • Potentially to cover all the key properties	• Measurement not as easy as slump flow • Not very widely used • B_J can be affected by filling ability • $T50_J$ very difficult to measure • Usually needs 2 operators • Operator sensitive • Can not detect moderate segregation

2.2.3.1.5 Orimet Test Method

The orimet was developed at the University of Paisley (Bartos, 1998) as a method for assessment of highly workable, flowing fresh concrete mixes on construction sites. The apparatus is shown in Figure 2.8. The test is based on the principle of an orifice rheometer. The orimet consists of a vertical casting pipe fitted with a changeable inverted cone-shaped orifice at its lower, discharge, end, with a quick-release trap door to close the orifice. Usually the orifice has an 80 mm internal diameter which is appropriate for assessment of concrete mixes of aggregate size not exceeding 20 mm. Orifices of other sizes, usually from 70 mm to 90 mm in diameter, can be fitted instead. Operation consists simply of filling the orimet with concrete then opening the trapdoor and measuring the time taken for light to appear at the bottom of the pipe (when viewed from above). This test is able to simulate the flow of fresh concrete during actual placing on sites. It is a rapid test, and the equipment is simple and easily maintained. The test has the useful characteristic of being capable of differentiation between highly workable, flowing mixes, and might therefore useful for compliance testing of successive loads on site (EFNARC, 2002). Advantages and disadvantages of orimet test method are shown in Table 2.9.

Table 2.9 Advantages and disadvantages of orimet test method (Bartos, 2005)

Test method	Advantages	Disadvantages
Orimet test (t_0) **Lab : Yes** **Site: Yes** **Rating: B**	• Sensitive to filling ability • Not operator-sensitive • Possible to change size of the orifice to suit application • Possible as 'go/no go' test	• Physically difficult to perform • Can be affected by segregation • Visual assessment impossible • t_0 can be too short to be measured reliably

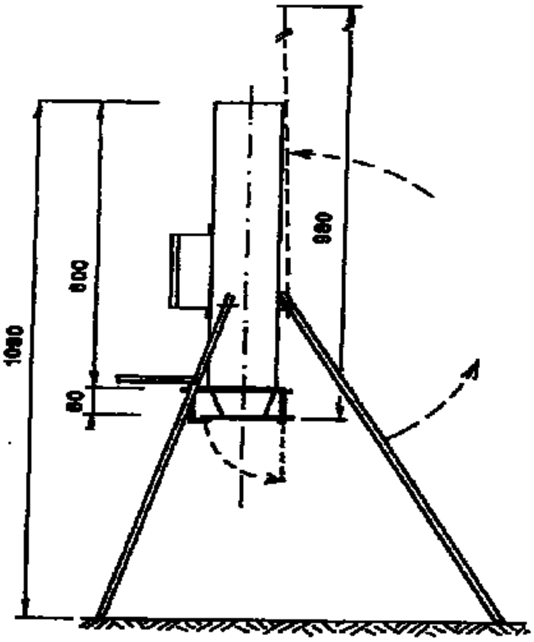


Figure 2.8 Orimet test apparatus (Ferraris, 1999)

2.2.3.1.6 U-Box Test

The test was developed by the Technology Research Centre of the Taisei Corporation in Japan (Haykawa, 1993). Sometimes the apparatus is called a “box-shaped” test. The test is used to measure the filling ability of self-compacting concrete. The apparatus consists of a vessel that is divided by a middle wall into two compartments, shown by R1 and R2 in Figure 2.9. An opening with a sliding gate is fitted between the two sections. Reinforcing bars with nominal diameters of 13 mm are installed at the gate with centre-to-centre spacings of 50 mm. This creates a clear spacing of 35 mm between the bars. The left hand section is filled with about 20 liter of concrete then the gate lifted and concrete flows upwards into the other section. The height of the concrete in both sections is measured (EFNARC, 2002).

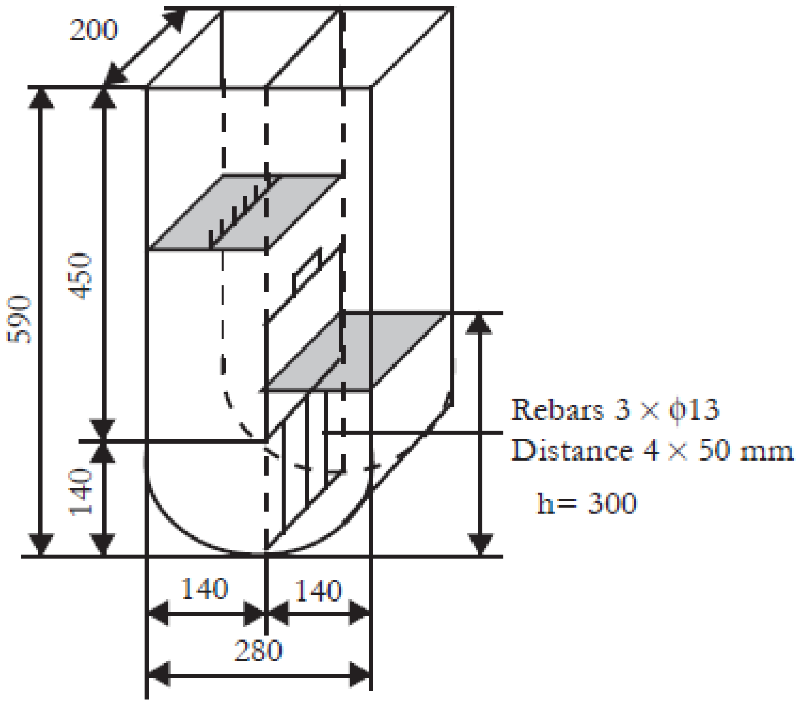


Figure 2.9 U-box test apparatus (EFNARC, 2002)

2.2.3.1.7 Fill Box Test Method

This test is also known as the ‘‘Kajima test’’. The test is used to measure the filling ability of self-compacting concrete with a maximum aggregate size of 20 mm. The apparatus consists of a container (transparent) with a flat and smooth surface. In the container are 35 obstacles made of PVC with a diameter of 20 mm and a distance centre to centre of 50 mm: see Figure 2.10. At the top side is put a filling pipe (diameter 100 mm height 500 mm) with a funnel (height 100 mm). The container is filled with concrete through this filling pipe and the difference in height between two sides of the container is a measure for the filling ability. This is a test that is difficult to perform on site due to the complex structure of the apparatus and large weight of the concrete. It gives a good impression of the self-compacting characteristics of the concrete. Even a concrete mix with a high filling ability will perform poorly if the passing ability and segregation resistance are poor (EFNARC, 2002).

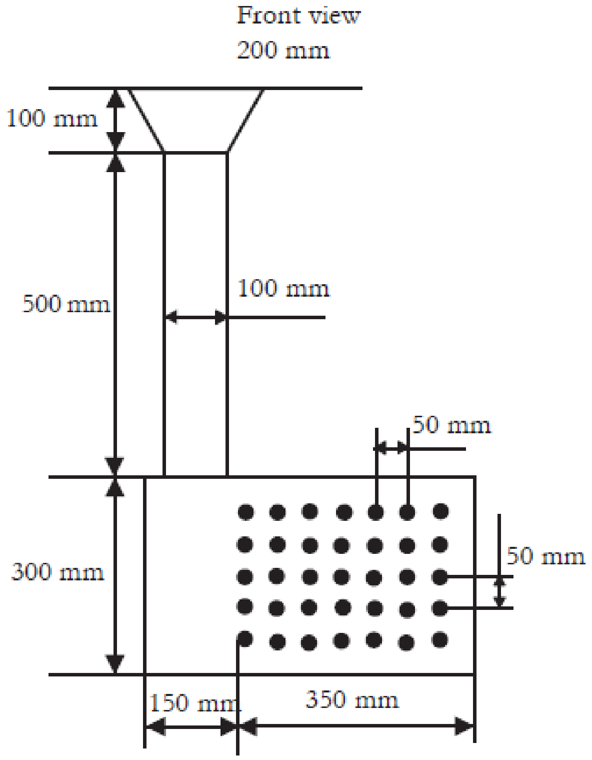


Figure 2.10 Fill box test apparatus (EFNARC, 2002)

2.2.3.1.8 GTM Screen Stability Test Method

This test has been developed by the French contractor, GTM, to assess segregation resistance (stability). It consists of taking a sample of 10 liter of concrete, allowing it to stand for a period to allow any internal segregation to occur, then pouring half of it on to a 5 mm sieve of 350 mm diameter, which stands on a sieve pan on a weigh scale. After two minutes, the mortar which passed through the sieve is weighed, and expressed as a percentage of the weight of the original sample on the sieve. Practicing engineers who have used this test say it is a very effective way of assessing the stability of SCC. However, though simple, it is not a rapid test, and requires an accurate weigh-scale, so may not be too suitable for site use (EFNARC, 2002).

2.3 Mineral Admixtures in Concrete Production

2.3.1 Mineral Admixtures

The addition of finely ground solid materials to concrete is an established practice in modern concrete technology. Collectively, these materials are called mineral admixtures or supplementary cementing materials. Mineral admixtures can be divided into three main categories:

1. Pozzolanic materials
2. Cementitious materials
3. Non-reactive materials

Table 2.10 Classification of mineral admixtures (Mehta and Monteiro, 1997)

Pozzolans		**Cementitious Materials**	**Non-reactive Materials**
Natural Pozzolans	Artificial Pozzolans	Natural cements	Ground quartz
Volcanic tuffs	Fly ash	Hydraulic limes	Ground limestone
Pumices	Silica fume	Slag cements	Bentonite
Some shales	Blast furnace slag	Granulated iron blast-furnace slag	Hydrated lime

The use of finely divided mineral admixtures can improve some of the properties of the fresh and hardened concrete. Such properties are:

- Workability and finishability of concrete
- Cohesion, bleeding and segregation
- Rate of heat of hydration development by replacement of a portion of portland cement
- Increase concrete strength
- Improvement of the chemical resistance of concrete
- Reduction of alkali-silica reaction

2.3.1.1 Fly Ash (FA)

Fly ash is available in most areas of the Turkey. Approximately 15 million tons of ashes are generated via the consumption of 40 million tons of lignite yearly. Unfortunately, the utilization of fly ash in Turkey is limited mainly as a substitute of clinker in cement production (Baba and Turkman, 2001).

According to ASTM C 618-89, fly ash, is a “finely divided residue that results from the combustion of ground or powdered coal”. Two kinds of fly ash are produced from the combustion of coal:

Class C – High, more than 10%, calcium content produced from sub-bituminous coal

Class F – Low, less than 10%, calcium content produced from bituminous coal.

Although the constituents of fly ash are typically not present as oxides, it is customary to represent them in this manner. The major oxide components are usually SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, and SO_3. If the sum of the first three ingredients is 70% or greater, the fly ash is technically considered as Class F. For a Class C fly ash, the sum of the first three components is greater than only 50%. The principal active ingredient in Class F ash is siliceous or alumino-silicate glass is the active ingredient. The glassy material in Class C fly ash is often more reactive than the glass in Class F fly ash. In addition, Class C fly ash may contain additional reactive components such as free lime, anhydrate, C_3A, C_3S, etc.

2.3.1.2 Marble Powder (MP)

All natural stones that industrially can be processed as cut to size, polished, used for decorative purposes and economically valuable are called as marble. USA, Belgium, France, Spain, Sweden, Italy, Egypt, Portugal, and Greece are among the countries with considerable marble reserve (Onargan et al., 2006). Turkey has the 40% of total marble reserve in the world. 7,000,000 tons of marble have been produced in Turkey annually and 75% of these production have been processed in nearly 5000 processing plants. It can be apparently seen that the waste materials of these plants reach millions of tons. Stocking of these waste materials is impossible. In marble quarries, the stones are being cut as blocks via different methods. These blocks are being moved to processing plants. In these plants, the blocks with 15–20 tons weight are being cut to size as decorative tiles and being polished. During the cutting process, the dust of the marble and water mixes together and become waste marble mud. The material that become dry mud after being refined within the refinement facilities are too big for stocking and becoming harmful for the environment day by day. During the cutting process 20–30% of the marble block become dust (Alyamaç and Ince, 2009).

These type solid waste materials should be inactivated properly without polluting the environment. The most suitable inactivating method nowadays is recycling.

Recycling provides with some advantages such as protecting the natural resources, energy saving, contributing to economy, decreasing the waste materials and investing for the future (Kaseva and Gupta, 1996). The self-compacting concrete technology has a big potential for this type solid waste materials.

Marble powder is a limestone origin waste material. Limestone dust as filler material in SCC shows quite good performance (Bonavetti et al., 2003; Yahia et al., 2005). Thus, it can be said that MP can be used in SCC as filler material and after then, it can also be a by-product for concrete industry (Topçu et al., 2009).

2.3.1.3 Limestone Filler

Ground limestone has been used in concrete production for the last 25 years (Nehdi et al., 1995), not only for the main purposes of lowering the costs and environmental load of cement production, but also to increase the concrete durability. More recently ground limestone is also used as a filler material to improve the workability and stability of fresh concrete. For a high flowable concrete, such as self-compacting concrete (SCC), limestone filler is added to increase the packing of the granular skeleton, bind (physically) excess water and increase the volume of the continuous phase of lubricating paste. SCC has to possess two incompatible properties: high flowability and high segregation resistance. This balance is made possible by the dispersing effect of high-range water-reducing admixture (superplasticizer) combined with cohesiveness of high concentration of fine particles in additional filler material (Okamura and Ouchi, 2003). The main mechanisms controlling this fine balance are related to surface physics and chemistry; hence SCC is strongly dependent on surface activity of the admixtures together with the high specific surface area generated by the fines (RILEM, 2006). A consequence of the high concentration of powder material and the retarding effect of superplasticizer, the concrete may develop a large autogenous shrinkage and plastic cracking tendency (Hammer et al., 1998). Limestone filler is not pozzolan, but nor fully inert as it reacts with the alumina phases of the cement. If the cement has a significant amount of tricalcium aluminate (C_3A), calcium carboaluminate will be produced from the reaction between calcium carbonate ($CaCO_3$) from the limestone and the C_3A (Bonavetti et al., 2003). This reaction, accelerating the hydration and increasing the compressive strength, increases with the C_3A content of the cement and the fineness and specific surface area of the filler. Since the ratio of surface area to volume increases exponentially with particle irregularity (shape, texture and porosity) and decreased size, and as this area has a predominating effect on fresh and hardened concrete (Esping, 2004), quantification of geometrical properties of fillers and fines is essential.

2.4 Effects of Mineral Admixtures on the Fresh Properties of Concretes

2.4.1 Effects of Fly Ash

The addition of fly ash to concrete has a considerable effect on the properties of fresh concrete. There is agreement that low calcium ashes show some retarding influence on the mix. This may be due to the fact that the cement is becoming more “diluted”.

The well known effects of fly ash on fresh concrete are improvement of workability and pumpability of concrete because of the increase in paste content, increase in the amount of fines, and the spherical shape of the fly ash particles (Figure 2.11). The use of fly ash may retard the time of setting of concrete. This is especially true of Class F fly ashes.

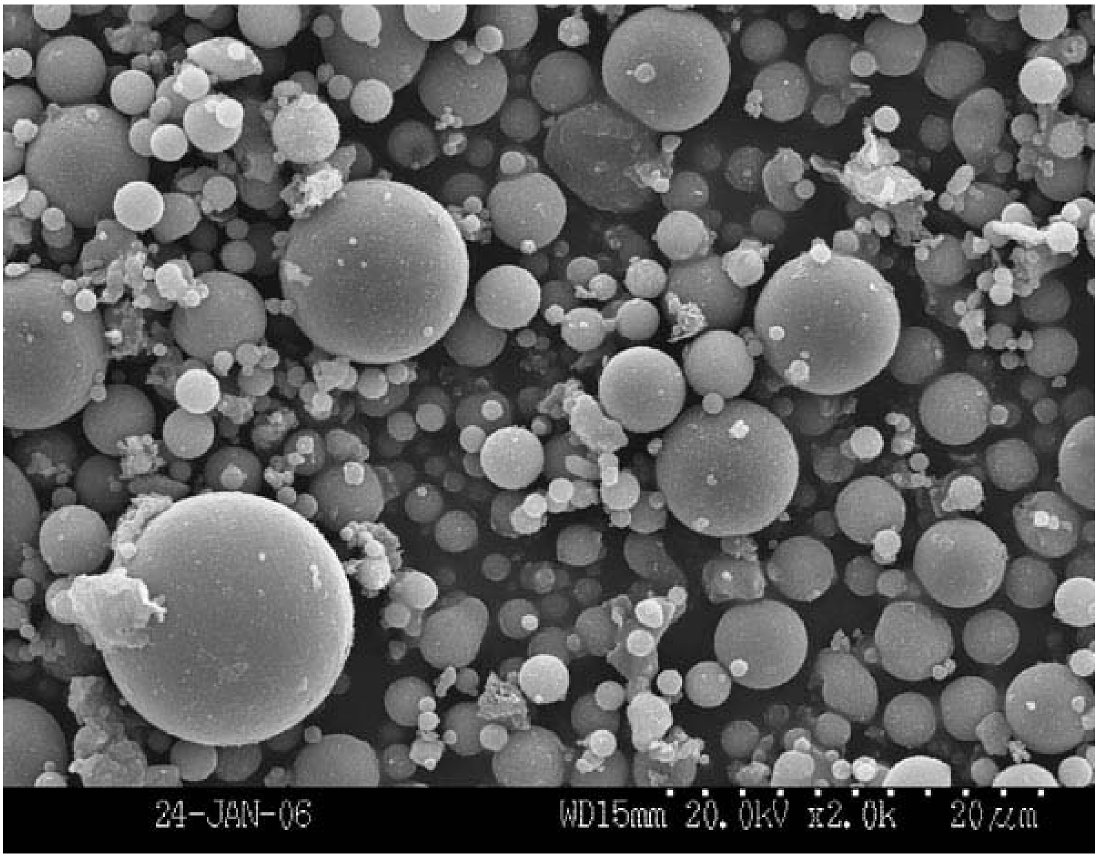


Figure 2.11 Electron microscope image of Class F fly ash 2000x magnification (University of Kentucky, 2006)

Fly ash, in contrast to other pozzolans, reduces the water requirement of a concrete mix. It has been suggested that the major influencing factor in the plasticizing effect of fly ash is the addition of very fine, spherical particles. In fact, it has been shown that as the particle size increases, the plasticizing effect decreases. Bouzoubaa and Lachemi (2001) produced self compacting concrete (SCC) with cement replacement of 40%, 50%, and 60% by Class F fly ash. They shown that incorporating fly ash improved the slump flow diameter and decreased the V-funnel time of SCCs. Besides, the temperature rise of the SCC was 5 to 10 ^{o}C lower than that of the control concrete and the setting times of SCCs were 3 to 4 hours longer than those of the control concrete.

Güneyisi (2010) produced self compacting rubberized concrete (SCRC) incorpareted with fly ash. He observed that FA decreased the amount of superplasticizer used and T_{50}, V-funnel flow times of concretes with respect to concretes without fly ash. And also, use of fly ash decreased the SCRC and prolonged the inintial and final setting times of SCRC (Güneyisi and Gesoğlu, 2008; Güneyisi et al., 2009).

2.4.2 Effects of Marble Powder

Topçu and Bilir (2009) produced self-compacting concrete with cement replacement up to 300 kg/m^3. They demonstrated that filling capability and passing ability were acceptable values of SCC containing up to 200 kg/m^3. In the case of using high volume of stone dust, filling capability and passing ability decreased due to the decrease in segregation resistance.

Marble powder proved to be very effective in assuring very good cohesiveness of mortar and concrete, even in the presence of a superplasticizing admixture, provided that water to cement ratio was adequately low. While combined use of marble powder with portland cement remarkably increased viscosity of self compactin mortars (Güneyisi et al., 2009). On the basis of the low thixotropy values obtained, it seems that the use of marble powder would not be accompanied by an evident tendency to energy loss during concrete placing, as it is usual for other ultra fine mineral additions that are able to confer high cohesiveness to the concrete mixture (Corinaldesi et al., 2002).

2.4.3 Effects of Limestone Filler

Limestone addition decreases the total porosity due to the formation of dense structure, crystallization of highly polymerized calcium silicate hydrate. Because of filler effect of limestone, porosity decreases as limestone ratio increases (Heikal et al., 2000). The physical effect of limestone filler depends on mixture parameters, especially the water/cement and the addition dosage of limestone filler. For a given water/cement and high–range water reducer dosage, the addition of limestone filler within a given range did not affect the fluidity of the mixture. However, when used beyond a critical dosage, the addition of limestone filler resulted in a substantial increase in viscosity. Suitable powder contents to proportion equivalent SCC mortar with adequate fresh properties are established for various w/c. For a w/c of 0.35, suitable powder content (cement + limestone filler) ranges between 23% and 29%, by volume of mortar. In the case of 0.40 and 0.45 w/c mixtures, this range is about 25% to 35% and 23% to 38%, respectively. A mathematical model is proposed and is shown to be reliable in predicting the viscosity of fluid mortar containing a limestone filler and proportioned with a w/c ranging between 0.35 and 0.45 (Yahia et al., 2005).

3. CHAPTER: EXPERIMENTAL STUDY

3.1 Introduction

The aim of the present study is to investigate the effects of different types of mineral admixtures in binary and ternary cementitious blends on fresh properties of self compacting concretes. For this purpose, three mineral admixtures, namely, fly ash, marble powder, and limestone filler were used in the production of SCCs. A total of 14 mixes were prepared at a total binder content of 520 kg/m^3 and at a constant water-binder ratio of 0.35. The fresh properties of self compacting concrete which were determined are slump flow diameter, slump flow time, V-funnel flow time, L-box height ratio, viscosity, and initial and final setting time. The compressive strength of hardened concretes was also tested at 28 days for obtaining strength levels.

3.2 Materials

3.2.1 Cement

The cement used in all mixtures was a normal portland cement CEM-I 42.5 R, which correspond to TS EN 197-1 (2002) manufactured by ÇİMKO Cement Factory was used. The physical properties and the chemical composition of the cement are presented in Table 3.1. Photographic view of the cement used is given in Figure 3.1.

Table 3.1 Physical properties and chemical composition of portland cement

Chemical Analysis (%)	Portland Cement
CaO (%)	63.60
SiO_2 (%)	19.49
Al_2O_3 (%)	4.54
Fe_2O_3 (%)	3.38
MgO (%)	2.63
SO_3 (%)	2.84
K_2O (%)	0.58
Na_2O (%)	0.13
LOI (Loss of Ignition) (%)	2.99
Specific Gravity	3.13
Blaine Fineness (cm^2/g)	3387

3.2.2 Fly Ash

The fly ash (FA) used in this research was a Class F type according to ASTM C 618 (2002) and obtained from Yumurtalik-Sugozu thermal power plant in the form of commercial grade. The chemical analysis of FA is shown in Table 3.2. Photographic view of fly ash used is presented in Figure 3.1.

Table 3.2 Chemical and physical properties of Fly Ash

Chemical Analysis (%)	Fly Ash
CaO (%)	4.24
SiO_2 (%)	56.20
Al_2O_3 (%)	20.17
Fe_2O_3 (%)	6.69
MgO (%)	1.92
SO_3 (%)	0.49
K_2O (%)	1.89
Na_2O (%)	0.58
LOI (Loss of Ignition)(%)	1.78
Specific Gravity	2.25
Blaine Fineness (cm^2/g)	2870

3.2.3 Marble Powder

For production of binary and ternary blends of SCC mixtures, marble powder (MP) which was obtained as a by-product of marble sawing and shaping and having specific gravity of 2.71 gr/cm3. The chemical and physical properties of MP are shown in Table 3.3. Photographic view of marble powder used is shown in Figure 3.1.

3.2.4 Limestone Filler

Limestone filler (LF) from a limestone quarry having specific gravity 2.68 gr/cm^3 was used in this study. Table 3.3 shows the chemical and physical properties of FA. Photographic view of limestone filler used is given in Figure 3.1.

Table 3.3 Chemical and physical properties of MP and LF

Chemical analysis (%)	Marble Powder	Limestone Filler
CaO (%)	52.45	55.07
SiO_2 (%)	1.29	0.22
Al_2O_3 (%)	0.39	0.18
Fe_2O_3 (%)	0.78	0.44
MgO (%)	0.54	0.34
SO_3 (%)	-	-
K_2O (%)	0.11	0.11
Na_2O (%)	-	-
LOI (Loss of Ignition) (%)	43.90	42.86
Specific Gravity	2.71	2.68
Blaine Fineness (cm^2/g)	5190	3990

Figure 3.1 Photographic view of mineral admixtures and cement. From left to right; fly ash, limestone filler, marble powder, and portland cement

3.2.5 Aggregates

The coarse aggregate used was river gravel with a nominal particle size of 16 mm in order to avoid the blocking effect of aggregate. As fine aggregate, the mixture of natural river sand and crushed limestone was used with a nominal particle size of 5 mm. The particle size gradation obtained through the sieve analysis and physical properties of the fine and coarse aggregates are presented in Table 3.4. Aggregate grading curve and zone is given in Figure 3.2.

Table 3.4 Sieve analysis and physical properties of the fine and coarse aggregates

Sieve Size (mm)	Fine Aggregate		Coarse Aggregate
	River Sand	Crush Sand	
16	100	100	100
8	100	100	31.5
4	86.6	95.4	1.0
2	56.7	63.3	0.5
1	37.7	39.1	0.5
0.5	25.7	28.4	0.5
0.25	6.7	16.4	0.4
Fineness Modulus	2.87	2.57	5.66
Specific Gravity	2.66	2.45	2.72

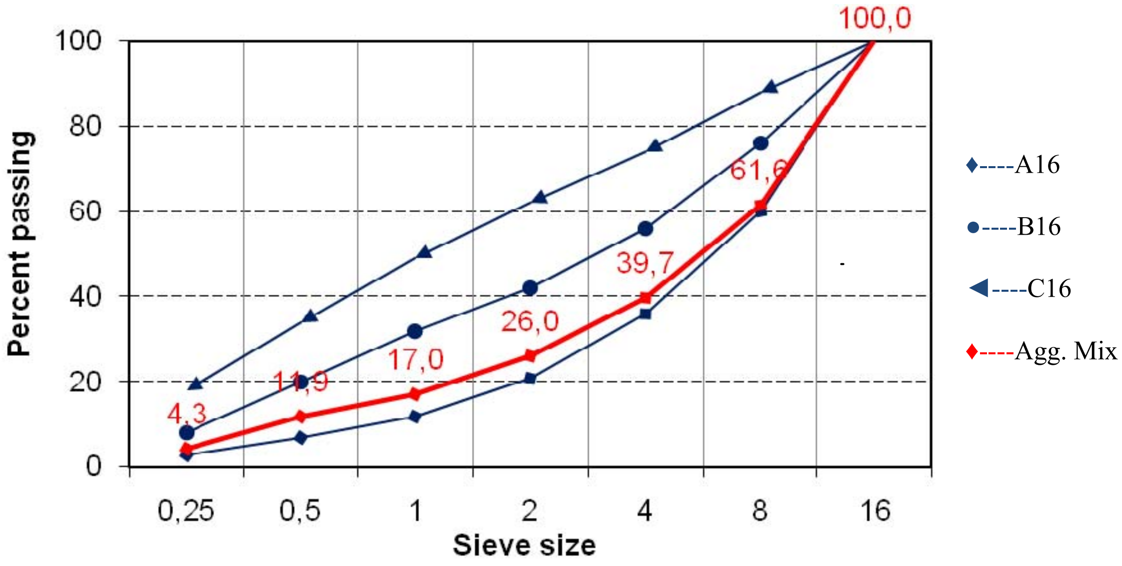


Figure 3.2 Aggregate grading curve and zones

3.2.6 Superplasticizer

A polycarboxylic-ether type superplasticizer (SP) with a specific gravity of 1.07 and pH of 5.7 was used in all mixtures. The properties of superplasticizer are given in Table 3.5 as reported by the local supplier.

Table 3.5 Properties of superplasticizer

Properties	Superplasticizer
Name	Glenium 51
Color Tone	Dark Brown
State	Liquid
Specific Gravity	1.07
Chemical Description	Modified polycarboxylic type of polymer

3.3 Concrete Mixtures

3.3.1 Concrete Mixture Proportioning

A total of 14 SCC mixtures were designed at 0.35 water/binder ratio (w/b). In the design of first group concretes, enumerated from M1 to M14 given in Table 3.6. The plain concrete, considered as reference, was made of only portland cement (PC) as the binder while the remaining mixtures incorporated binary (PC+FA, PC+MP, PC+LF), ternary (PC+FA+MP, PC+FA+LF) blends in which the mineral admixtures were used as replacement materials by weight of cement. A constant replacement level of 30% by total weight of binder content was considered for FA, while the various levels (5, 10, and 20%) were assigned for MP and LF replacement. Details of the concrete mixture proportioning are given in the Table 3.6.

Table 3.6 Concrete mixture proportioning at a w/b ratio of 0.35

Mix ID	Mix Description	Mix System	W/B	Water [kg/m^3]	Binder [kg/m^3]	PC [kg/m^3]	FA [kg/m^3]	M [kg/m^3]	LF [kg/m^3]	Natural sand [kg/m^3]	Crushed sand [kg/m^3]	Coarse aggregate [kg/m^3]	Superplasticizer [kg/m^3]
M1	PC	Control	0.35	182	520	520	0	0	0	533	184	953	12.8
M2	5M	Binary	0.35	182	520	494	0	26	0	532	184	951	13.9
M3	10M	Binary	0.35	182	520	468	0	52	0	531	183	949	15.1
M4	20M	Binary	0.35	182	520	416	0	104	0	528	182	945	15.8
M5	5LF	Binary	0.35	182	520	494	0	0	26	531	183	950	13.0
M6	10LF	Binary	0.35	182	520	468	0	0	52	529	183	947	14.6
M7	20LF	Binary	0.35	182	520	416	0	0	104	526	182	941	14.9
M8	30FA	Binary	0.35	182	520	364	156	0	0	516	178	923	4.5
M9	30FA5M	Ternary	0.35	182	520	338	156	26	0	515	178	921	7.0
M10	30FA10M	Ternary	0.35	182	520	312	156	52	0	514	177	919	8.5
M11	30FA20M	Ternary	0.35	182	520	260	156	104	0	511	177	915	10.0
M12	30FA5LF	Ternary	0.35	182	520	338	156	0	26	514	178	920	5.5
M13	30FA10LF	Ternary	0.35	182	520	312	156	0	52	512	177	917	6.0
M14	30FA20LF	Ternary	0.35	182	520	260	156	0	104	509	176	910	6.7

3.3.2 Concrete Casting, Test Specimens and Curing

In the production of SCC, the mixing sequence and duration are so important that the procedure for batching and mixing proposed by Sonebi et al. (2002) was employed to supply the same homogeneity and uniformity in all mixtures. The batching sequence consisted of homogenizing the fine and coarse aggregates for 30 sec in a rotary planetary mixer (Figure 3.3), then adding about half of the mixing water into the mixer and continuing to mix for one more minute. Thereafter, the aggregates were left to absorb the water in the mixer for one minute. After cement and mineral additives were added, the mixing was resumed for another minute. Finally, the SP with remaining water was introduced, and the concrete was mixed for 3 min and then left for 2 min rest. Eventually, the concrete was mixed for additional two minutes to complete the mixing sequence. The concretes were designed to give a slump flow of 70 ± 3 cm which was achieved by using the superplasticizer at varying amounts. For this, trial batches were produced for each mixture till the desired slump flow was obtained by adjusting dosage of superplasticizer by trial-error.

Figure 3.3 The standard mixer used

After the mixing procedure was completed, fresh state tests were conducted on the SCC to determine slump flow time and diameter, Brookfield rheometer for determination of viscosity V-funnel flow time, L-Box height ratio, ELE penetration resistance instrument used for determining initial and final setting times, unit weight, and viscosity. Segregation and bleeding were also visually checked during the slump flow test. To determine the mechanical properties of SCC, the compressive strength test at 28 days were conducted. Test specimens were all cast without any compaction and vibration. After casting and surface finishing, all of the specimens were covered with plastic sheet and kept in laboratory for 24 hours. Then, demoulded and stored in water (23±2 ^{o}C) for curing until testing day. The compressive strengths of SCCs were in the range of 44-64 MPa.

3.3.3 Specimen Preparation

All concretes were mixed in accordance with ASTM C 192 standard using power-driven revolving pan mixer. For determination of initial and final setting time 14 mixtures prepared and casted all in one day. Each mixture sieved to 100x100x100 mm cube mortar in order to measure initial and final setting times of SCCs conforming ASTM C/C 403M-99. Furthermore, a 0.5 liter beaker mortar was obtained by sieving SCC for viscosity determination.

Process of SCC production are:

- PC, minerals, water, aggregates and SP were measured according to mix design rates. Water and SP were divided to two part in 1/3 rate and 2/3 rate.
- Aggregates were poured and mixed homogenously in concrete mixer and water with superplasticizer in 1/3 rate were added and mixed again.
- Cement and mineral admixtures were added and mixed again.
- Water with superplasticizer in 2/3 rate were added and mixed again.
- Slump test were realized if test results are capable. In other case superplasticizer rates can be increased or decreased according to slump flow diameter and process should be renewed.

- V-funnel and L-box tests were realized.
- Weight of empty cube was measured and filled with concrete and measured again for density measurement.
- Cubes were filled for setting time tests. And also concrete and weather temperature was measured.

3.4 Test for Fresh Properties

3.4.1 Slump Flow

In this study, the slump flow of all the mixtures was kept constant at about 70±3 cm whilst the slump flow time (T_{50}) was measured. This test made according to EFNARC (2002) test methods. To measure the slump flow, an ordinary slump flow cone (EN 12350-2) is filled with self compacting concrete without any compaction and leveling. The cone is lifted and the average diameter of the spreading concrete is measured as shown on the Figure 3.4 and Figure 3.5. And also, the time (T_{50}) recorded for the concrete to reach the 500 mm

Figure 3.4 Photographic view of slump flow test

Figure 3.5 Photographic view of slump flow diameter measurement

3.4.2 V-Funnel Flow Time

The V-funnel flow test for SCC is also was made like described in EFNARC (2002) (Figure 3.6). The flow time is determined in this test. The funnel completely filled with fresh SCC without any compacting or tamping, and the flow time (t) is measured as the time between the opening of bottom outlet and complete emptying of the funnel that light is seen from above through the funnel.

(a) Front view of V-funnel (b) Top view of V-funnel

Figure 3.6 Photographic view of V-funnel flow time measurement

3.4.3 L-Box Height Ratio

The L-box test consists of L-shaped apparatus. The vertical section is filled with concrete, and then the gate is lifted to let the concrete flow into the horizontal section (Figure 3.7). When the flow has stopped, the height of concrete flow into the horizontal section is expressed as a proportion of that remaining in the vertical section. It shows the slope of the concrete when at rest. This is an indication of passing ability. The horizontal section of the box can be marked at 200 mm and 400 mm from the gate and the times taken to reach these points measured These are known as T_{200} and T_{400} times and are an indication for the filling ability.

Figure 3.7 Photographic view of filled L-box

3.4.4 Viscosity

Viscosity of SCC was measured on the mortar phase of the SCC. For this, a part of fresh concrete for each mix was wet sieved on a vibrating sieve through a mesh size of 5 mm size. The separated matrix mortar was then taken as the sample for determination of viscosity (Xing and Isamu, 2004). Viscosities of SCCs were measured by a Brookfield DV-II+Pro viscometer at 0 min (Figure 3.8). It is a rotational viscometer with a smooth-walled concentric cylinder. Firstly, the sieved mortar was poured into the pot of the viscometer. After this initial preparation, viscosity measurements were performed at a full cycle of increasing rotational speed by 7 steps from 1.0 to 100 rpm (1, 2.5, 5, 10, 20, 50, and 100).

Figure 3.8 Photographic view of Brookfield DV-II+Pro viscometer and viscosity measuring

3.4.5 Setting Time

Initial setting time and the hardness development of SCC was determined by the setting time apparatus shown in Figure 3.9. This test procedure was in accordance with ASTM C403/ C403M-99. Setting time was measured on the mortar phase of the SCC. The mortar was obtained by sieving fresh SCC through a 5 mm sieve in the case the viscosity measurement. The mortar is discharged to a 10 x 10 cm cubic mold and stored at 20±2°C temperature and 65±5% relative humidity throughout the test duration (Figure 3.10). At regular intervals, the resistance of mortar to penetration by a standard needle is measured. From a plot of penetration resistance versus elapsed time, the initial and final setting time is determined through interpolation as shown in Figure 3.11. The former and the latter are defined as the times at which the penetration resistance reaches values of 3.5 and 27.6 MPa, respectively.

Figure 3.9 Photographic view of setting time apparatus and measurement of setting time

Figure 3.10 Photographic view of cubic (10x10x10) molds

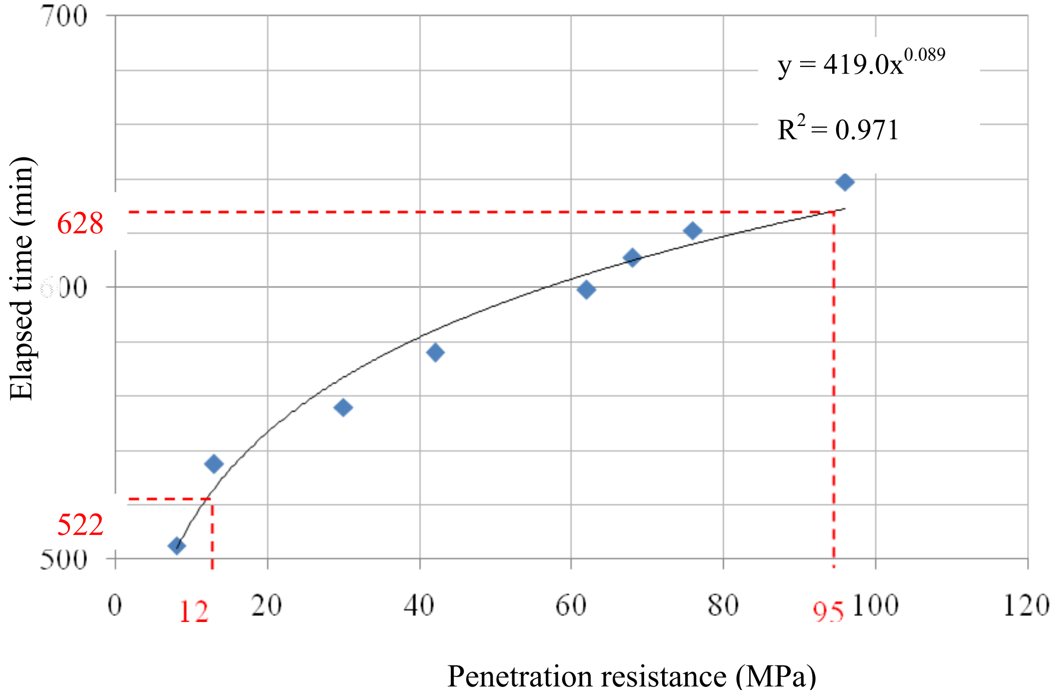


Figure 3.11 Plot of penetration resistance values versus elapsed time and fit curve used to determine time of setting

4. CHAPTER: TEST RESULTS AND EVALUATION

4.1 Fresh Concrete Properties

To classify a concrete as SCC, the requirements for filling, passing and segregation resistance must be fulfilled in order to provide the ease of flow when unconfined by formwork or reinforcement and an ability to remain homogeneous in fresh state. It is specified that the filling ability and stability of self-compacting concrete in the fresh state can be defined by four key characteristics namely flowability, viscosity, passing ability, and segregation resistance (EFNARC, 2002). The evaluations of the fresh properties of the concretes were carried out according to the limitations specified by EFNARC (2005). Limits are given in Table 4.1. The variations in slump flow time (T_{50}), slump flow diameter, and V-funnel flow time for the concrete mixtures of binary, and ternary systems investigated in this study were illustrated in Table 4.2. T_{200} and T_{400} times to be taken for the mixture to reach a distance of 200 and 400 mm along the horizontal section from the sliding door of the L-box were also given in Table 4.2. T_{200} and T_{400} times were observed as an indication filling ability.

Table 4.1 Slump flow, viscosity, and passing ability classes with respect to EFNARC (2005)

Slump flow classes		Viscosity classes			Passing ability classes	
Class	Slump flow diameter (mm)	Class	T_{50} (sec)	V-funnel time (sec)	PA1	≥ 0.8 with two rebar
SF1	550-650	VS1/VF1	≤ 2	≤ 8	PA2	≥ 0.8 with three bar
SF2	660-750	VS2/VF2	> 2	9 to 25		
SF3	760-850					

Table 4.2 Fresh properties of SCC

Mix No	Mix ID	L-Box			Unit Weight	V-Funnel	Slump Flow	
		H2/H1	T_{200} (sec)	T_{400} (sec)	(kg/m^3)	t_v (sec)	T_{50} (sec)	D (cm)
M1	CONTROL PC	0.61	7.0	15.0	2529	11.3	3.8	70.0
M2	5M	0.60	6.5	19.4	2534	25.0	3.5	66.0
M3	10M	0.69	8.2	19.7	2518	23.2	4.4	68.0
M4	20M	0.78	6.2	17.2	2491	25.9	4.5	66.8
M5	5LF	0.82	9.2	23.6	2519	17.0	3.4	67.0
M6	10LF	0.74	10.0	32.2	2487	16.3	3.2	65.5
M7	20LF	0.79	8.0	24.0	2526	19.5	3.4	67.5
M8	30FA	0.91	3.8	9.20	2455	11.6	2.9	72.0
M9	30FA5M	0.84	1.8	5.40	2430	16.0	2.6	68.0
M10	30FA10M	0.86	3.0	13.0	2465	17.0	2.6	69.0
M11	30FA20M	0.79	4.8	11.2	2475	17.5	2.5	68.0
M12	30FA5LF	0.85	4.6	11.2	2499	12.0	2.6	67.0
M13	30FA10LF	0.90	5.4	15.6	2516	14.8	2.4	69.0
M14	30FA20LF	0.87	3.8	10.2	2463	15.4	2.3	72.0

4.1.1 Slump Flow Diameter and Slump Flow Time

In order to keep the slump flow diameters for all mixtures within the range of 700±50 mm, trial batches were produced to adjust the amount of superplasticizer for each mixture throughout the study. It was observed that using MP and LF in all of the mixtures resulted in increased amount of superplasticizer to achieve the target slump flow diameter (Table 3.6). For same replacement levels, MP incorporated concretes required higher superplasticizer in both binary and ternary systems, owing to its greater fineness. However, with the inclusion of FA in ternary mixtures, the amount of superplasticizer required remarkably decreased due to the viscosity modifying property of FA. Figure 4.1 shows the slump flow diameter of SCCs produced in the study. It was seen that all of the mixtures were conformed SF2 class in terms of slump flow according to the EFNARC (2005). Such concretes may be applied to construction of various normal structural members.

As seen in the Figure 4.2 that slump flow times of all concretes were within the range of 2-5 sec. While the mixture 30FA20LF had the lowest slump flow time, the highest was measured for 20M mixture. LF included concretes had lower T_{50} slump flow times than the concretes with MP, irrespective of the FA incorporation and replacement level. The slump flow times of concrete mixtures including FA were relatively lower than the others.

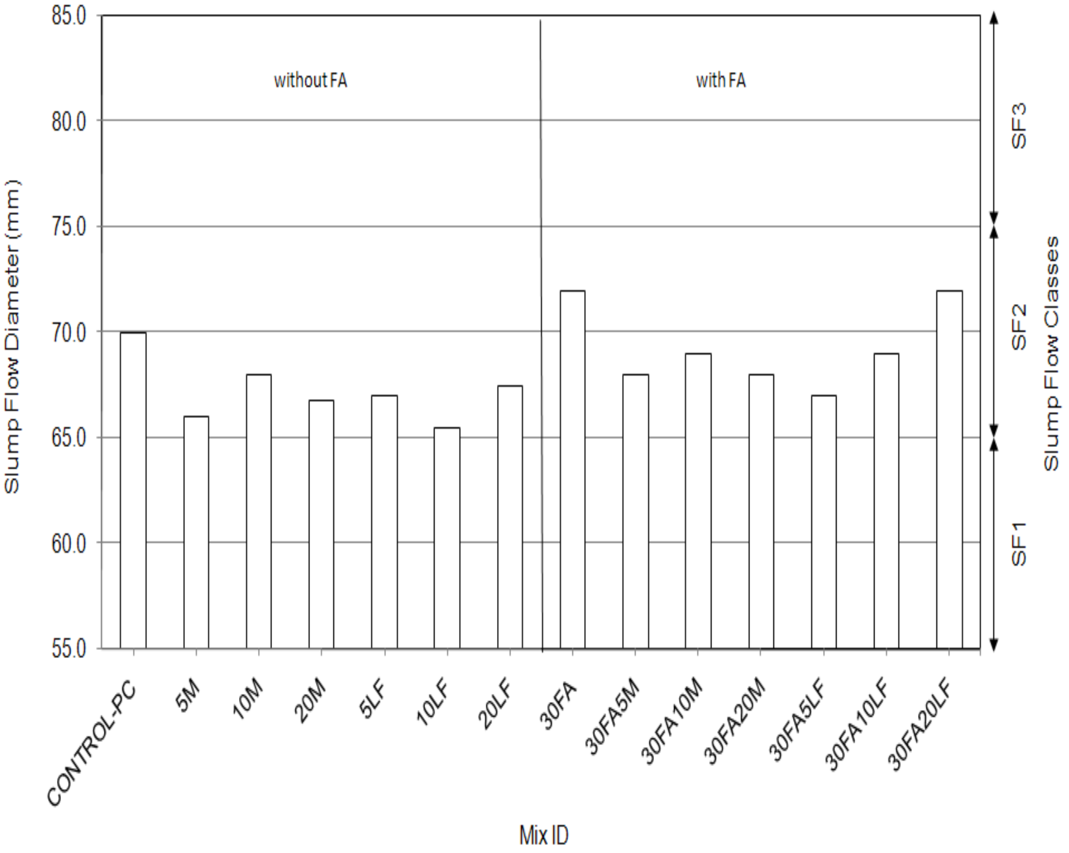


Figure 4.1 Variation of slump flow diameter and slump classes with marble powder, limestone filler content and inclusion of fly ash

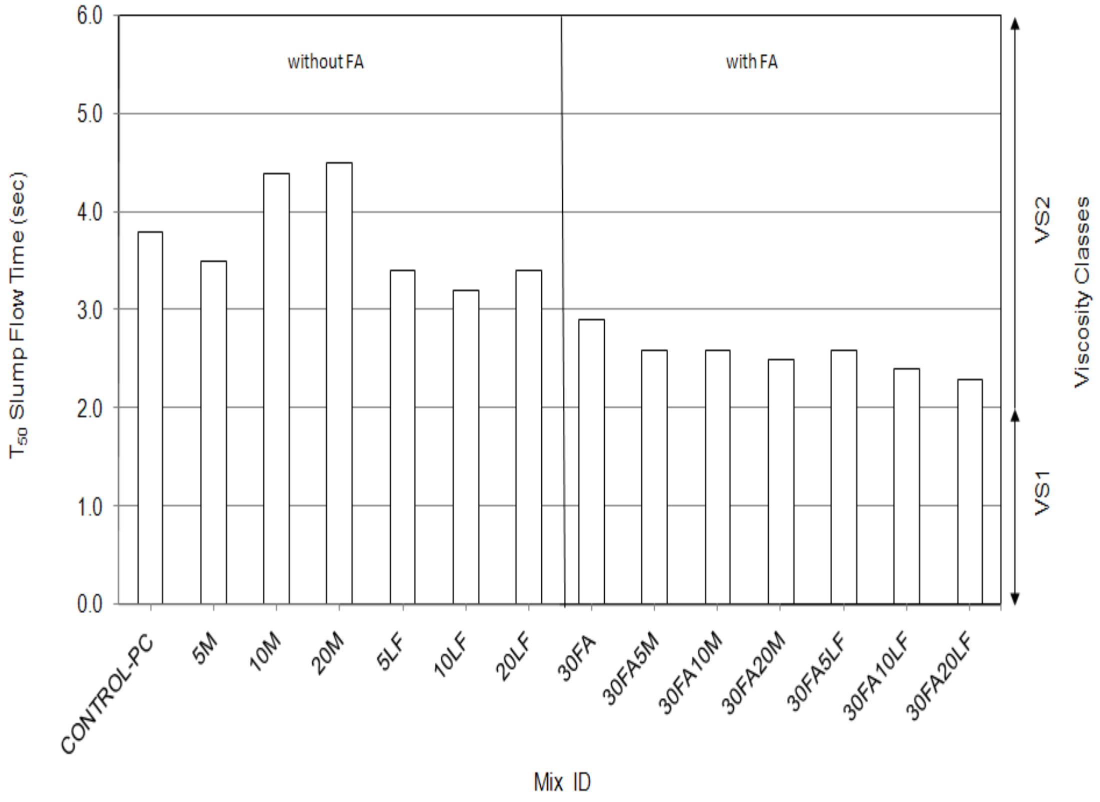


Figure 4.2 Variation of T_{50} slump flow time and viscosity classes with marble powder, limestone filler contents and inclusion of fly ash

4.1.2 V-Funnel Flow Time

In Figure 4.3, V-funnel flow times were presented as indicators for viscosity of SCCs like slump flow times (T_{50}). Moreover, Figure 4.4 was additionally prepared to indicate the relation between slump flow time and V-funnel flow time for the assessment of the viscous behaviors of SCCs. Figure 4.3 demonstrates that, all of the mixtures, except 20M, investigated in this study were classified as VF2 according to EFNARC (2005), in terms of viscosity. Nevertheless, observing Figure 4.4, we can see that mix 20M is quite close to the upper limit of VS2/VF2 class.

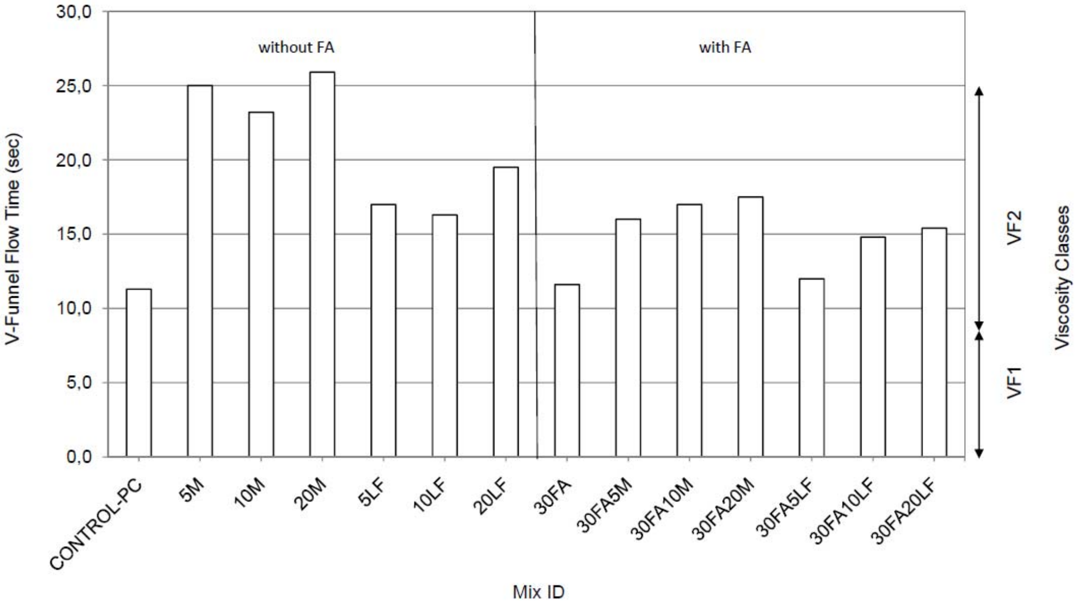


Figure 4.3 Variation of V-funnel flow time and viscosity classes with marble powder, limestone filler contents and inclusion of fly ash

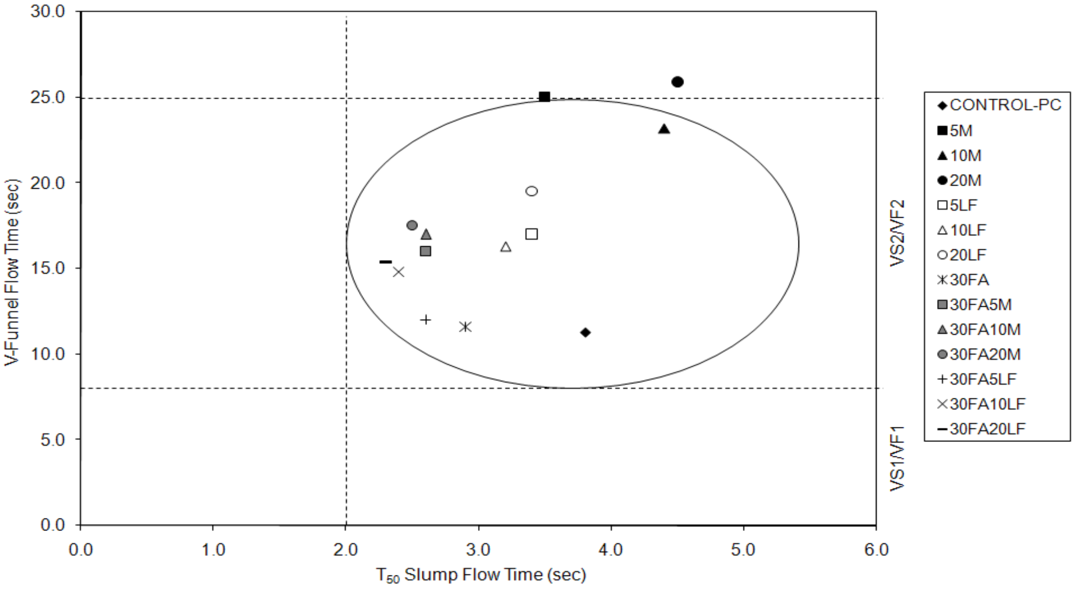


Figure 4.4 Variation of viscosity classes with T_{50} slump flow and V-funnel flow times

4.1.3 L-Box Height Ratio, T_{200} and T_{400} Times

The L-box height ratio (H_2/H_1) and flow times to reach 200 mm and 400 mm at horizontal section of L-box (T_{200}, T_{400}) were given in Figs. 4.5-4.6, in order to asses the passing ability and self compactibility of concretes through confined spaces. Passing ability classes according to the L-box height ratio values was also given in Table 4.2. The L-box height ratios were between 0.60-0.82 for binary and 0.79-0.91 for ternary SCC mixtures. The concretes having L-box height ratio between 0.8 and 1.0 is classified as PA2 in terms of passing ability (Table 4.2). So, in binary mixtures, only 5LF can be classified in this category. However, it was clearly observed that almost all of the concretes, except 30FA20M, satisfied the EFNARC (2005) limitation in terms of L-box height ratio to be classified as PA2.

In binary mixtures, T_{200}, and T_{400} values were increased by increasing the amount of filler, but, at 20% level of replacement for both LF and MP (20LF and 20M), these values were decreased. T_{400} times in ternary mixtures were relatively less than that of binary mixtures. In ternary systems, due to the incorporation of FA, easier flow through reinforcement within relatively shorter time was observed. Having spherical shape particles with smooth surface texture, FA has lubricating effect in fresh SCC's fresh state to modify the viscosity.

Therefore the concretes without FA did not fulfill the EFNARC limitatition. However, using FA increased H_2/H_1 ratio so that, almost all of the concretes with FA satisfied the EFNARC (2005) limitation in terms of L-box ratio to be classified as PA2.

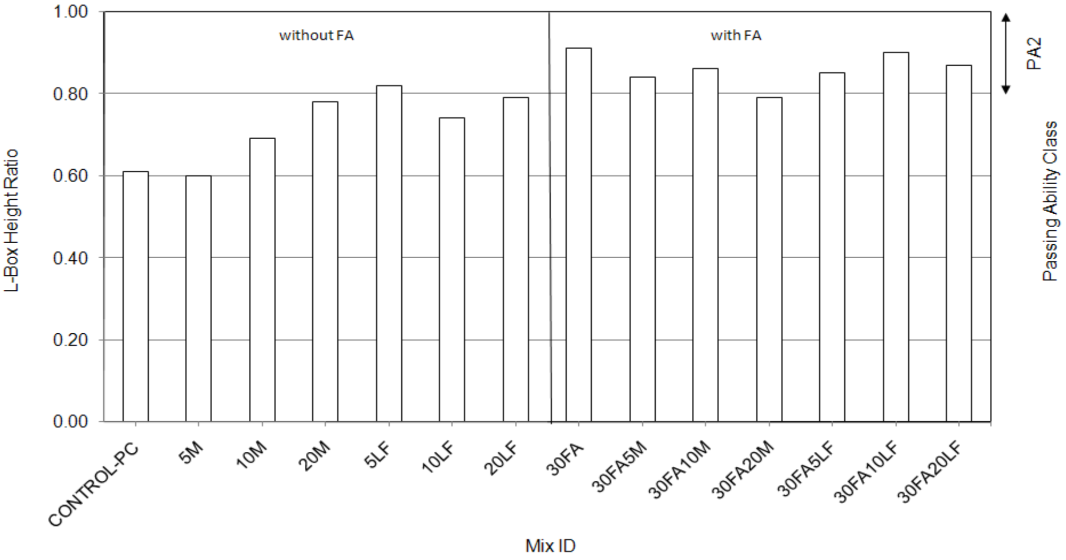


Figure 4.5 Variation of L-box height ratio and passing ability class with marble powder, limestone filler contents and inclusion of fly ash

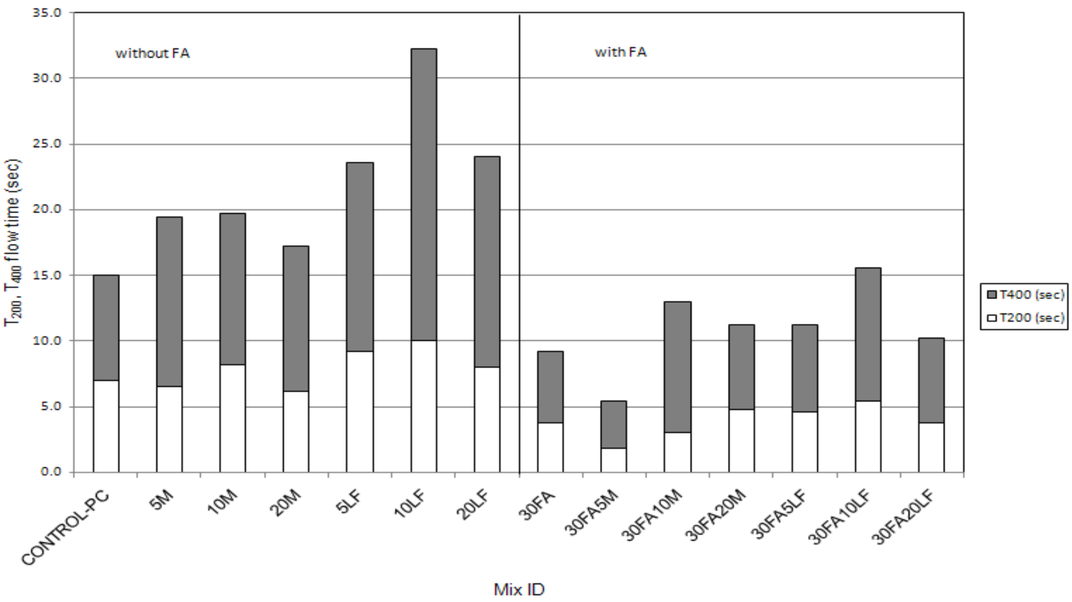


Figure 4.6 Variation of T_{200} and T_{400} L-box flow times with marble powder, limestone filler contents and inclusion of fly ash

4.1.4 Initial and Final Setting Times

Figure 4.7 shows the effect of LF and MP contents on the initial and final setting times for the fresh SCCs with or without FA. It is known that the inclusion of FA causes retardation of initial and final setting times of concretes (Güneyisi, 2010).

In the same line with the literature, both initial and final setting times of the ternary blends of SCC were greater than those of the binary system. The initial setting times of binary and ternary mixtures ranged from 276 to 505, and 480 to 620 min. respectively, while final setting times within the range of 386 to 674, and 670 to 790 min. respectively.

It was observed in Figure 4.7 that increasing the quantity of filler substitution resulted in the systematic rise of both initial and final setting times of binary mixtures. Nevertheless, considering the fluctuations presented in Figure 4.7, there is not a clear proportionality between the magnitudes of percent replacement levels of MP and the variations in setting times of ternary system mixtures.

The highest initial and final setting times (620 and 790 min.) were measured for 30FA20LF, while the lowest values belonged to the Control mix (276 and 386 min.). The influence of LF on prolong the setting times of the mixtures was generally more pronounced than MP when considering the both binary and ternary mixtures.

Table 4.3 Setting time results of SCC

Mix No	Mix ID	Initial Set	Final Set
M1	CONTROL-PC	276	386
M2	5M	344	462
M3	10M	354	478
M4	20M	419	534
M5	5LF	394	492
M6	10LF	503	656
M7	20LF	505	674
M8	30FA	480	686
M9	30FA5M	491	670
M10	30FA10M	556	703
M11	30FA20M	512	655
M12	30FA5LF	522	680
M13	30FA10LF	558	785
M14	30FA20LF	620	790

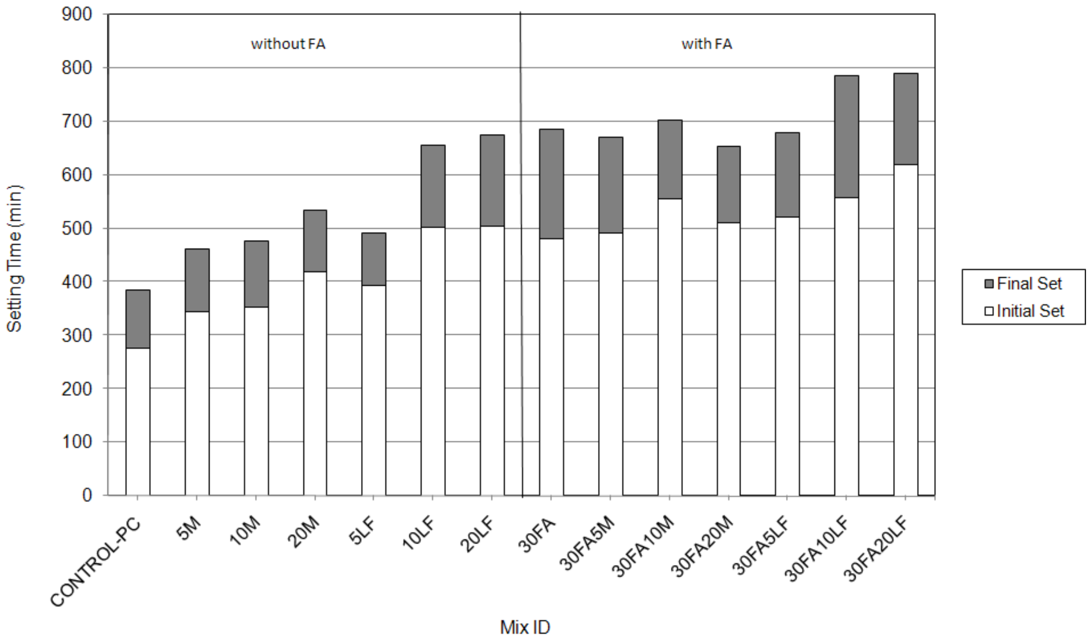


Figure 4.7 Initial and final setting times of SCC with respect to the composition

4.1.5 Viscosity

Variations in the viscosity of SCCs with respect to the rotational speed (revolution/minute), LF and MP contents are plotted in Figure 4.8a and 4.8b for the binary and ternary systems, respectively. Moreover, the data obtained from the viscosity test are given in Table 4.4.

It was found that the inclusion of MP or LF increased the viscosity of concretes with binary systems when compared to the control concrete. However, introduction of FA to concretes in ternary systems remarkably decreased the viscosity as seen in Figure 4.8b. Almost none of the concretes with MP or LF alone had viscosity fell between control and 30FA concretes (Figure 4.8a). On the other hand all of the ternary mixtures, had viscosity values ranging between control and 30FA concretes (Figure 4.8b).

The variations in viscosity of the mixtures containing MP were mainly depended on the replacement level of this filler in both binary and ternary systems. Higher the amount of MP used, the more the viscosity of the mortar observed. The same tendency was observed in the case of binary mixtures with LF, whereas in ternary blends of mixtures the effect of replacement level almost disappeared.

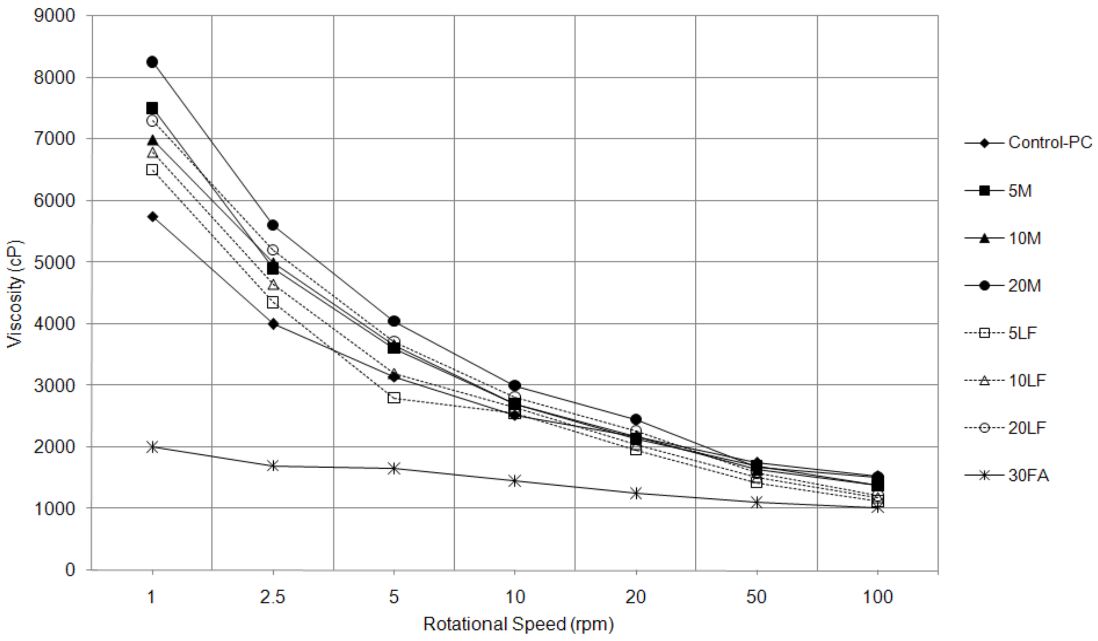
Table 4.4 Viscosity results of SCC with (a) without fly ash and (b) with fly ash

(a) Without fly ash

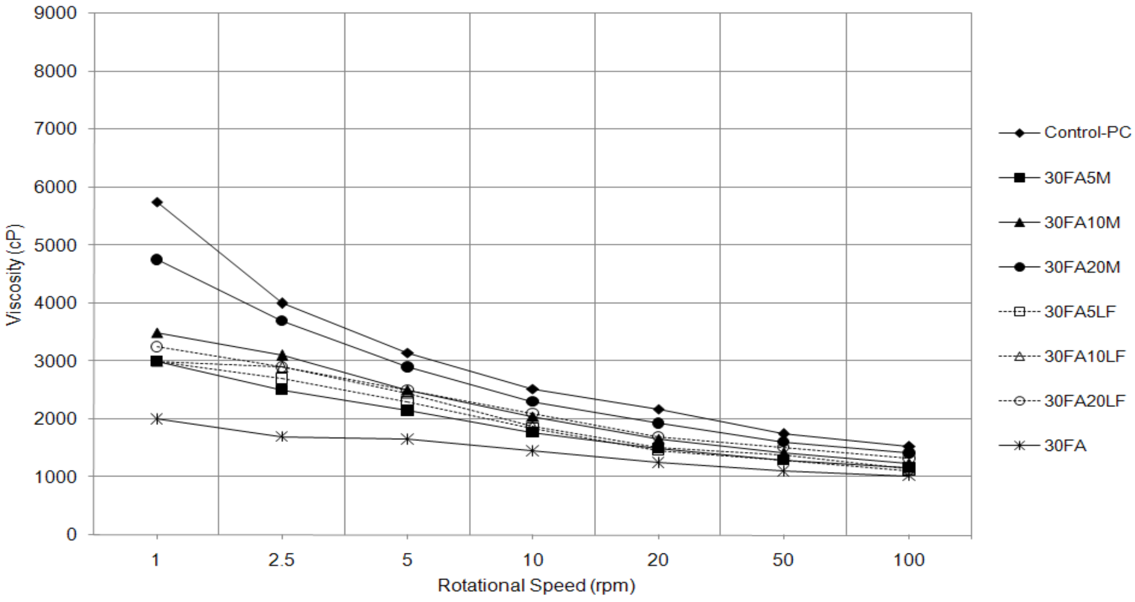
SPEED rpm	Control-PC	5M	10M	20M	5LF	10LF	20LF
1	5750	7500	7000	8250	6500	6800	7300
2.5	4000	4900	5000	5600	4350	4650	5200
5	3150	3600	3650	4050	2800	3200	3720
10	2525	2700	2700	3000	2550	2650	2810
20	2175	2138	2175	2450	1950	2050	2270
50	1745	1700	1635	1680	1420	1510	1580
100	1525	1375	1375	1505	1120	1180	1210

(b) With fly ash

SPEED rpm	30FA	30FA5M	30FA10M	30FA20M	30FA5LF	30FA10LF	30FA20LF
1	2000	3000	3500	4750	3000	3000	3250
2.5	1700	2500	3100	3700	2700	2900	2900
5	1650	2150	2500	2900	2300	2450	2500
10	1450	1775	2050	2300	1850	1875	2100
20	1250	1500	1663	1925	1462	1513	1700
50	1100	1300	1415	1610	1300	1380	1520
100	1015	1170	1245	1415	1115	1150	1320



a) Binary



b) Ternary

Figure 4.8 Viscosity of SCC with a) Binary and, b) Ternary blends of mixtures at different rotational speeds

5. CHAPTER: CONCLUSIONS

Two series of self compacting concretes having various compositions of additives were produced and fresh state tests were applied to determine the influence of the type and amount of the substituting fillers as well as use of FA. Based on the findings of the current study, the following conclusions may be drawn:

1. Use of MP and LF resulted in an increase in the dosage of the superplasticizer in order to keep a constant range of slump flow. However, addition of the FA has remarkably decreased the amount of superplasticizer. Utilization of FA also provided a prominent benefit in terms of cost of SCC, due to the reduction in amount of cement and superplasticizer.

2. Slump flow times of all concrete mixtures were measured to be within the range of 2-5 seconds. Increasing the amount of filler, irrespective of the type, generally increased the duration to reach 50 cm (T_{50}) in slump flow test. All of the mixtures dealt with in this study were classified as SF2 in terms of slump flow class.

3. Same trend was also observed in V-funnel flow times of the fresh SCC. 20M mixture was slightly exceeded the upper limit of VF2 class. LF incorporated mixes showed lower flow times than that of MP mixes. This situation can be attributed to the differences in fineness of the fillers. Ternary blends of mixtures, due to the inclusion of FA, had relatively less flow times.

4. Almost all of the L-box height ratios of the binary mixes were less than 0.8, whereas all of the ternary mixes, except 30FA20M, were between 0.8 and 1.0 and classified as PA2 in terms of passing ability class.

5. The increase in the amounts of MP and LF increased the viscosity of both binary and ternary mixtures. It was notified that the addition of FA to concretes in ternary systems, provided decrease in the viscosities of the mixtures when comparing to binary mixtures.

6. Since use of the fillers requires the increase in the amount of superplasticizer and decreases the amount of cement, addition of these materials increased the initial and final setting times of SCC in comparison to control and 30FA reference mixes.

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