EFFECT OF CHEMICAL AND MINERAL ADMIXTURES ON THE FRESH PROPERTIES OF SELF COMPACTING MORTARS

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ABSTRACT

EFFECT OF CHEMICAL AND MINERAL ADMIXTURES ON THE FRESH PROPERTIES OF SELF COMPACTING MORTARS

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Fresh properties of mortars are important factors in altering the performance of self compacting concrete (SCC). Measurement of the rheological properties of the fine mortar part of concrete is generally used in the mix design of SCC. It can be stated that SCC rheology can be optimized if the fine mortar part of concrete is designed properly. However, measurement of the rheological properties is often impractical due to the need for complex equipment. Therefore, more practical methods of assessing mortar workability are often preferred.

In this study, four mineral admixtures, three superplasticizers (SP) and two viscosity modifying admixtures (VMA) were used to prepare self compacting mortar (SCM). The mineral admixtures included fly-ash, brick powder, limestone powder, and kaolinite. Two of the SPs were polycarboxylate based and another one was melamine formaldehyde based. One of the viscosity modifying admixtures was based on an aqueous dispersion of microscopic silica and the other one was based on high molecular weight hydroxylated polymer.

Within the scope of the experimental program, 43 mixes of SCM were prepared from different materials with keeping the amount of mixing water constant. Workability of the fresh mortar were determined using V - funnel and slump flow tests. The setting time of the mortars, were also determined. The hardened properties

that were determined included the ultrasonic pulse velocity (UPV) and the strength which was determined at 7, 28, and 56 days.

It was concluded that among the mineral admixtures used, only fly-ash and limestone powder increased the workability of the mixes. The two polycarboxylate based SPs yield approximately the same workability and the melamine formaldehyde based SP was not as effective as the other two.

Keywords: Self compacting concrete, self compacting mortar, chemical and mineral admixture, slump flow test, v-funnel test, ultrasonic pulse velocity.

ÖZ

KİMYASAL VE MİNERAL KATKILARIN KENDİLİĞİNDEN YERLEŞEN HARÇLARIN TAZE ÖZELLİKLERİ ÜZERİNDEKİ ETKİLERİ

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Kendiliğinden yerleşen betonlarda (KYB) aranan özellikleri etkileyen önemli faktörlerden biri harçların taze özelliğidir. Bu nedenle KYB'lerin karışım hesaplarına harçların reolojik özellikleri üzerinde yapılan testler sonucunda karar verilmektedir. Bu testler ise karmaşık deney aletleri içerdiği için çoğunlukla yapılamamakta ve bunun yerine harçların işlenebilirliğini tahmin etmeye yarayan daha basit deneyler tercih edilebilmektedir.

Bu çalışmada, dört farklı mineral katkı, üç farklı süperakışkanlaştırıcı katkı ve iki farklı viskozite iyileştirici katkı kullanılarak, kendiliğinden yerleşen harç üretilmiştir. Mineral katkı olarak, uçucu kül, tuğla tozu, kalker tozu ve kaolin kullanılmıştır. Süperakışkanlaştırıcı katkı olarak, iki polikarboksilik bazlı ve biri naftalin formaldehid bazlı olmak üzere üç farklı katkı kullanılmıştır. Viskozite iyileştirici katkı olarak ise mikroskobik silika bazlı ve yüksek moleküler ağırlıklı hidroksil polimer bazlı iki farklı katkı kullanılmıstır.

Bu deneysel çalışmada, yukarıda isimleri verilmiş mineral ve kimyasal katkılar değişik oranlarda kullanılarak 43 ayrı kendiliğinden yerleşen harç üretilmiştir. Tüm karışımlardaki toplam su miktarı eşit tutulmuştur. Harçların işlenebilirliklerinin tespiti için, yayılma testi (akma gerilmesi ile ilintili olarak kendiliğinden yerleşme kabiliyeti) ve V-hunisi (viskozite ile bağlantılı olarak huniden boşalma süresi)

deneyleri yapılmıştır. Ayrıca farklı katkı maddelerinin betonun priz süresine etkilerini tespit edebilmek amacıyla tüm karışımların priz süreleri ölçülmüştür. Betonun sertleşmiş özelliklerini ölçmek amacıyla tüm karışımlarda, 7, 28 ve 56 günlerde ultrasonik ses hızları tesbit edilmiştir.

Sonuç olarak incelenen mineral katkılarından uçucu kül ve kalker tozunun harçların işlenerbilirliğini artırdıkları gözlemlenmiştir. İki karboksil bazlı katkı diğerine göre betonun işlenebilirliğini daha iyi artırmıştır.

Anahtar Kelimeler: Kendiliğinden yerleşen beton, kendiliğinden yerleşen harç, mineral ve kimyasal katkılar, yayılma deneyi, V-hunisi deneyi, ultrasonik ses hızı.

To My Parents, **Djarot & Tuti Sujadi**

and

To **Mr. Erie** & **Mrs. Hani Bawono**

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LIST OF SYMBOLS

μ : Coefficient of Viscosity

τ : Shear Stress

τ_0 : Yield Stress

γ : Rate of Shear

Γ_m : Relative Slump Flow

R_m : Relative Funnel Speed

d : Diameter of Slump Flow

λ : Wavelength

f : Frequency

N : Length of Near Field Zone

D : Diameter of Transducer

LIST OF ABBREVIATIONS

SCC	: Self Compacting Concrete
SCM	: Self Compacting Mortar
SP	: Superplasticizer
MA	: Mineral Admixture
VMA	: Viscosity Modifying Admixture
EFNARC	: European Federation of National Trade Association
FA	: Fly Ash
LP	: Limestone Powder
BP	: Brick Powder
K	: Kaolinite
LF	: Limestone Filler
PC	: Portland Cement
PE	: Polycarboxylate Ester
PA	: Polycarboxylate Acid
NSA	: Naphthalene Sulphate Acid
UFFA	: Ultra Fine Fly-Ash
ASTM	: American Society for Testing and Materials
NIST	: National Institute of Standards and Technology
ITZ	: Interfacial Transition Zone

CHAPTER 1

INTRODUCTION

1.1 General

Self compacting concrete (SCC) is considerably a new concrete technology that was developed within the last two decades. The technology was first discovered in 1986 by Japanese researchers to increase concrete durability by increasing the workability of concrete and thus by increasing the construction quality [Ozawa et. al. 1989]. SCC can be defined as a concrete with very high flowability together with a good stability. These two parameters allow the concrete to fill every corner of the formwork to which it is placed under its own weight without the need of any external vibrator. Another property that is always needed for SCC is its passing ability that is needed for filling heavily congested sections of reinforced concrete structures [Ozawa et. al. 1989].

As mentioned earlier SCC is a new concrete technology and therefore there aren't any standards describing the requirements of SCC. The only available standard is published by EFNARC (European Federation of National Trade Associations) which is the European federation dedicated to special construction chemicals and concrete systems [EFNARC 2002]. EFNARC lists the three workability requirements of SCC as its filling ability, passing ability and segregation resistance and just like the conventional concrete there isn't a single test method to measure the abovementioned workability parameters. Therefore a list of test methods is described to determine the workability properties of SCC. Among these slump-flow, J-ring, V-funnel, L-box, U-box, and fill-box are the most widely accepted and used tests. It should be mentioned here that, all these tests are empirical but quantitative test procedures to assess the workability properties of SCC.

The common practice to obtain self-compactibility is to limit the coarse aggregate content and to utilize an appropriate mortar. Therefore, mortar serves as the basis for the workability properties of SCC and these properties could be assessed by investigating self compacting mortars (SCM) [Domone and Jin 1999]. In fact, assessing the properties of SCM is an integral part of SCC design [EFNARC 2002].

In order to achieve self compactibility in SCMs usually the sand content in mortar is limited to 40% of mortar volume. Moreover, lower water cement ratios together with superplasticizers (SP) are also used [Okamura and Ozawa 1995]. In order to achieve an optimum mix design of SCC or SCM it is also important to use viscosity modifying admixtures (VMA). VMAs increase the viscosity of the SCC and prevent segregation [Lachemi et. al. 2002]. However, addition of all these chemical admixtures increases the cost of the SCM.

One alternative to reduce the cost of SCC is the use of mineral admixtures, which are finely divided materials added to concrete as separate ingredients either before or during mixing [Erdoğan 1997]. If the mineral admixtures can replace some or all of the chemical admixtures without any loss in the fresh properties of SCC, the cost will be reduced especially if the mineral admixture is an industrial by-product or waste. Moreover, the mineral admixtures will also increase the durability & long-term strength.

1.2 Objective

The objective in this thesis is to investigate the effect of mineral admixtures, different SPs and different VMAs on the fresh properties of SCMs. In this context four mineral admixtures, both pozzolanic and non-pozzolanic, namely, fly-ash, limestone powder, brick powder and kaolinite are utilized. Two of the SPs were polycarboxylate based and one was melamine formaldehyde based admixtures. The VMAs, however, were an aqueous dispersion of microscopic silica based and a high molecular weight hydroxylated polymer based admixtures.

A total of 43 mortar mixes are prepared and slump flow and V-funnel tests, and setting properties are determined as for the fresh properties. Hardened properties that are considered are the strength, ultrasonic pulse velocity and density which are determined at 7, 28, and 56 days of age.

1.3 Scope

This thesis consists of five Chapters. Chapter 2 presents a literature review and gives a general background on SCC and SCM. Included in this Chapter are the test methods to assess workability of SCMs and the use of mineral admixtures, as cement replacement. At the end of Chapter 2, a brief introduction to ultrasonic pulse velocity testing is also provided.

Chapter 3 presents the experimental program, briefly explains the test procedures, and summarizes the experimental data.

Chapter 4 presents the results of the test program focusing on the fresh properties of SCMs. The effect of mineral and chemical admixture on the workability and setting properties of SCMs are also explained. Also included in this Chapter is the effect of mineral and chemical admixtures on the hardened properties of SCMs.

Chapter 5 gives a summary of thesis and lists the findings of this research. Possible further research areas complementing this thesis are also included in Chapter 5.

CHAPTER 2

LITERATURE REVIEW AND BACKGROUND

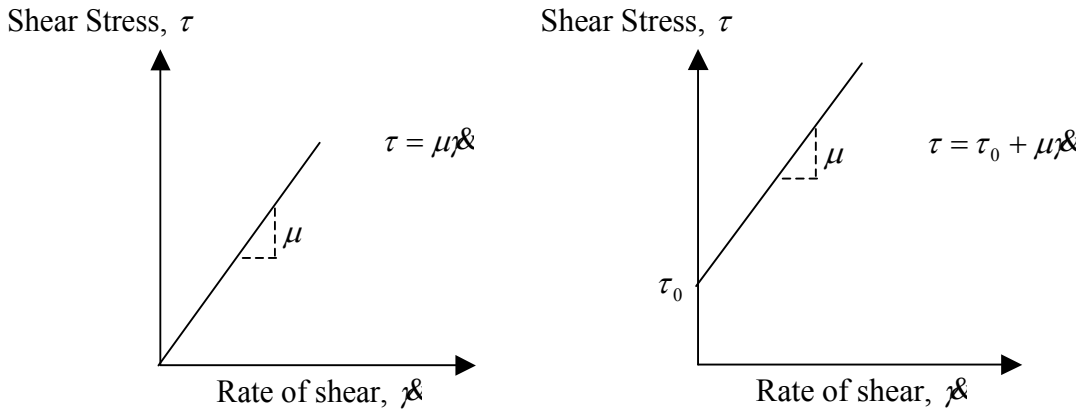
2.1 Rheology of Self Compacting Concrete (SCC)

Characteristic phenomena of liquid and gas to immediately deform when subjected to small shearing stresses is called "flow". The study of flow process that deals with relations between stress, 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 than those of a simple fluid (liquid or gas) or an ideal elastic solid [Tattersall et. al. 1983].

The flow properties of materials are often determined through shear stress-rate of shear plots (Figure 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 the material. The rheology of fresh concrete, however, is most often described by the Bingham model. In this model the flow curve has an intercept on the stress axis, indicating a minimum stress which is required to start the flow [Tattersall et. al.1983]. According to this model, fresh concrete must overcome a limiting stress (yield stress, τ_0) before it can flow. Once the concrete starts to flow, shear stress increases linearly with an increase in strain rate as defined by plastic viscosity. 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].

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].



(a) Newtonian liquid **(b) Fresh concrete (Bingham model).**

Figure 1 Flow Properties of Materials

2.2 Test Methods for Assessing the Workability of SCC

As mention earlier, the measurement of the two parameters of the concrete flow by a rheometer is not practical, and not yet standardized. Therefore, there are other, more practical, test methods in assessing the workability of SCC. However, it should not be forgotten that these practical test methods are also not standardized by any standardization agency. The only agency that has listed these test methods is EFNARC, yet, it is also mentioned by EFNARC that these methods are descriptions and not definitive test procedures. In this section, brief descriptions of these test procedures will be provided.

2.2.1 Slump Flow

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. The procedure for the slump flow test and the commonly used slump test are almost identical. In the slump test, the change in height between the cone and the spread concrete is measured, whereas in the slump flow test the diameter of spread concrete is determined as the slump flow diameter (Figure 2)

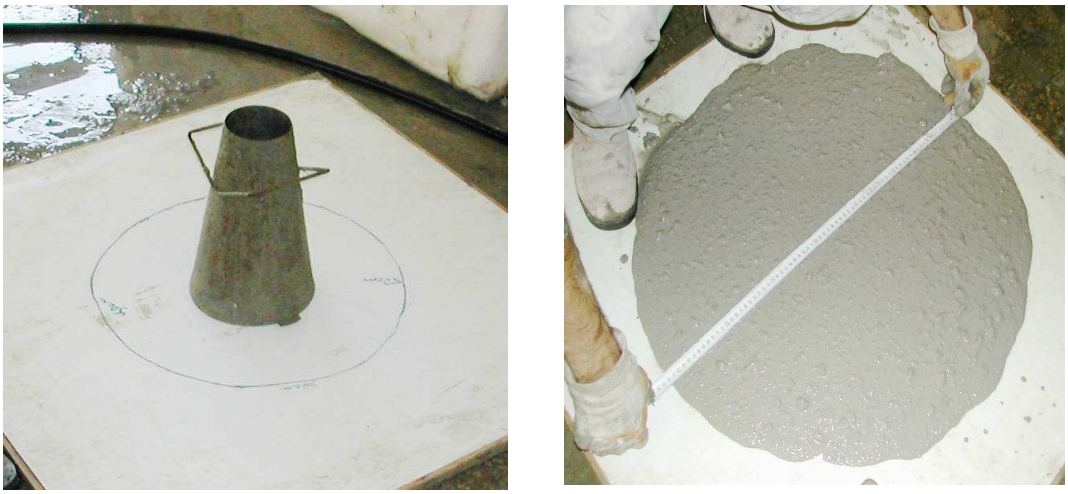


Figure 2 Slump Flow Test

The slump flow test is also used to assess the properties of SCM with a slight modification to the slump cone (Figure 3). This cone has been described by EFNARC and has also been used by other researchers [Domone and Jin 1999].

Figure 3 Mini Slump Cone

2.2.2 V - Funnel Test

The V-Funnel is used to measure the flowability or viscosity of SCC. In this test a standard funnel is filled completely with concrete and the bottom outlet is opened allowing the concrete to flow. The V-funnel time is the elapsed time (t) in second between the opening of the bottom outlet and the time when the light becomes visible from the bottom, when observed from the top (ENARCH 2002).

The V-funnel test is also used to assess the fresh properties of SCM with a slight modification to the V-funnel apparatus (Figure 4b). This apparatus has been used by other researchers and was also used in this study [Domone and Jin 1999; Golasweski and Swabowski 2002]

(a) V Funnel Test for SCC

(b) V Funnel Test for SCM

Figure 4 V – Funnel Test Apparatus

2.2.3 Other Test Methods

In addition to the abovementioned tests there are others to determine the workability properties of SCC, such as J-ring, L-box, U-box (Figure 5). These test procedures are all described by EFNARC and measure the passing ability of SCC in between reinforcements. Since SCMs do not incorporate aggregates, which are the main cause of blockage between reinforcements these test procedures are not utilized in this thesis.

Figure 5 U-Box, L-Box, and J-Ring

2.3 Methods of Achieving Deformability

To achieve self compactability in SCC high deformability of the paste or the mortar and the resistance to segregation between coarse aggregate and mortar when concrete flows through the confined zone of reinforcing bars is needed. Okamura and Ozawa (1995) have listed the following requirements to achieve self compactability of concrete:

- Limited aggregate content.
- Low water-powder ratio.
- Use of superplasticizers (SP).

In a SCC, the amount of coarse aggregate has to be reduced since moving them requires more energy. The reduction in the coarse aggregate content will be balanced by an increase in the paste volume which in return increases the aggregate inter particle distance hence reducing the contact and friction among the aggregate particles [Okamura and Masahiro 2003].

The addition of water will help to reduce both the yield stress and viscosity to achieve fluidity in SCC. However, extra water can reduce viscosity to such an extent that segregation may occur. Therefore, water-powder ratio of SCC is usually limited.

The addition of SP reduces the yield stress without significant viscosity reduction. The effect of SP on Bingham constants was studied earlier by Jacek Golasweski and Januz Swabowski. In their study, the water to powder ratio of a paste was maintained at 0.36 with various combinations of Portland cement and limestone. The dosage of SP was expressed as percentage of total powder content. As seen from Table 1, it is clear that yield stress decreases drastically as the SP dosage is increased. However, the effect on viscosity is relatively small [Golasweski and Swabowski, 2002].

Table 1 Bingham Constant for Pastes with W/P of 0.36

Powder (%)		SP	Yield Stress	Plastic Viscosity
Cement	Limestone	(%)	(Pa)	(Pa.s)
65	35	0.10	33.4	0.26
		0.20	10.8	0.21
		0.30	1.4	0.17
55	45	0.10	23.3	0.22
		0.20	10.2	0.21
		0.30	4.3	0.19
45	55	0.10	12.8	0.20
		0.15	6.3	0.18
		0.20	2.6	0.16

2.4 Use of Mineral Admixtures for SCC

Mineral admixtures are finely divided solids which are added to concrete to improve its workability, strength, durability, economy, and to control the rate of hydration. There are two groups of mineral admixtures. The first group has pozzolanic properties and the second group doesn't have any pozzolanic properties and are also termed as fillers. A pozzolanic property is defined for materials that exhibit binding property when they are hydrated in the presence of hydrated lime so they can replace the Portland cement. Natural pozzolans, artificial pozzolans such as fly-ash and silica fume and ground granulated blast furnace slag are examples of such mineral admixtures [Erdoğan 1997].

Fly-ash is a finely divided residue of the very fine ash resulting as a by product from the combustion of powdered coal in power plants. The fineness of fly-ash which ranges from 1 to 150 μm affects its pozzolanic properties and the workability of concrete by reducing the water demand. Furthermore, the permeability of fly-ash concrete is normally less than that of concrete made without fly-ash. The reason of such a decrease in permeability is that the calcium hydroxide liberated by the hydration of calcium silicate compound (C_2S and C_3S) reacts with pozzolans and leads to the formation of additional calcium-silicate-hydrates which reduces the capillary pore spaces [Erdoğan 1997].

Nonpozzolanic fillers are frequently used to optimize the particle packing and flow behavior of cementitious paste in SCC mixes. Among nonpozzolanic fillers, limestone and dolomite fines are most frequently used to increase the content of fine particles in SCC mixes. The addition of limestone filler (LF) to Portland cement has several effects on the properties of fresh and hardened concrete. The LF grains act as nucleation sites for CH and C-S-H reaction products at early hydration ages, and accelerate the hydration of clinker minerals, especially C_3S, resulting in an improvement in early strength [Pera et. al. 1999; Bonavetti et. al. 2000]. Moreover Improvement of fine-particle packing can considerably enhance stability and workability of fresh concrete [Bartos 1998; Bonavetti 2000], as well as increase the

density of paste matrix and interfacial transition zone (ITZ) in hardened concrete [Corinaldesi et. al. 2002; Domone and Jin 1999].

The increasing waste production and public concerns about the environment lead people to search for the possibility of reusing materials from building demolition. If these waste materials are suitably selected, ground, cleaned and sieved, they can be profitably used in concrete. Among them, Brick powder was discovered to have pozzolanic properties [Corinaldesi et. al 2002]. Therefore, brick powder obtained as a by product of a brick factory can be used as an artificial pozzolan in concrete production.

Other mineral admixture for cement replacement is metakaolin which is produced by controlled thermal treatment of kaolin and known to have pozzolanic properties [Dunster et. all. 1993]. A study about kaolin conducted by G. Batis et. al. [2004] concluded that metakaolin improves the compressive strength and the 10% addition shows the optimum contribution to the strength development. The use of metakaolin, either as a sand replacement up to 20%, or as a cement replacement up to 10%, improved the corrosion behavior of mortar specimens. Higher percentages of metakaolin, however, decreased the corrosion resistance.

2.4 Effects of Admixtures on the Fresh Properties of SCMs

2.4.1 Chemical Admixtures

As explained earlier, chemical admixtures such as SPs and VMAs are important materials used for the production of SCC. Therefore, effects of these chemical admixtures on the properties of SCCs have been investigated by other researchers [Sakata et. al. 2003]. In a research conducted by Jacek Golasweski and Januz Swabowski (2002) mortars of given superplasticizer type and dosage with different cements show clear differences in rheological properties of SCMs. The research revealed that polycarboxylate ester (PE) and polycarboxylate acid (PA) type superplasticizers are more effective than naphthalene sulphate acid (NSA) superplasticizers. Used in the same dosage, these two superplasticizers make it

possible to obtain mortars with considerably reduced yield stress and workability loss. The characteristic of mortars with PA and PE superplasticizers is high plastic viscosity, which is an advantage from a segregation point of view. It was also concluded that the type, chemical and phase composition of the cement are also important factors for the performance of superplasticizers.

In another study, Lachemi, et. al. 2002 studied the effect of VMAs on the properties of cement pastes. They used five different types of VMA as a chemical admixture for making the cement pastes. Various tests were conducted to measure the fresh properties, such as fluidity, segregation, and washout resistance. Using a SP of 0.25% together with VMAs, they showed that there was an increase in the slump flow diameter of the paste prepared with the VMAs compared the mix prepared with the SP alone. The mini slump value in VMA pastes ranged between 127 and 132 mm compared with 116 mm in the control paste [0% VMA]. It was concluded that combining proper dosages of VMA and SP could be produced high-performance cement pastes high fluidity and moderate cohesiveness to reduce water dilution and enhance water retention.

2.4.2 Mineral Admixtures

It may be expected that, for the same w/p ratio, increasing the volume of fine particles such as mineral admixtures will result in a reduction in the workability of concrete. The reason is the increase in water demand due to an increase in the surface area of particles. However, it is also well known that the shape of mineral admixture is also an important factor for the workability characteristic concrete. For example it is reported that for the same workability the round and spherical geometry of fly ash particles generally help to decrease the water requirement of concrete mixture [Erdoğan 1997].

In a study conducted by Ferraris et. al. (2000) the effect of fly-ash on the rheological properties of cement paste were studied. In that research four types of fly-ash with mean particle sizes of 18 μm, 10.9 μm, 5.7 μm and 3.1 μm were used. The fly-ash with mean particle size 3.1 μm was term as ultra fine fly-ash (UFFA). It was

concluded that replacement of cement with UFFA leads to a decrease in high range water reducer dosage at given yield stress and viscosity.

Bosiljkov (2003) also indicated that finer and better-graded limestone dust significantly increases the deformability of the paste. Bosiljkov concluded that if a high volume of filler was added to the SCC mix, the required self-compacting properties were achieved at a lower water/(cement + filler) ratio, and it also appeared that the addition of filler improves the 28-day compressive strength of concrete mixes due to the filler effect and improved fine-particle packing.

Another research on the fresh properties of mortar conducted by Domone and Jin (1999) included four different types of SPs, various combinations of powder, including Portland cement, ground granulated blast furnace slag, pulverized fuel ash, and limestone powder. The rheological properties that were determined included spread, V-funnel flow time, yield stress and plastic viscosity. It was concluded that the workability retention depends on a combination of factors, including the powder composition and the dosage and type of SP, and ternary blends of powder.

An adverse effect of replacing the Portland cement with mineral admixture is the increase in setting times of mixture. One study by Vu et. al. (2001) studied the effect of calcined kaolinite on setting time of Portland cement. Vu et. al. concluded that the addition of calcined kaolinite to Portland cement increases the normal consistency of blended Portland cement mixture. Blending Portland cement by 10-20% calcined kaolinite by weight not significantly altered the setting time, but exceeding this range caused a significant increase in the observed setting time.

2.5 Ultrasonic Pulse Velocity Testing

There are numerous studies on the applications of nondestructive testing on concrete [Malhotra and Carino 1991]. Some of these studies are the well-known surface hardness and penetration methods developed using the physical principles such as magnetic/electric methods, and infrared thermographic methods. Another set of methods are grouped using the common terminology involved in these techniques,

namely the stress waves. The ultrasonic methods, acoustic emission methods and impact-echo methods are examples of this group.

Ultrasonic waves are part of a broad group of waves classified as stress or elastic waves. These waves propagate in the medium as a result of the minute elastic distortion of the medium, vibrating in response to small dynamic loads applied on the surface of the member. The loads are applied by means of acousto-electric transducers. These transducers vibrate through application of a voltage difference, and these vibrations represent the applied excitation (pulser). Similarly, transducers also can receive these vibrations and output a voltage (receiver). Three basic types of stress waves are created upon the application of this load, namely; longitudinal (compression) waves, transverse (shear) waves, and surface (rayleigh) waves [Bray et. al. 1992].

The velocities of these waves are different and depend on the elastic properties of the medium. Wave velocities are determined by measuring the time elapsed for a pulse wave to traverse the specimen. Generally, in determining the wave velocity two modes of measurements can be used: through transmission and pulse echo. In through transmission, two transducers are used; one is the transmitter while the other is the receiver. In the pulse echo procedure, only one transducer is used. It delivers the pulse and also receives the reflected signal [Malhotra and Carino 1991; Krautkrämer 1990].

The wave velocity or ultrasonic pulse velocity (UPV) is expressed in units of velocity, such as meter/second (m/s), and the excitation frequency (f) is expressed in 1/second (Hz). The wavelength (λ) is the least distance in the propagation medium between identical particle displacements, and the relation between these three parameters is given by:

$$\lambda = \frac{\mathrm{UPV}}{f}$$

In concrete, through transmission is preferred because of its highly attenuative nature. Attenuation is the loss of the energy of the wave as it propagates through a medium. Attenuation commonly increases with the frequency of the wave and the

length of the path. Major categories of attenuation mechanisms include scattering, absorption, and geometric factors [Bray et. al. 1992]. In heterogeneous materials such as concrete, the particle diameter to wavelength ratio influences the loss in the wave energy. This is because of the scattering of the waves at the aggregate-matrix boundaries. Therefore, based on the attenuation characteristics of concrete, through transmission and low frequency ultrasonic transducers (between 50 and 100 kHz) are considered most suitable [Malhotra and Carino 1991].

Another limitation that is generally followed by researchers working with UPV of concrete is the length of the concrete member that would be investigated. For 50 kHz transducers usually a minimum length of about 20 cm is selected. The reason for such a limitation can be explained by another parameter that is important in UPV measurements: the intensity and spread of the beam (wave path) as it propagates. Intensity is the strength of the beam per unit cross-sectional area. As the wave-front first moves away from the transducer, it passes through a formative region or zone near to the element face. This zone, called the near field zone, is explained by considering each small area on the surface of the transducer as a point source emitting spherical waves. Interference of these waves emitted by the numerous sources causes variations in pressure as the beam propagates in the near field zone. Beyond the near field zone, however, the numerous wave fronts support rather than interfere with each other, and a wave front of nearly uniform intensity is formed. This is the far field zone. For full confidence in an ultrasonic inspection, interrogation areas should be limited to the far field zone [Bray et. al. 1992]. For flat, disk-shaped transducers the length of the near field is approximately equal to:

$$N = \frac{D^2}{4\lambda}$$

where

N = length of near field zone

D = diameter of transducer

λ = ultrasonic wavelength

In mortar specimens, however, aggregates don't exist and so higher frequency transducers such as 150 kHz or 250 kHz could be utilized. Moreover, using smaller

diameter higher frequency transducers, the length of the near field zone is reduced. Therefore, shorter specimens such as 5 cm could be used to measure the UPV of a mortar specimen with 150 kHz transducers.

CHAPTER 3

EXPERIMENTAL STUDY

3.1 Experimental Program

Our objective was to investigate the effects of mineral admixtures, SPs and VMAs on the fresh properties of SCMs. In this respect, four mineral admixtures, namely, fly-ash, limestone powder, brick powder and kaolinite, three SPs, and two VMAs were used in preparing SCMs. A total of 43 mixes were prepared maintaining the total powder content and the water-powder ratio (w/p) constant. The fresh properties that were determined are the initial and final setting times, slump flow diameter, and V-funnel flow time. The hardened properties that were tested are strength, density, and ultrasonic pulse velocity which were determined at 7, 28, and 56 days of age.

3.2 Material Properties

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

3.2.1 Portland Cement

An ordinary Turkish Portland Cement PÇ 42.5 manufactured by Yibitaş LaFarge was used corresponding to ASTM Type I cement. The physical properties and the chemical composition of the cement used throughout the tests are presented in the tables below.

Table 2 Physical Properties of Portland Cement

Property	Determined as	ASTM C150 Limits
Specific Gravity	3.09	-
Blaine Fineness (cm^2/g)	3030	min 2800
Specific S.A.	0.7180 sq.m/ g	-
Above 90 µm	0.50%	-
Above 45 µm	10.90%	-

Table 3 Chemical Composition of Portland Cement

Oxide	Determined as (%)	ASTM C150 Limits
CaO	61.94	-
SiO_2	18.08	-
Al_2O_3	5.58	-
Fe_2O_3	2.43	-
MgO	2.43	max. 6.0%
SO_3	2.93	max 3.5%
K_2O	0.99	-
Na_2O	0.18	-
LOI	4.4	max 3.0%

3.2.2 Fine Aggregate

The fine aggregate used in the experimental program was natural river sand. The specific gravity and absorption of the sand is presented in Table 4. The gradation of the aggregate was determined by sieve analysis and presented in Table 5.

Table 4 Properties of Fine Aggregate

Property	Determined as
Specific Gravity	
Apparent	2.56
Dry	2.52
SSD	2.54
Absorption (%)	0.68

Table 5 Sieve Analysis of Fine Aggregate

Sieve No	Cumulative Percent Passing	
	Fine Aggregate	ASTM C-33 Requirement
3/8" (9.5mm)	100	100
No.4 (4.75mm)	99.73	95-100
No.8 (2.36mm)	88.73	80-100
No.16 (1.18mm)	66.02	50-85
No.30 (600µm)	38.07	25-60
No.50 (300µm)	15.10	10-30
No.100 (150µm)	5.10	2-10

3.2.3 Chemical Admixtures

Three types of superplasticizers and two types of viscosity modifying admixtures were used in the experimental program. The properties of the chemical admixtures as obtained from the manufacturers' presented in Table 6.

Table 6 Properties of the Chemical Admixtures

ID	Specific Gravity	pH	Solid Content (%)	Quantity (%) by cement weight	Main Component
SP1	1.08	5.7	40	0.5 -2.5	Polycarboxylate Eter
SP2	1.07	6.9	26	1-2	Polycarboxylate Eter
SP3	*	*	100	*	Melamine Formaldehyde
VMA1	*	*	20	1-2	Aqueous Dispersion of Microscopic Silica
VMA2	*	*	*	0,05-0.15	High Molecular Weight Hydroxylated Polymer

* Data were not provided by the manufacturer

3.2.4 Mineral Admixtures

The mineral admixtures used in the experimental program was a high-lime fly-ash, limestone powder, brick powder and kaolinite. Their physical properties and chemical analysis result are presented in Table 7 and 8. The particle size distribution of the mineral admixtures is provided in Figure 6.

Table 7 Physical Properties of Mineral Admixtures

Physical Properties	Fly-ash	Brick Powder	Limestone Powder	Kaolinite
Specific Gravity	2.01	2.64	2.70	2.62
Specific SA (sq.m/g)	0.4551	0.5103	1.5972	1.0733
Blaine Fineness	2420	2005	*	7958
Above 90 µm	26.50	50.20	*	69.50
Above 45 µm	41.30	64.80	*	78.20

***** The related data of the limestone powder can't be detected

Table 8 Chemical Properties of Mineral Admixtures

Chemical Analysis (%)	Cement	Fly-ash	Brick Powder	Limestone Powder	Kaolinite
CaO	61.94	11.31	4.65	54.97	0.16
SiO_2	18.08	49.55	63.11	0.01	47.2.
Al_2O_3	5.58	13.34	15.08	0.17	35.4
Fe_2O_3	2.43	8.51	6.66	0.05	0.81
MgO	2.43	4.10	1.94	0.64	0.38
SO_3	2.54	1.70	0.36	0.00	0.00
K_2O	0.99	1.99	2.34	0.00	2.59
Na_2O	0.18	3.08	0.78	0.00	0.16
LOI	4.40	2.74	2.33	43.66	11.70

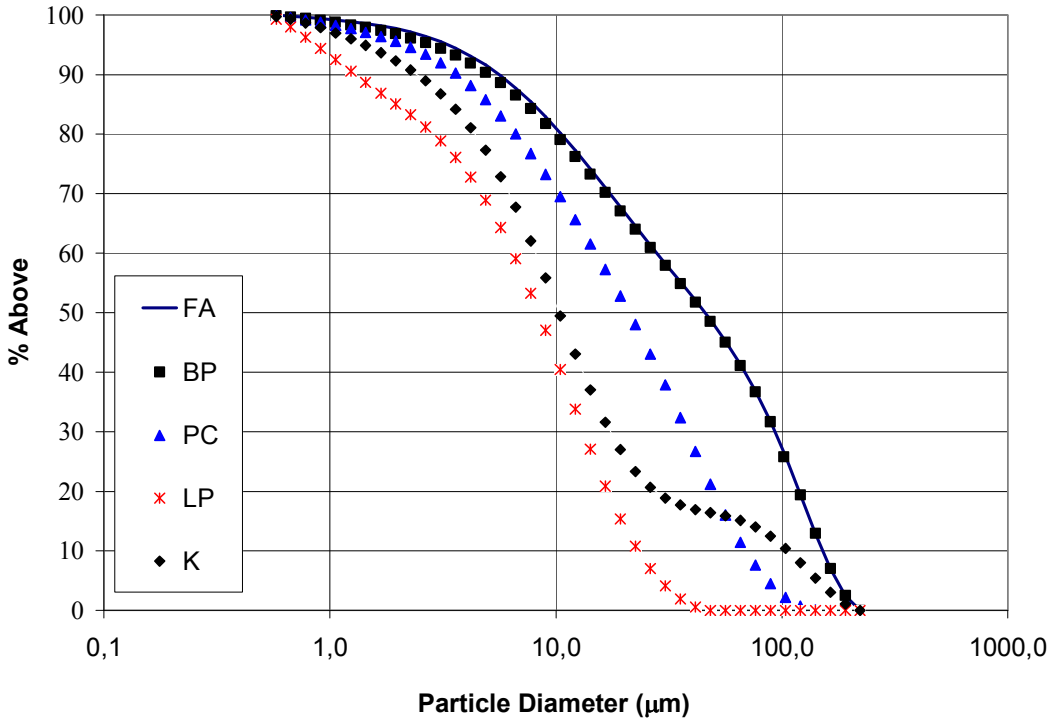


Figure 6 Particle Size Distributions of Cement and Mineral Admixtures

3.3 Experimental Procedures

3.3.1 Specimen Preparation

Mortars were prepared using a standard mixer described by ASTM C109/C 109M – 01 (Figure 7). The mix procedure for the SCMs is described in Figure 8. The setting times are determined from one batch and later, the workability properties are determined and a total of nine cubic mortars with a dimension of 5 cm are prepared for the hardened property testing. After casting, the specimens are cured at 23 ºC ± 1.7 ºC until the age of testing (Figure 9).

Figure 7 The Standard Mini-Mixer

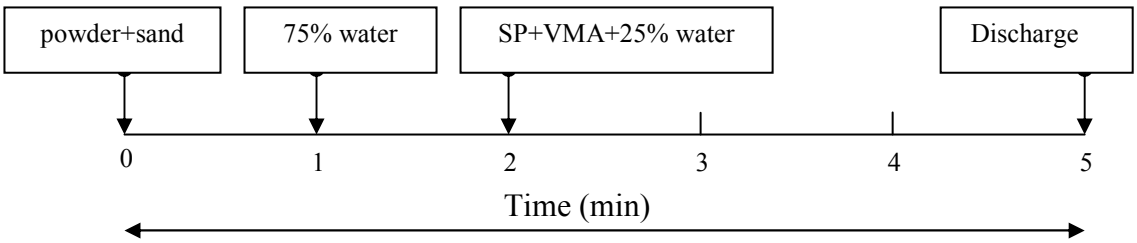


Figure 8 The Mix Procedure

Figure 9 Curing of Specimens

3.3.2 Determination of Setting Time

Initial setting time and the hardness development of mortars was determined by the setting time apparatus shown in Figure 10. This test procedure was in accordance with ASTM C403/ C403M-99. The mortar is discharged to a 10 x 10 cm cubic mold and stored at 23^{o}C temperature. At regular intervals, the resistance of mortar to penetration by a standard needle is measured. From a plot of penetration resistance versus elapsed time (Figure 11), the initial and final setting time is determined through interpolation.

Figure 10 Apparatus for Testing Setting Time

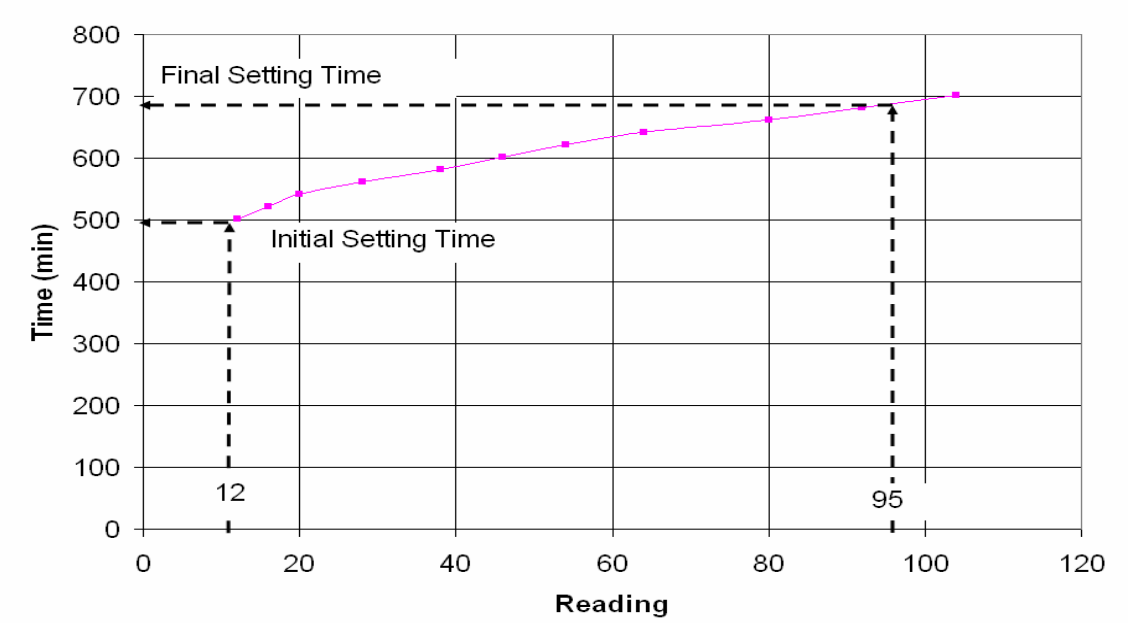


Figure 11 Determination of Initial and Final Setting Time by Interpolation

3.3.2 Determination of Slump Flow

The slump flow test for SCM is described by EFNARC 2002 (Figure 12). In this test, the truncated cone mould is placed on a smooth plate, filled with mortar, and lifted upwards. The subsequent diameter of the mortar is measured in two perpendicular dimensions and the average is reported as the final diameter. Finally the relative slump is calculated by the following formula:

$$\Gamma_m = (d / d_0)^2 - 1$$

where, d_0 is the initial diameter of the cone, and d is the final diameter of flow.

3.3.3 Determination of V-funnel Flow Time

The V-funnel flow test for SCM is also described by EFNARC (Figure 13). The funnel is filled completely with mortar and the bottom outlet is opened, allowing the concrete to flow. The flow of mortar is the elapsed time (t) in seconds between the opening of the bottom outlet and the time when the light becomes visible from the

bottom, when observed from the top. The relative funnel speed is then calculated as:

$$R_m = 10/t$$

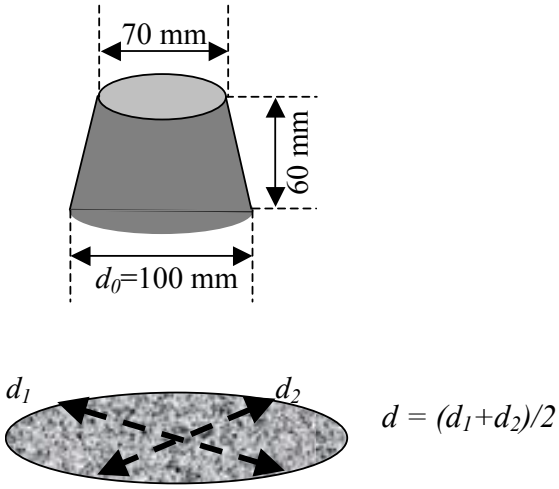


Figure 12 Flow Cone and Determination of the Slump Flow

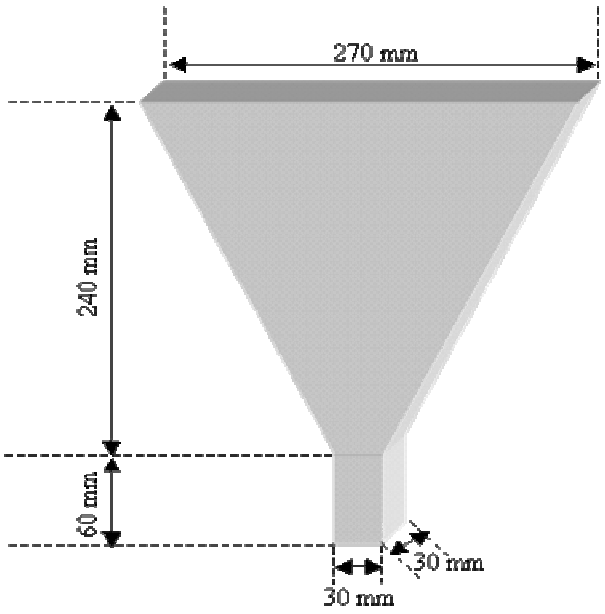


Figure 13 V-Funnel to Determine the Flow Time of Mortar

3.3.4 Determination of Strength

Compressive strength of 5 cm cubic mortars are determined at 7, 28, and 56 days or mortar age. The test was conducted in accordance with ASTM C 109/C 109M-01 using a universal testing machine (Figure 14).

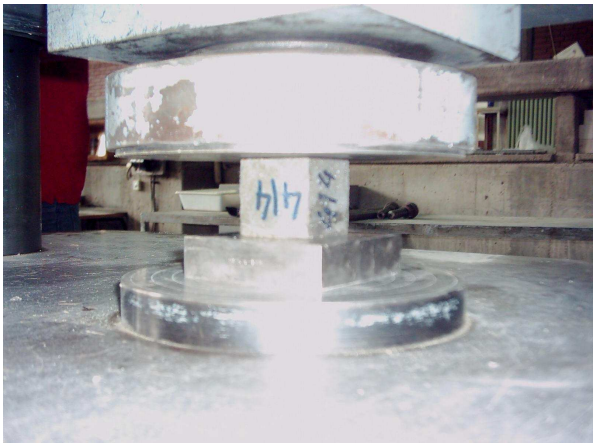


Figure 14 Determination of Compressive Strength

3.3.4 Determination of Density and Ultrasonic Pulse Velocity

All three dimensions of the cubic specimens are measured using a caliper of 0.01 mm. resolution and their weights are also measured with a balance of 0.01 gr. resolution at ages 7, 14, 28, and 56 days (Figure 15). Using these data the density of the specimens was determined.

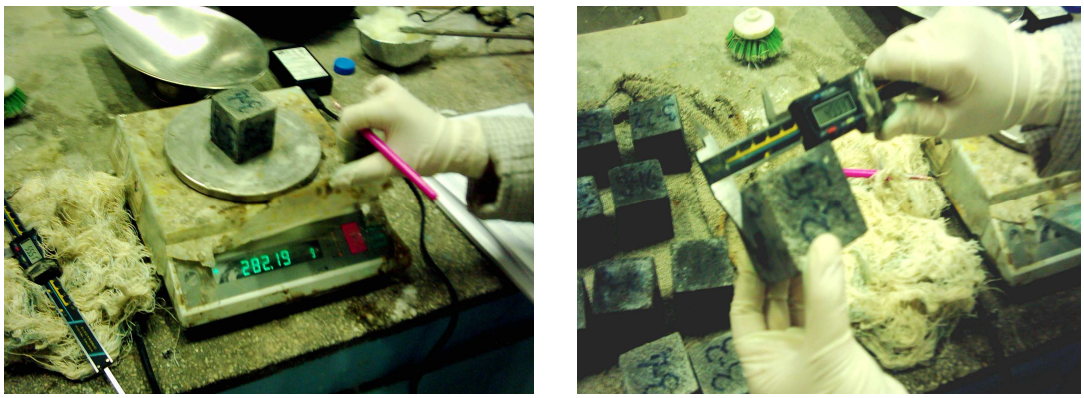


Figure 15 Weight and Dimensional Measurements of Cubic Specimens

The UPV measurement is described in ASTM C 597-83. The testing system consists of a pulser/receiver unit with a built-in data acquisition system and a pair of narrow band, 150 kHz transducers. UPV measurements were conducted with the transducers firmly coupled to the opposite ends of the specimens using a coupling gel (petroleum jelly) between the transducer and the specimen (Figure 16). UPV computation requires the acquisition of the pulse arrival time and specimen length. Pulse arrival time describes the elapsed time between the time of pulse application and arrival on the opposite face of the specimen. UPV was computed as the specimen length divided by the elapsed time. Using the UPV measurements the internal structure of mortar at 7, 28 and 56 days of age were nondestructively monitored.

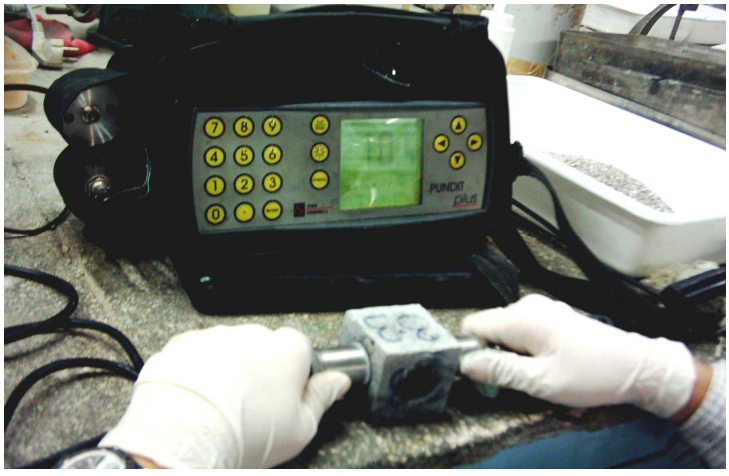


Figure 16 UPV Testing on Cubic Specimens

3.4 Experimental Data

3.4.1 Mix Design

One control and 42 mixes with mineral and chemical admixtures were prepared as shown in Table 9. The w/p ratio was selected as 0.40 and the total powder content was fixed to 650 kg/m^3. Part of the cement was interchanged with the mineral admixtures on the amounts of 15 and 30% of cement weight. There were also ternary mixes of the mineral admixtures. In Table 9, C stands for Portland cement, and FA, LP, BP, K stands for the mineral admixtures fly-ash, limestone powder, brick powder, and kaolinite respectively. The amounts of chemical admixtures, superplasticizers (SP1, SP2, SP3) and viscosity modifying admixtures (VMA1, VMA2) are also given in that Table. The mixes are identified such that the ingredients are clear from their IDs. For example, the mix SP1-FA2 contained SP1 and 30% replacement of FA, the mix SP3-FA1-LP1 contained SP3, 15% replacement of FA and 15% replacement of LP, and the mix SP2-VMA1 contained no mineral admixtures but SP2 and VMA1 as chemical admixtures.

3.4.2 Fresh Properties

Table 10 presents the tested fresh properties of all 43 mixes. Included in that table is the measured slump flow diameters, d_1 and d_2, the calculated average slump flow diameter, d, the measured V-funnel time, t, and finally the initial and final setting time in minutes. As seen in Table 10, in every 14 mix a different SP was used. The amount of powder (PC+mineral admixtures), water and superplasticizers were kept constant by weight. When a VMA was used, the mixture only consisted of PC, sand, water and SP without any mineral admixture. Moreover, the control mix consisted of only PC, sand and water without any chemical and mineral admixtures.

3.4.3 Hardened Properties

The hardened properties that were determined for all the 43 mixes were the density, ultrasonic pulse velocity and strength at 7, 28, and 56 days. Table 11, 12, and 13 presents the averages and the coefficient of variations of the density, UPV, and strength of all the specimens tested. At 7 days of age the densities and UPVs of 9 specimens were tested. 3 of the specimens were tested afterwards, therefore the number of specimens tested for density and UPV reduces to 6 at 28 days of age. Finally, 3 more specimens were tested again at 28 days for compressive strength and at 56 days of age all the measurements were tested on the remaining 3 specimens.

Table 9 Mix Design of SCMs

MIX ID	Amount of Ingredient (kg/m^3)											
	C	FA	BP	LP	K	Sand	Water	SP1	SP2	SP3	VMA1	VMA2
SP1	650	0	0	0	0	1,298	260	9.75	0	0	0	0
SP1-FA1	550	100	0	0	0	1,272	260	9.75	0	0	0	0
SP1-FA2	450	200	0	0	0	1,246	260	9.75	0	0	0	0
SP1-BP1	550	0	100	0	0	1,283	260	9.75	0	0	0	0
SP1-BP2	450	0	200	0	0	1,269	260	9.75	0	0	0	0
SP1-LP1	550	0	0	100	0	1,286	260	9.75	0	0	0	0
SP1-LP2	450	0	0	200	0	1,273	260	9.75	0	0	0	0
SP1-FA1-LP1	450	100	0	100	0	1,260	260	9.75	0	0	0	0
SP1-BP1-LP1	450	0	100	100	0	1,271	260	9.75	0	0	0	0
SP1-K1	550	0	0	0	100	1,282	260	9.75	0	0	0	0
SP1-FA1-K1	450	100	0	0	100	1,256	260	9.75	0	0	0	0
SP1-K2	450	0	0	0	200	1,266	260	9.75	0	0	0	0
SP1-VMA1	650	0	0	0	0	1,298	260	9.75	0	0	9.75	0
SP1-VMA2	650	0	0	0	0	1,298	260	9.75	0	0	0	1.3
SP2	650	0	0	0	0	1,298	260	0	9.75	0	0	0
SP2-FA1	550	100	0	0	0	1,272	260	0	9.75	0	0	0
SP2-FA2	450	200	0	0	0	1,246	260	0	9.75	0	0	0
SP2-BP1	550	0	100	0	0	1,283	260	0	9.75	0	0	0
SP2-BP2	450	0	200	0	0	1,269	260	0	9.75	0	0	0
SP2-LP1	550	0	0	100	0	1,286	260	0	9.75	0	0	0
SP2-LP2	450	0	0	200	0	1,273	260	0	9.75	0	0	0
SP2-FA1-LP1	450	100	0	100	0	1,260	260	0	9.75	0	0	0
SP2-BP1-LP1	450	0	100	100	0	1,271	260	0	9.75	0	0	0
SP2-K1	550	0	0	0	100	1,282	260	0	9.75	0	0	0
SP2-FA1-K1	450	100	0	0	100	1,256	260	0	9.75	0	0	0
SP2-K2	450	0	0	0	200	1,266	260	0	9.75	0	0	0
SP2-VMA1	650	0	0	0	0	1,298	260	0	9.75	0	9.75	0
SP2-VMA2	650	0	0	0	0	1,298	260	0	9.75	0	0	1.3
SP3	650	0	0	0	0	1,298	260	0	0	9.75	0	0
SP3-FA1	550	100	0	0	0	1,272	260	0	0	9.75	0	0
SP3-FA2	450	200	0	0	0	1,246	260	0	0	9.75	0	0
SP3-BP1	550	0	100	0	0	1,283	260	0	0	9.75	0	0
SP3-BP2	450	0	200	0	0	1,269	260	0	0	9.75	0	0
SP3-LP1	550	0	0	100	0	1,286	260	0	0	9.75	0	0
SP3-LP2	450	0	0	200	0	1,273	260	0	0	9.75	0	0
SP3-FA1-LP1	450	100	0	100	0	1,260	260	0	0	9.75	0	0
SP3-BP1-LP1	450	0	100	100	0	1,271	260	0	0	9.75	0	0
SP3-K1	550	0	0	0	100	1,282	260	0	0	9.75	0	0
SP3-FA1-K1	450	100	0	0	100	1,256	260	0	0	9.75	0	0
SP3-K2	450	0	0	0	200	1,266	260	0	0	9.75	0	0
SP3-VMA1	650	0	0	0	0	1,298	260	0	0	9.75	9.75	0
SP3-VMA2	650	0	0	0	0	1,298	260	0	0	9.75	0	1.3
Control	650	0	0	0	0	1,298	260	0	0	0	0	0

Table 10 Fresh Properties of SCMs

MIX ID	Diameter	V-funnel time	Setting Time (min)	
	d (cm)	*t* (sec)	$t_{i.s.}$	$t_{f.s.}$
SP1	23.00	5.03	502	687
SP1-FA1	24.50	4.15	632	904
SP1-FA2	26.50	3.28	791	1052
SP1-BP1	18.00	12.28	590	789
SP1-BP2	16.00	21.25	494	730
SP1-LP1	25.00	3.50	525	743
SP1-LP2	26.00	2.70	482	658
SP1-FA1-LP1	27.00	1.80	574	755
SP1-BP1-LP1	24.50	3.20	426	649
SP1-K1	16.50	9.00	392	713
SP1-FA1-K1	20.00	5.80	620	903
SP1-K2	*	*	475	699
SP1-VMA1	22.50	3.36	479	676
SP1-VMA2	23.00	4.56	475	667
SP2	25.00	4.50	541	777
SP2-FA1	24.50	3.70	632	876
SP2-FA2	26.50	3.28	751	970
SP2-BP1	23.50	4.03	412	746
SP2-BP2	21.50	7.09	480	755
SP2-LP1	26.00	3.23	458	684
SP2-LP2	27.50	2.28	460	627
SP2-FA1-LP1	28.00	2.76	565	784
SP2-BP1-LP1	24.50	4.10	485	652
SP2-K1	18.00	6.20	500	750
SP2-FA1-K1	23.00	4.10	610	861
SP2-K2	*	*	465	691
SP2-VMA1	24.00	3.44	477	654
SP2-VMA2	25.50	5.01	504	739
SP3	20.50	4.81	451	641
SP3-FA1	22.50	4.49	653	895
SP3-FA2	26.00	2.93	687	1023
SP3-BP1	18.50	9.97	468	687
SP3-BP2	15.50	23.48	508	752
SP3-LP1	24.50	9.36	467	703
SP3-LP2	24.75	4.03	469	634
SP3-FA1-LP1	24.50	3.65	565	841
SP3-BP1-LP1	21.75	5.85	510	772
SP3-K1	19.00	10.70	466	738
SP3-FA1-K1	23.25	4.56	559	845
SP3-K2	*	*	464	688
SP3-VMA1	21.50	5.63	487	646
SP3-VMA2	20.00	6.80	515	733
Control	*	*	333	583

***** There was no flow

Table 11 Density of SCMs

MIX ID	Density (kg/m^3)					
	7		28		56	
	Mean of 9	COV (%)	Mean of 6	COV (%)	Mean of 3	COV (%)
SP1	2234	1.31	2257	0.71	2267	0.88
SP1-FA1	2200	1.64	2224	0.71	2265	2.22
SP1-FA2	2180	1.20	2190	0.45	2210	1.46
SP1-BP1	2175	0.97	2177	2.67	2226	0.57
SP1-BP2	2160	1.19	2164	1.85	2171	1.29
SP1-LP1	2241	1.19	2247	1.59	2252	0.19
SP1-LP2	2237	1.31	2260	0.58	2264	0.43
SP1-FA1-LP1	2189	1.56	2207	1.05	2213	0.10
SP1-BP1-LP1	2217	1.77	2229	0.86	2237	0.49
SP1-K1	2179	1.94	2189	1.05	2199	0.57
SP1-FA1-K1	2160	1.41	2179	2.14	2188	1.64
SP1-K2	2115	1.90	2143	0.78	2154	0.37
SP1-VMA1	2218	1.72	2223	1.11	2237	2.07
SP1-VMA2	2239	1.19	2247	0.89	2291	0.60
SP2	2256	1.19	2260	0.73	2266	0.94
SP2-FA1	2199	1.36	2207	1.50	2213	1.93
SP2-FA2	2145	1.42	2153	1.38	2161	0.83
SP2-BP1	2183	3.19	2206	0.87	2227	0.71
SP2-BP2	2160	1.26	2185	0.80	2207	1.24
SP2-LP1	2224	1.20	2238	0.65	2261	2.92
SP2-LP2	2221	1.04	2244	0.97	2239	0.92
SP2-FA1-LP1	2174	1.90	2188	1.12	2194	1.21
SP2-BP1-LP1	2236	2.04	2261	2.48	2281	5.94
SP2-K1	2157	1.36	2181	0.62	2189	1.03
SP2-FA1-K1	2168	1.21	2187	2.13	2194	0.21
SP2-K2	2116	1.24	2147	1.57	2155	1.93
SP2-VMA1	2205	1.17	2211	1.02	2232	2.27
SP2-VMA2	2229	1.15	2238	1.99	2259	0.25
SP3	2179	0.76	2248	4.03	2259	2.14
SP3-FA1	2115	0.86	2124	0.46	2135	1.75
SP3-FA2	2105	1.29	2124	0.87	2133	1.04
SP3-BP1	2108	1.69	2126	0.52	2140	0.73
SP3-BP2	2073	1.72	2085	1.69	2091	2.37
SP3-LP1	2134	2.17	2146	1.29	2159	2.34
SP3-LP2	2240	4.77	2249	1.94	2261	1.22
SP3-FA1-LP1	2232	2.25	2240	1.10	2260	2.84
SP3-BP1-LP1	2227	1.53	2232	2.40	2245	2.92
SP3-K1	2182	2.35	2202	1.14	2218	0.76
SP3-FA1-K1	2127	1.19	2167	0.42	2170	0.23
SP3-K2	2126	1.55	2172	1.22	2178	1.48
SP3-VMA1	2125	1.73	2131	1.31	2141	1.92
SP3-VMA2	2174	3.18	2176	1.40	2181	1.42
Control	2171	1.48	2173	1.88	2204	0.98

Table 12 Ultrasonic Pulse Velocity (UPV) of SCMs

MIX ID	UPV (m/s)					
	7		28		56	
	Mean of 9	COV (%)	Mean of 6	COV (%)	Mean of 3	COV (%)
SP1	4721	1.62	4829	1.91	4912	0.98
SP1-FA1	4684	2.62	4790	1.47	4848	0.45
SP1-FA2	4580	2.88	4736	1.78	4792	0.75
SP1-BP1	4424	1.70	4664	1.24	4726	0.80
SP1-BP2	4244	2.46	4514	1.47	4608	1.90
SP1-LP1	4464	2.05	4844	0.56	4929	1.28
SP1-LP2	4489	1.33	4730	1.25	4817	1.52
SP1-FA1-LP1	4287	0.88	4630	0.84	4681	1.83
SP1-BP1-LP1	4366	2.09	4722	0.72	4766	1.18
SP1-K1	4371	1.40	4680	1.21	4747	2.23
SP1-FA1-K1	4294	1.98	4549	1.65	4588	0.82
SP1-K2	4175	2.22	4339	1.47	4470	2.71
SP1-VMA1	4575	1.84	4730	0.75	4826	0.45
SP1-VMA2	4643	1.42	4798	0.79	4878	0.87
SP2	4707	0.85	4835	0.68	4956	1.84
SP2-FA1	4418	0.85	4623	1.04	4787	1.72
SP2-FA2	4331	0.88	4467	1.30	4666	0.64
SP2-BP1	4376	1.46	4537	2.02	4706	0.75
SP2-BP2	4271	1.34	4523	2.09	4694	0.06
SP2-LP1	4490	0.91	4723	0.98	4913	1.59
SP2-LP2	4357	0.96	4596	1.58	4755	0.28
SP2-FA1-LP1	4409	1.33	4618	1.92	4788	0.23
SP2-BP1-LP1	4436	2.33	4615	1.56	4785	3.06
SP2-K1	4452	0.91	4626	1.19	4767	1.31
SP2-FA1-K1	4327	1.81	4540	1.29	4711	1.35
SP2-K2	4099	1.90	4227	1.30	4415	2.41
SP2-VMA1	4625	1.10	4718	0.93	4774	1.10
SP2-VMA2	4639	1.65	4762	1.46	4816	1.09
SP3	4581	0.83	4750	1.94	4832	1.05
SP3-FA1	4424	0.62	4620	0.41	4711	0.82
SP3-FA2	4318	1.27	4535	1.10	4635	0.26
SP3-BP1	4390	0.72	4554	0.86	4681	0.82
SP3-BP2	4348	0.98	4519	0.87	4668	1.12
SP3-LP1	4462	1.06	4607	1.66	4740	0.89
SP3-LP2	4444	1.90	4580	1.86	4705	0.81
SP3-FA1-LP1	4344	0.95	4606	0.71	4712	1.44
SP3-BP1-LP1	4335	0.74	4642	0.82	4736	0.65
SP3-K1	4384	0.70	4563	1.45	4690	0.99
SP3-FA1-K1	4338	1.37	4547	1.23	4657	1.14
SP3-K2	4290	0.76	4470	0.97	4615	0.99
SP3-VMA1	4554	1.35	4714	1.16	4754	0.54
SP3-VMA2	4501	1.56	4671	1.01	4694	0.46
Control	4536	1.02	4682	0.81	4813	1.13

Table 13 Strength of SCMs

MIX ID	Strength (MPa))					
	7		28		56	
	Mean of 3	COV (%)	Mean of 3	COV (%)	Mean of 3	COV (%)
SP1	34.5	8.8	50.9	13.2	60.0	7.1
SP1-FA1	30.8	10.0	51.5	4.2	59.4	3.5
SP1-FA2	22.5	6.9	34.4	8.4	49.7	7.9
SP1-BP1	28.8	4.6	42.8	6.8	46.0	4.4
SP1-BP2	20.6	11.1	38.7	2.8	44.4	11.7
SP1-LP1	20.7	12.9	40.3	1.7	54.1	3.5
SP1-LP2	27.1	3.3	44.8	7.3	46.9	7.4
SP1-FA1-LP1	25.0	9.5	40.1	3.9	43.7	4.3
SP1-BP1-LP1	26.5	7.0	39.5	8.1	43.5	7.9
SP1-K1	27.1	8.0	44.2	2.1	44.9	3.4
SP1-FA1-K1	26.2	7.9	31.6	5.3	37.4	1.0
SP1-K2	24.4	2.1	29.3	6.0	31.1	6.2
SP1-VMA1	40.3	14.2	52.8	2.9	55.4	9.3
SP1-VMA2	46.2	9.3	49.4	6.7	56.1	6.7
SP2	29.5	12.1	55.6	1.2	58.3	0.4
SP2-FA1	29.3	10.8	45.9	0.6	46.9	4.4
SP2-FA2	21.2	9.0	36.9	8.6	41.6	7.9
SP2-BP1	24.3	8.7	44.3	3.9	47.2	10.0
SP2-BP2	28.1	1.0	38.9	3.1	44.0	2.4
SP2-LP1	29.7	10.4	51.4	7.8	53.6	11.9
SP2-LP2	26.3	10.6	38.4	5.3	42.9	5.7
SP2-FA1-LP1	30.0	13.7	40.5	4.0	44.7	2.8
SP2-BP1-LP1	28.1	7.2	43.8	2.0	44.4	4.1
SP2-K1	19.8	12.5	40.4	6.5	42.5	6.7
SP2-FA1-K1	27.7	8.3	35.5	7.1	37.4	1.5
SP2-K2	18.2	3.6	28.0	1.7	30.4	4.1
SP2-VMA1	39.6	13.2	53.0	4.3	54.0	4.3
SP2-VMA2	43.7	8.5	47.2	5.0	59.9	10.0
SP3	34.6	10.4	53.8	6.8	61.0	5.8
SP3-FA1	26.8	14.0	40.7	1.4	48.4	2.9
SP3-FA2	19.2	8.9	38.7	3.4	41.9	3.3
SP3-BP1	26.5	4.3	41.8	5.8	49.1	6.2
SP3-BP2	20.8	12.6	35.9	7.0	39.1	5.6
SP3-LP1	24.2	5.4	37.4	12.0	44.1	8.8
SP3-LP2	24.8	8.3	40.9	4.9	41.4	1.1
SP3-FA1-LP1	26.1	12.2	38.0	14.0	40.3	2.6
SP3-BP1-LP1	29.7	12.8	38.7	6.7	41.6	2.8
SP3-K1	25.4	4.4	28.8	5.2	33.4	16.2
SP3-FA1-K1	23.3	10.4	31.4	12.9	36.4	9.9
SP3-K2	21.3	9.1	25.0	3.7	27.7	16.0
SP3-VMA1	29.6	10.6	46.7	1.8	48.5	0.7
SP3-VMA2	35.2	3.4	39.7	10.5	40.6	5.8
Control	29.7	9.2	44.4	11.2	50.3	12.1

CHAPTER 4

DISCUSSION OF RESULTS

4.1 Effect of Chemical Admixtures on SCMs

The effect of chemical admixtures on the properties of SCMs will be investigated on the mixes that do not have any mineral admixtures. Fresh properties that were determined included the workability parameters, slump flow test (Γ_m) and V-funnel test (R_m), and the setting time. Hardened properties included the UPV and compressive strength that were determined at 7, 28, and 56 days.

4.1.1 Fresh Properties

When the fresh properties are examined from Figure 17 and Figure 18, one of the first observations is the increased setting times and workability parameters when chemical admixtures are used in a mix. These two properties will be investigated separately in the following sections.

4.1.1.1 Workability

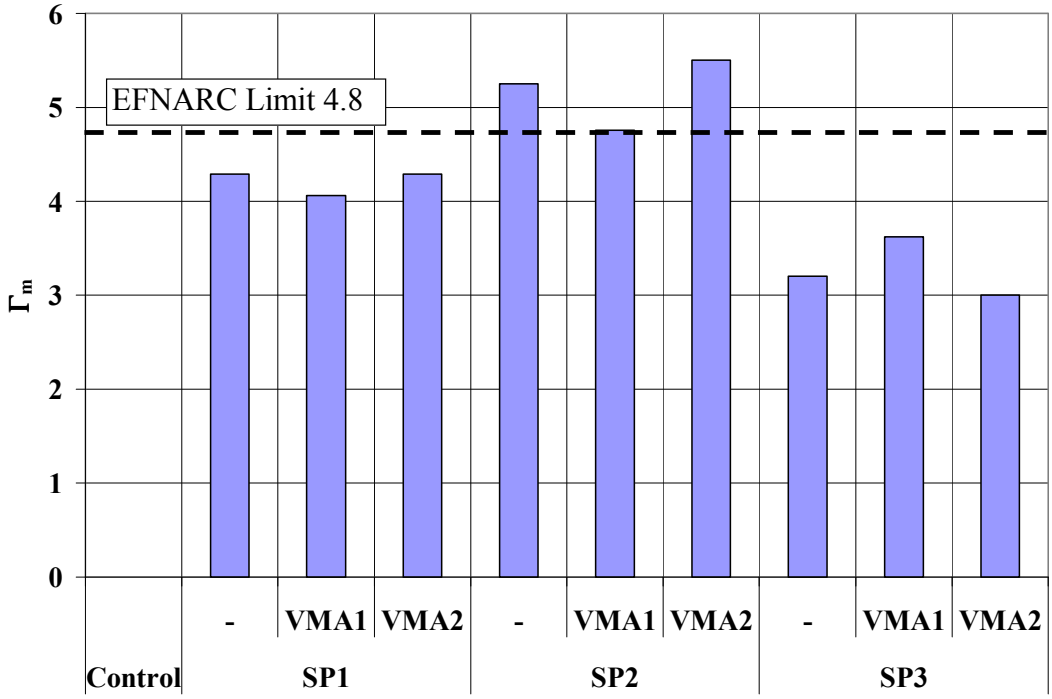
Figure 17 presents the plots of the two workability tests. Both of the workability tests showed the non-self-compacting characteristic of the control mix as both Γ_m and R_m were zero. As the chemical admixtures are included these parameters increase rapidly indicating self-compacting characteristics.

The results of the slump flow tests reveal that mixes containing SP2 showed the largest spread whereas the mixes containing SP3 showed the lowest spread. Moreover, as seen from the slump flow test, addition of a VMA didn't significantly affect the slump flow diameter. The results of the V-funnel tests also reveal similar

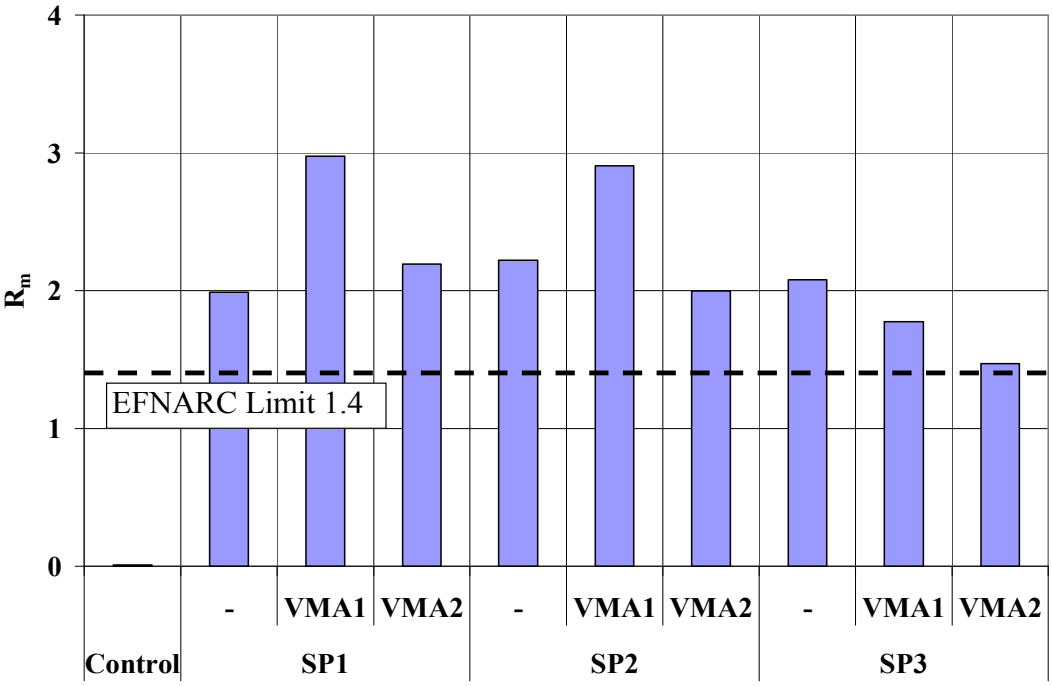
results. The relative funnel speed was higher for the mixes containing SP1 and SP2 when compared to the ones with SP3. Moreover, except for the mixes with SP3, addition of a VMA, especially VMA1, increased the relative funnel speed indicating a better flowability through the funnel. These observations were in line with the expectations that VMAs increase the cohesiveness but do not significantly affect the deformability of a mixture.

EFNARC recommends a minimum relative slump flow diameter (Γ_m) of 4.8 and a minimum relative V-funnel speed (R_m) of 1.4 [EFNARCH 2002]. Comparing these recommended values with the abovementioned mixes only the mixes with SP2 are qualified for a SCM. The border line in Figure 17 and Figure 18 presents the EFNARC recommended values of Γ_m and R_m.

The result of used SP alone in this study showed good correlation with the study conducted by Golasweski et. al. (2003). In that study, the effects of five types SPs on fresh properties of SCC were compared. They used two types of polycarboxylate ester based SPs, one type of polycarboxylate acid based SP and two more naphthalene sulphonate acid based SPs. They concluded that using SPs base on polycarboxylate ester improved the workability better than others.



(a) Slump Flow Test



(b) V-funnel Test

Figure 17 Effect of Chemical Admixtures on the Workability of SCMs

4.1.1.2 Setting Time

The initial and final setting times of the mixes are presented in Figure 18. As seen from the figure, addition of chemical admixtures significantly delayed the initial setting time and expedite the duration between initial and final setting time. The initial and final setting time of the control mixture, which did not show any self-compacting characteristics, was 333 and 583 minutes respectively. The increase in the initial setting time was the highest for SP2 (62%) and lowest for SP3 (35%). When both of the chemical admixtures (SPs and VMAs) were used, however, the increase in initial setting time was between 43% to 55%.

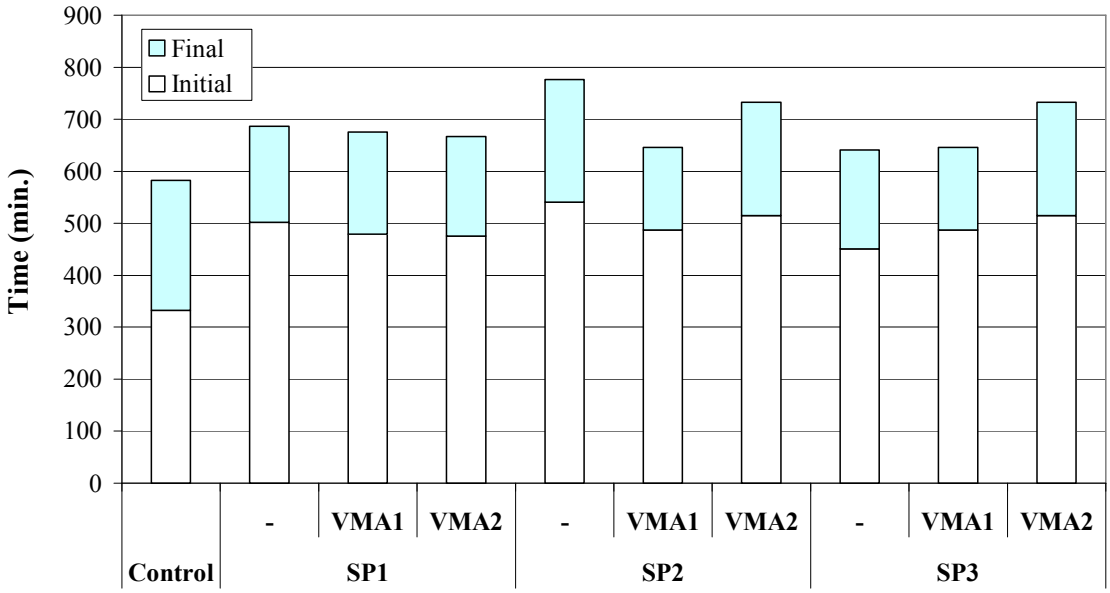


Figure 18 Effect of Chemical Admixture on Setting Time of SCMs

The delay of initial setting time was partially recovered due to expedited time to final setting time. The increase in the final setting time was again the highest for SP2 (33%) and lowest for SP3 (10%), when both of the chemical admixtures were used, however, the increase in final setting time again decreased and was between 12 to 27%. Therefore it can be concluded that the chemical admixtures significantly affect the initial setting time and consequently the final setting time.

4.1.2 Hardened Properties

Compressive strength and the UPV of the mixes were determined at 7, 28, and 56 days of mortar age. In the following sections the effects of the chemical admixtures on these two properties will be presented.

4.1.2.1 Compressive Strength

Figure 19 presents the compressive strength of the mortars determined at 7, 28, and 56 days. As seen from the figure, when compared to the control mix the chemical admixtures increased the strength except for SP3. Such an increase was not expected as the w/c ratio was kept constant. However, similar observations were also made by other researchers (Neville 2000), and the increase in strength was attributed to a better distribution of the cement grains in the mortar matrix when chemical admixtures were used.

Another observation that can be made from Figure 19 could be the similarity of the SP1 and SP2 mixes when combined with the VMAs. Both of the VMAs didn't affect the strength properties of the SCMs when used with SP1 and SP2. As SP1 and SP2 were polycarboxylate based superplasticizers, it can be concluded that these SPs are not affected by the VMAs used in this study. The same conclusion will not hold for SP3, a melamine formaldehyde based SP, as the strength of the SP3 mixes when used with both of the VMAs decreased considerably.

4.1.2.2 UPV

Figure 20 presents the UPV of the mortars determined at 7, 28, and 56 days of age. The UPV and compressive strength test results show a close correlation and similar to compressive strength test results the chemical admixtures increased the UPV of mortars when compared to the control mix, except for SP3.

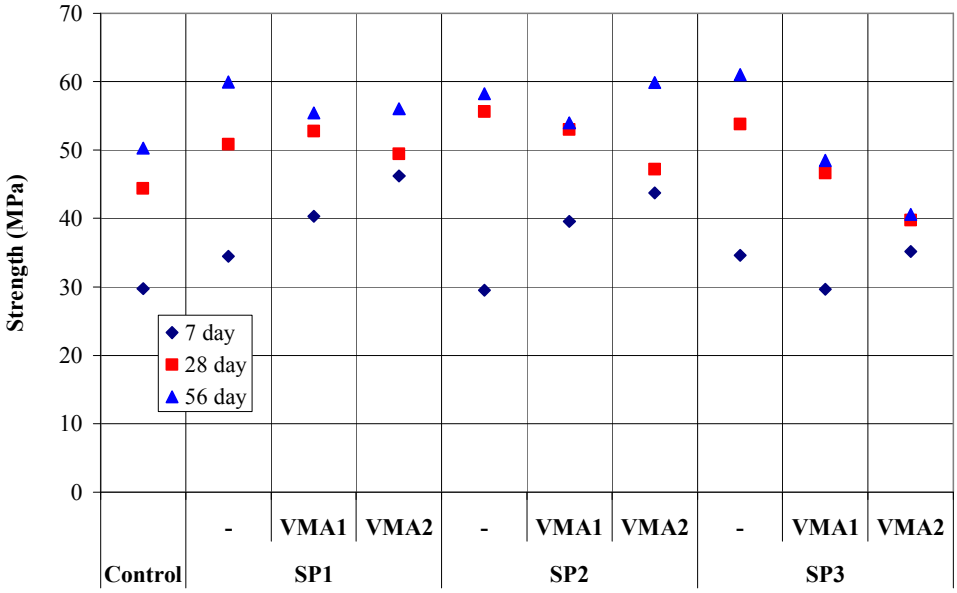


Figure 19 Effect of Chemical Admixtures on the Strength of SCMs

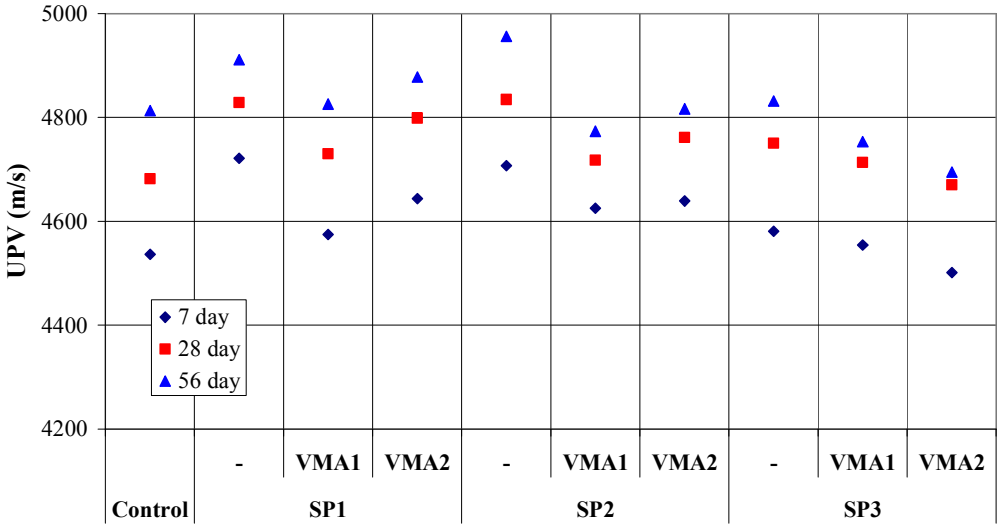


Figure 20 Effect of Chemical Admixture on UPV of SCMs

4.2 Effect of Mineral Admixtures on SCMs

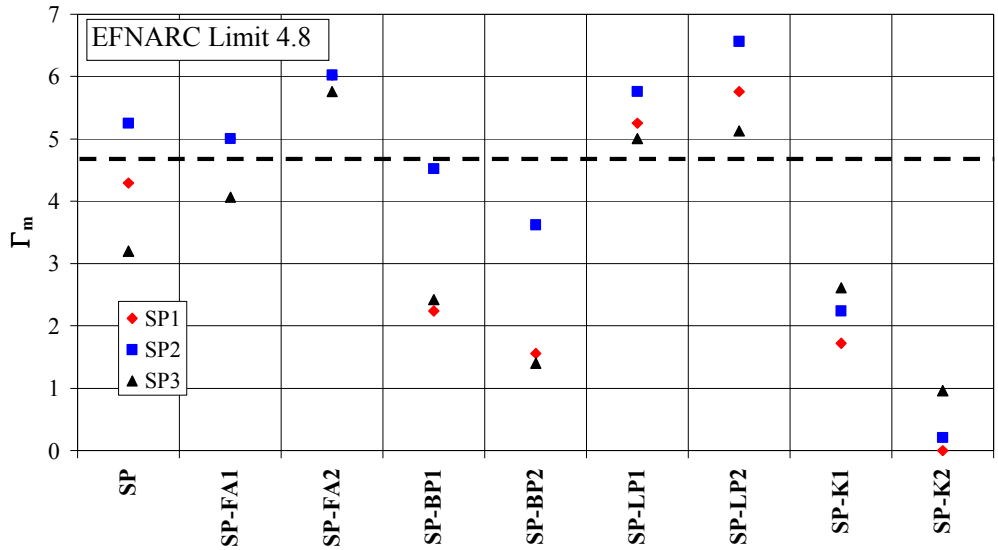
The effect of mineral admixtures on the properties of SCMs will be investigated on the mixes that have mineral admixtures considering each SP separately.

4.2.1 Fresh Properties

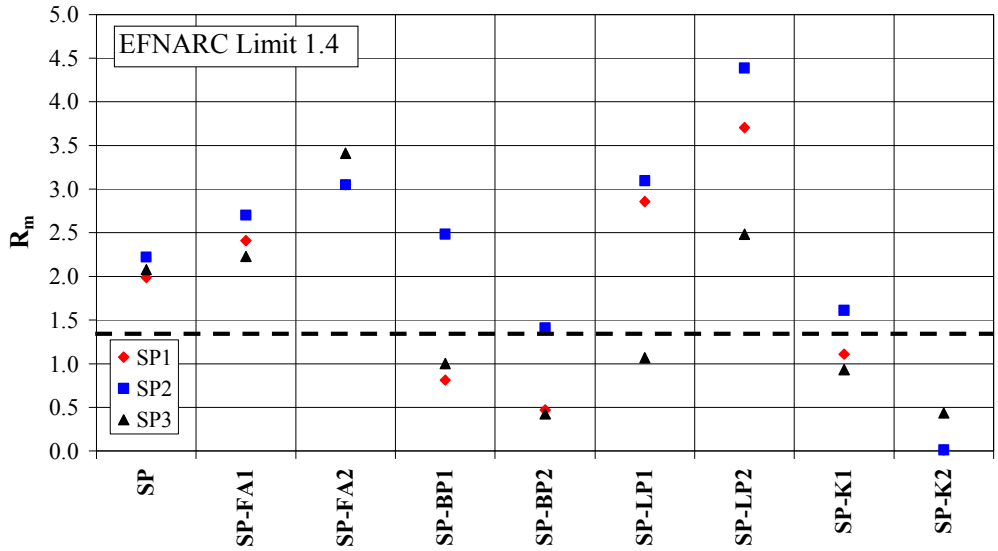
The effect of mineral admixtures on the fresh properties of mixes will be investigated separately for each SPs.

4.2.1.1 Workability

Figure 21 presents the plots of two workability tests performed on the mixes containing mineral admixtures together with the corresponding SP.



(a) Slump Flow Test



(b) V-funnel Test

Figure 21 Effect of Mineral Admixtures on the Workability of SCMs

The results of the slump flow test and V-funnel tests both reveal that mixes containing FA and LP showed better flowability and deformability when compared to BP and K. Increasing the amount of FA and LP increased the workability of the mixes and for the mixes with increased amounts of BP and especially K, the self-

compacting characteristics could not be observed. The use of mineral admixtures which are lighter than PC increase the paste volume. The increased paste volume reduces the friction at the fine aggregate paste interface thus increases the workability. Moreover, the spherical shape of FA particles and their fineness have beneficial effects on the workability (Erdoğan 1997).

Another observation that could be made from the figure is the effectiveness of LP in increasing the viscosity of the mix as observed from the V-funnel test. As seen in the Figure 21, increasing the amount of LP in mortar increased the relative funnel speed. This could be attributed to the improved fine-particle packing when LP was used as a filler.

Comparing the EFNARC recommended minimum Γ_m of 4.8 and minimum R_m of 1.4 with the abovementioned mixes, it can be seen that only the mixes with mineral admixtures FA and LP are qualified for a SCM. Border line in Figure 21 presents the Γ_m and R_m limitation for these qualified mixes. As can be seen from that figure both of the polycarboxylate based SPs performed well with the mineral admixtures. SP3 admixture, however, was only effective with an increased amount of FA and LP.

4.2.1.2 Setting Time

The initial and final setting times of the mixes prepared by mineral admixtures for each of the SP used in this study are presented in Figure 22. As seen from Figure 22, for all the SPs used in this study FA significantly prolongs both the initial and the final setting time of the mortar when compared to the mixes with SPs only. Moreover, setting times also increased as the amount of FA increased.

Generally, all pozzolans, like fly-ash increase the setting time (Erdoğan 1997). The reason for such a significant delay is due to the fineness and composition of the pozzolans. Since the FA used in this study was coarser the increase in the setting times for the mixes with the FA is reasonable. Other mineral admixtures slightly affected the initial and final setting times but this observation was not consistent

with all the SPs considered. Moreover, an increase in the amount of BP, LP, and K reduced the setting times

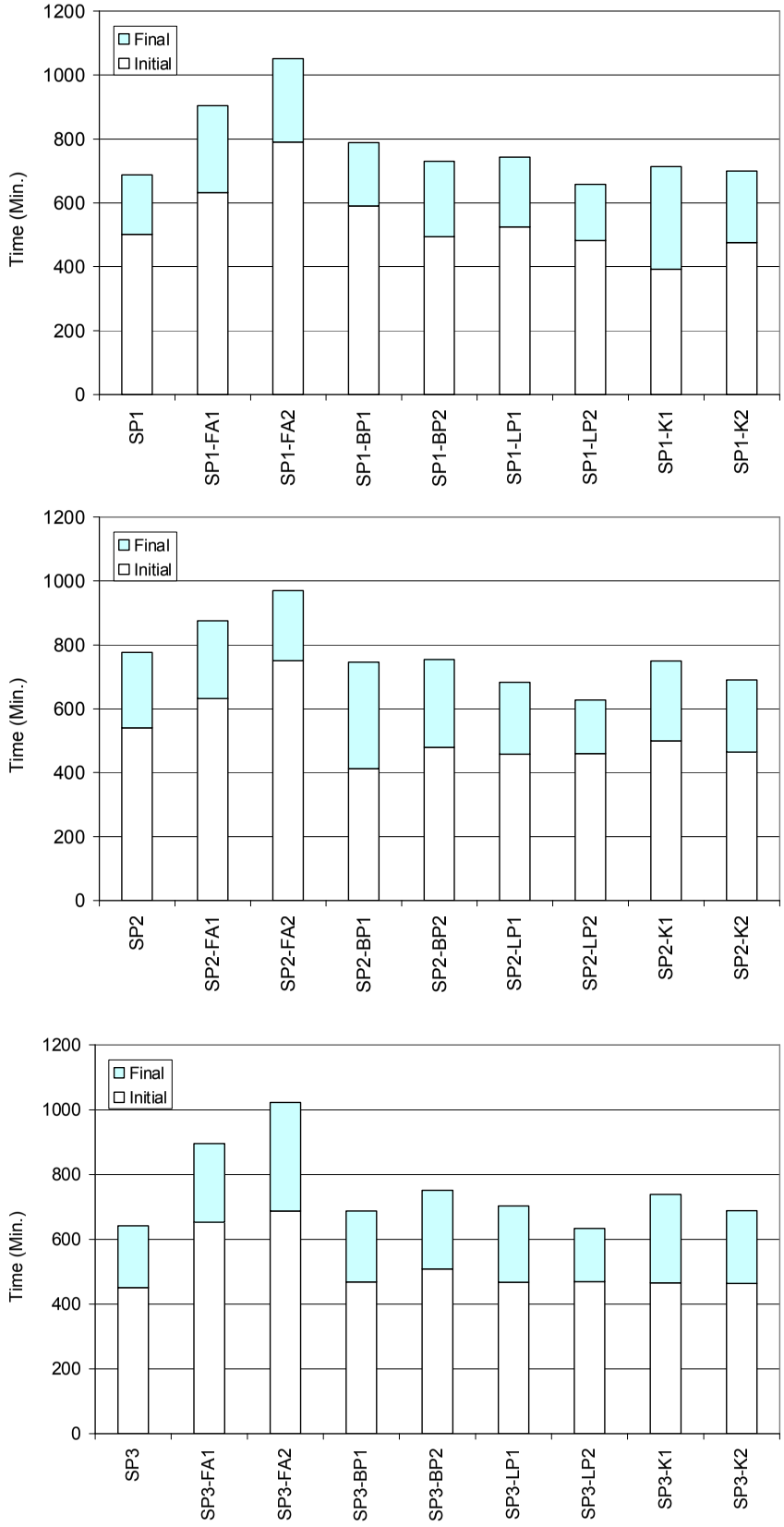


Figure 22 Effect of Mineral Admixtures on Setting Time of SCMs

4.2.2 Hardened Properties

4.2.2.1 Compressive Strength

Figure 23 presents the compressive strength of the mortars determined at 7, 28, and 56 days. As seen in Figure 23, the use of mineral admixtures in the SCMs result in a decrease in strength at all ages considered. Moreover, as the amount of mineral admixture increases the strength decreases. Another observation that could be made from the figure is the interaction of the SPs and the mineral admixtures. Among the mineral admixtures considered, FA and BP are known to have pozzolanic properties. However, both of these admixtures are quite coarse and since the fineness is an important parameter in the pozzolanic activity they did not seem to take in effect before 56 days of mortar age. LP and K however are known to be inert fillers and their contribution to strength was not expected and therefore was not observed.

4.2.2.2 UPV

Figure 24 presents the UPV of the mortars determined at 7, 28, and 56 days of age. As seen as Figure 24, the use of mineral admixtures in mortars causes a decrease in the UPV. The reduction in the UPVs was in line with the reduction in the strengths.

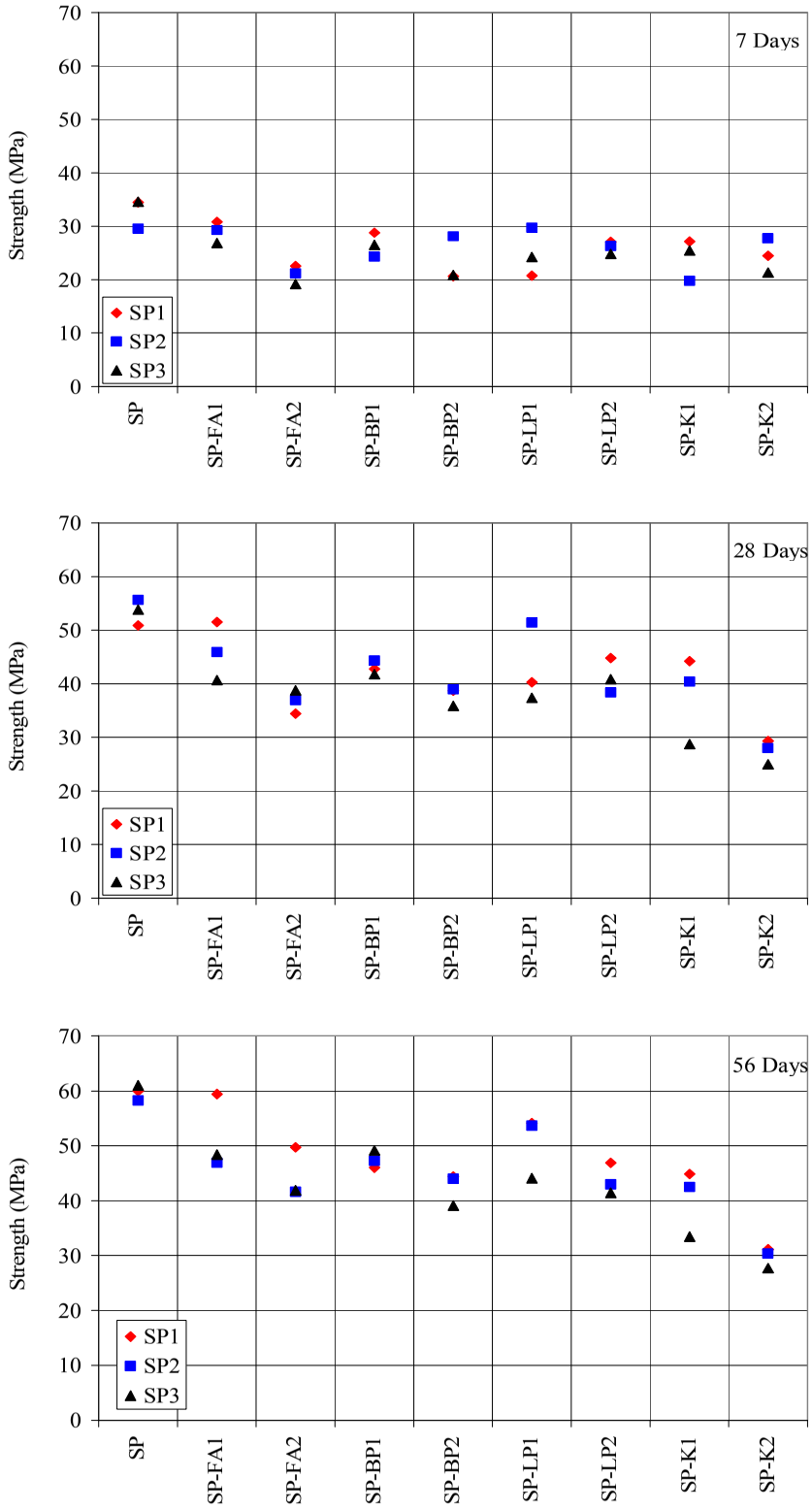


Figure 23 Effect of Mineral Admixtures on Strength of SCM

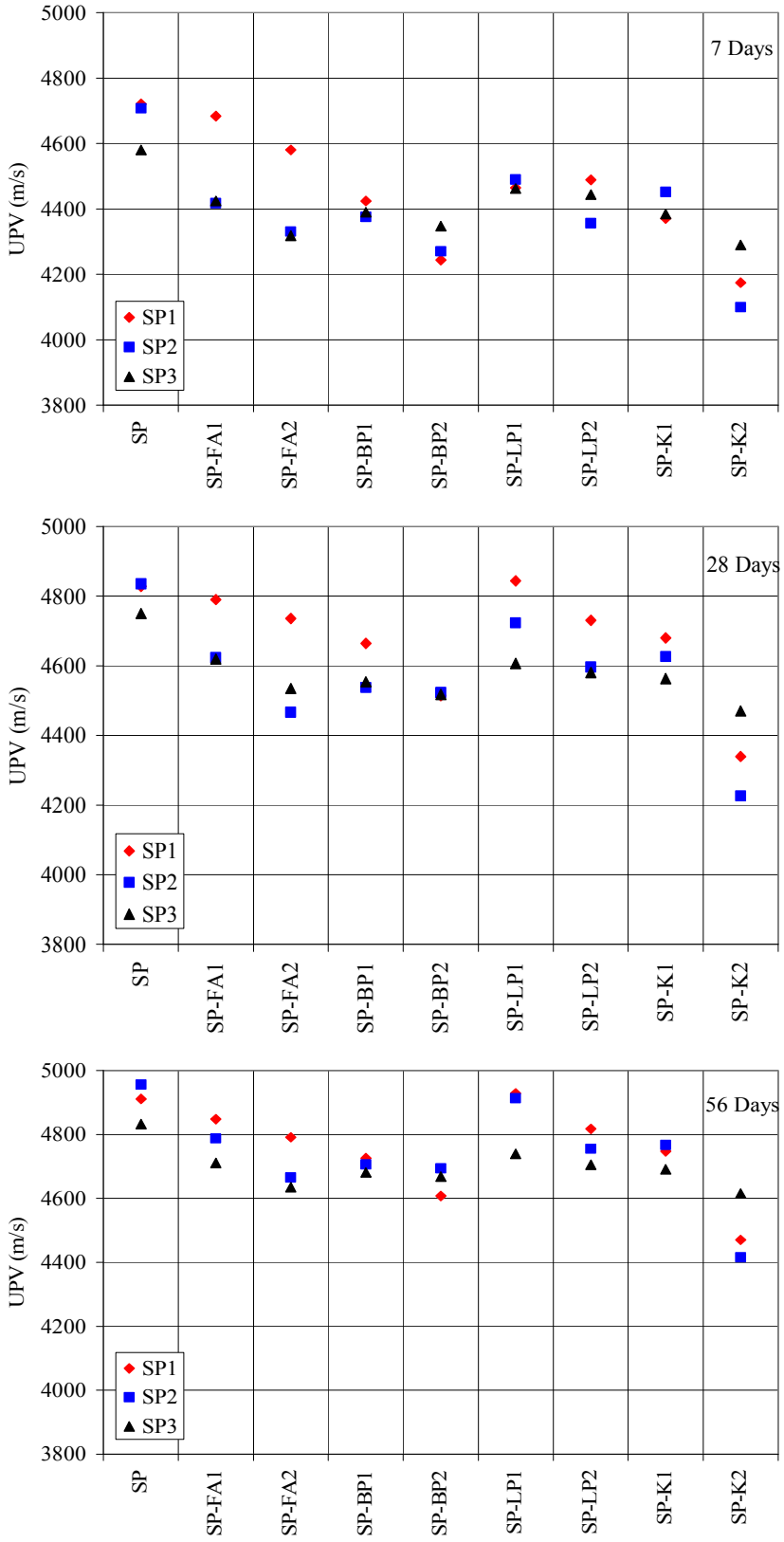


Figure 24 Effect of Mineral Admixtures on UPV of SCMs

4.3 Effect of Ternary Mixtures on SCMs

As mentioned in Chapter 4.2 among the mineral admixtures considered FA and LP was effective in increasing the workability of SCMs. However, these mineral admixtures, when used alone, had some disadvantages. For example, FA prolonged the setting time and both FA and LP reduced the strength of the SCMs. Therefore, ternary mixtures were prepared combining two mineral admixtures. The effect of ternary mixes on the properties of SCMs will be compared to the qualifying mineral admixtures, FA and LP, and the chemical VMAs. Therefore, in Table 14 the properties of all those mixes are presented separately for each SP. As for the ternary mixes, only the combinations of FA-LP, BP-LP, and FA-K were considered within the scope of the experimental program.

4.3.1 Fresh Properties

The plots of two workability tests performed on the ternary mixes are presented in Figure 25 together with the other qualifying mixes. As seen in Figure 25, all the ternary mixes produced satisfactory SCMs. Especially, the FA-LP mix showed comparable slump flows and V-funnel flow times when compared to the FA and LP mixes.

It can also be seen in the figure that all of the ternary mixes showed better flowability when compared to the mixes prepared with VMAs. As the prices of the mineral admixtures are much lower than the VMAs, they can be a good alternative to the VMAs.

When the setting time plots of the ternary mixes (Figure 26) are investigated, for all the ternary mixes significant reduction in the setting times was observed when compared to the FA mix. This observation was the same for all the SPs utilized in this study. Therefore, ternary mixes can be utilized in SCMs where one mineral admixture hinders the negative effects of the other mineral admixture.

Table 14 Properties of Ternary Mixes

MIX ID	Fresh Properties				Hardened Properties					
	Setting Time (min)		Workability		UPV (m/s)			Strength (MPa)		
	Initial	Final	Γ_m	R_m	7	28	56	7	28	56
SP1	502	687	4.29	1.99	4721	4829	4912	34.5	50.9	60.0
SP1-VMA1	479	676	4.06	2.98	4575	4730	4826	40.3	52.8	55.4
SP1-VMA2	475	667	4.29	2.19	4643	4798	4878	46.2	49.4	56.1
SP1-FA2	791	1052	6.02	3.05	4580	4736	4792	22.5	34.4	49.7
SP1-LP2	482	658	5.76	3.70	4489	4730	4817	27.1	44.8	46.9
SP1-FA1-LP1	574	755	6.29	5.56	4287	4630	4681	25.0	40.1	43.7
SP1-BP1-LP1	426	649	5.00	3.13	4366	4722	4766	26.5	39.5	43.5
SP1-FA1-K1	620	903	3.00	1.72	4294	4549	4588	26.2	31.6	37.4
SP2	541	777	5.25	2.22	4707	4835	4956	29.5	55.6	58.3
SP2-VMA1	477	654	4.76	2.91	4625	4718	4774	39.6	53.0	54.0
SP2-VMA2	504	739	5.50	2.00	4639	4762	4816	43.7	47.2	59.9
SP2-FA2	751	970	6.02	3.05	4331	4467	4666	21.2	36.9	41.6
SP2-LP2	460	627	6.56	4.39	4357	4596	4755	26.3	38.4	42.9
SP2-FA1-LP1	565	784	6.84	3.62	4409	4618	4788	30.0	40.5	44.7
SP2-BP1-LP1	485	652	5.00	2.44	4436	4615	4785	28.1	43.8	44.4
SP2-FA1-K1	610	861	4.29	2.44	4327	4540	4711	27.7	35.5	37.4
SP3	451	641	3.20	2.08	4581	4750	4832	34.6	53.8	61.0
SP3-VMA1	487	646	3.62	1.78	4554	4714	4754	29.6	46.7	48.5
SP3-VMA2	515	733	3.00	1.47	4501	4671	4694	35.2	39.7	40.6
SP3-FA2	687	1023	5.76	3.41	4318	4535	4635	19.2	38.7	41.9
SP3-LP2	469	634	5.13	2.48	4444	4580	4705	24.8	40.9	41.4
SP3-FA1-LP1	565	841	5.00	2.74	4344	4606	4712	26.1	38.0	40.3
SP3-BP1-LP1	510	772	3.73	1.71	4335	4642	4736	29.7	38.7	41.6
SP3-FA1-K1	559	845	4.41	2.19	4338	4547	4657	23.3	31.4	36.4

4.3.2 Hardened Properties

Figures 27 and 28 present the hardened properties of the ternary mixes when compared to the other mixes. As seen in Figure 27, the strength of all the ternary mixes was comparable to the mixes prepared with the mineral admixtures FA and LP alone. It is clear from the figure that the mineral admixtures reduce the strength of the SCMs. The reasons for such a decrease were explained earlier in Chapter 4.2. Similar to the strength results, the UPVs of mortars have also decreased with the addition of mineral admixtures as shown in Figure 28.

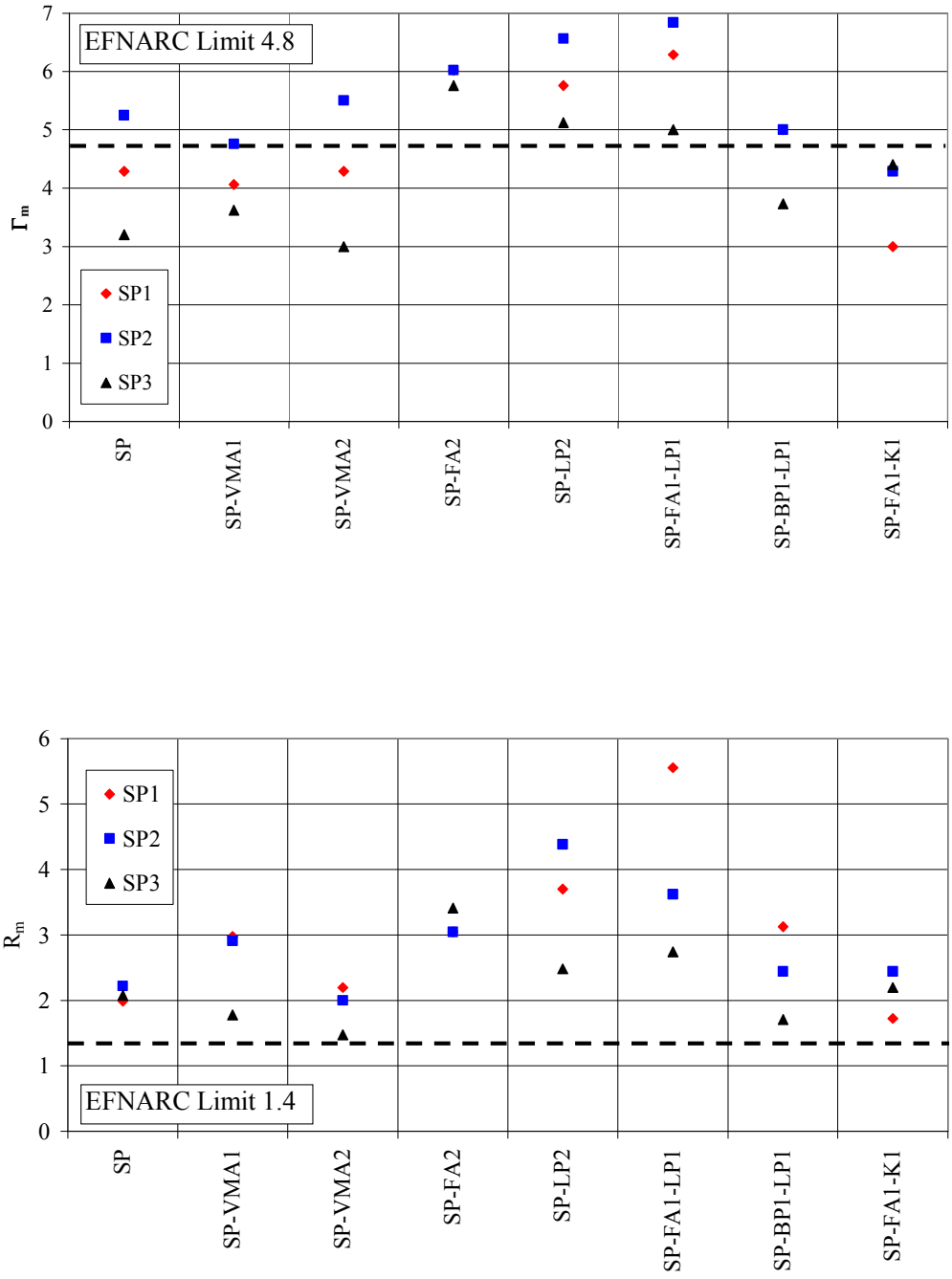


Figure 25 Effects of Ternary Mixes on the Workability of SCMs

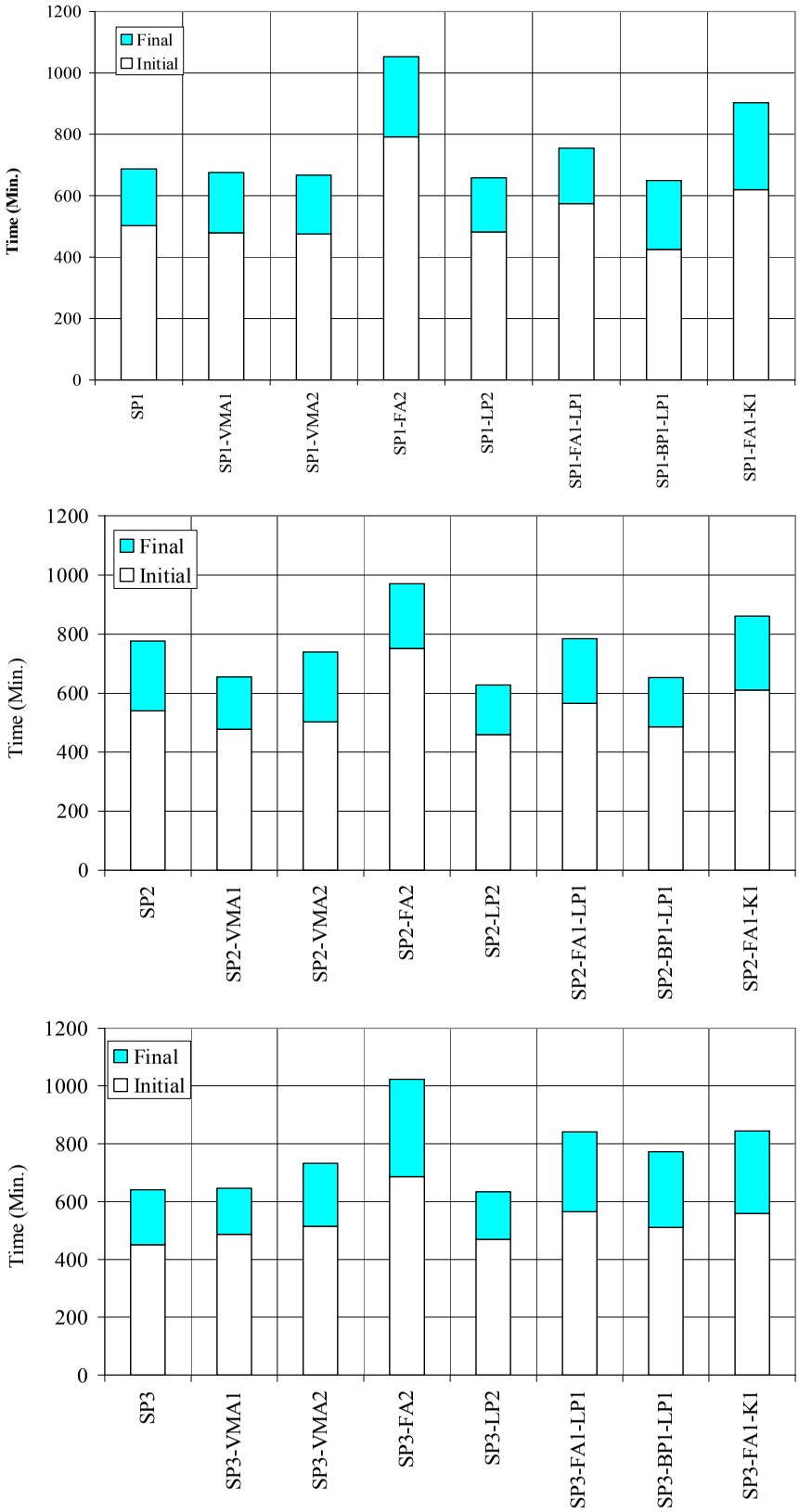


Figure 26 Effects of Ternary Mixes on the Setting Time of SCMs

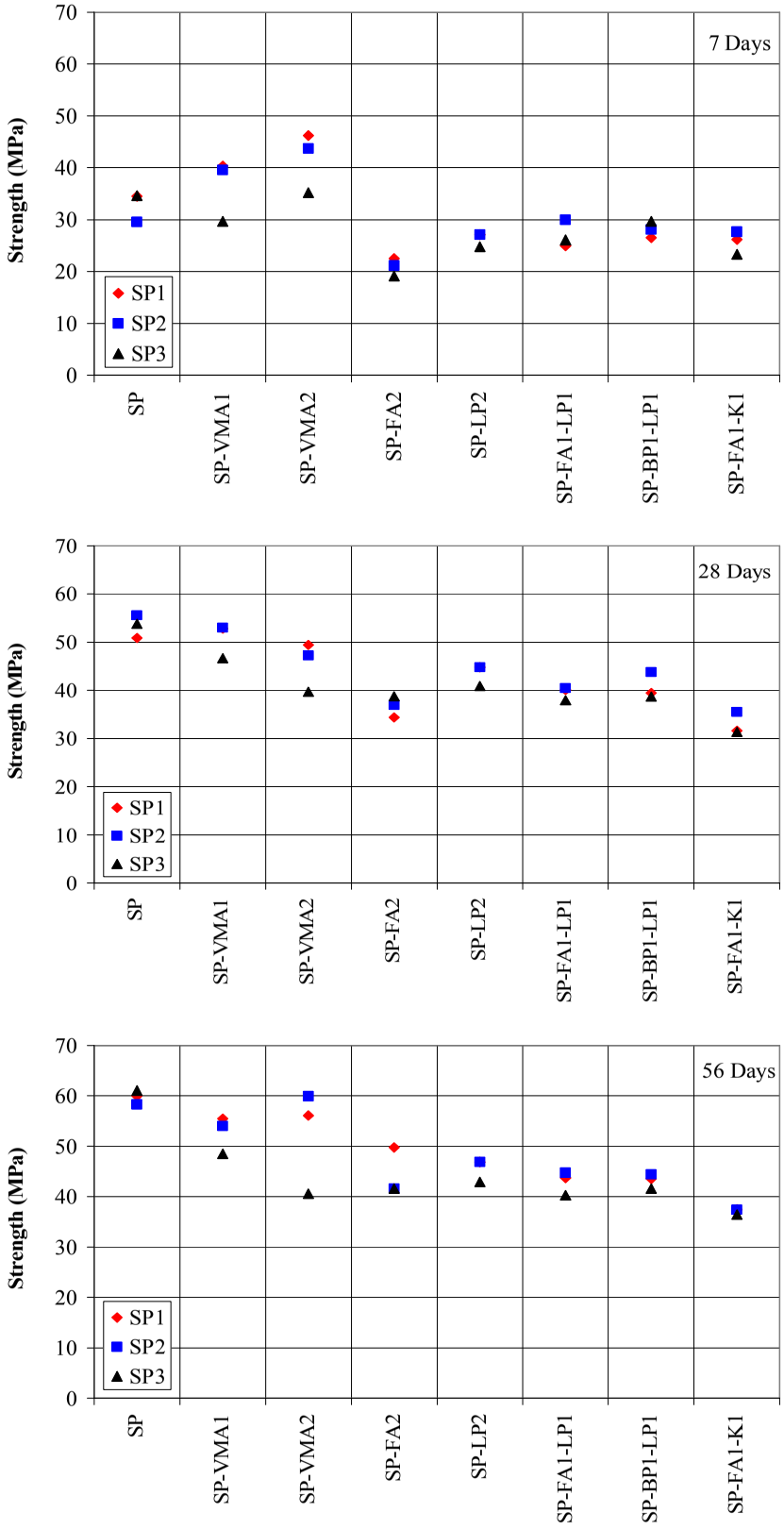


Figure 27 Effects of Ternary Mixes on the Strength of SCMs

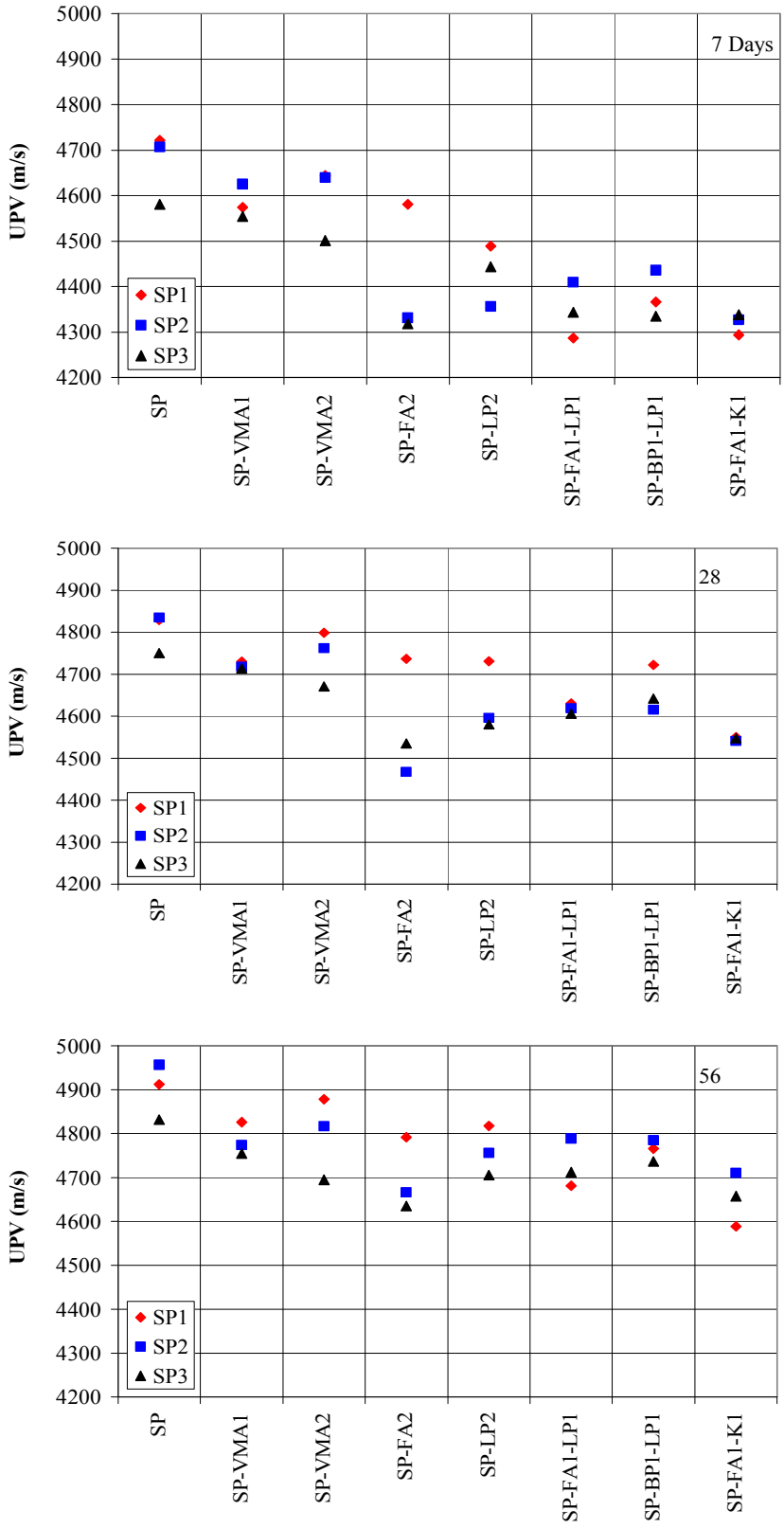


Figure 28 Effects of Ternary Mixes on the UPV of SCMs

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary

Self compacting concrete (SCC) is considerably a new concrete technology. SCC can be defined as a concrete with very high flowability together with a good stability. The common practice to obtain self-compactibility is to limit the coarse aggregate content and to utilize an appropriate mortar. Since, mortar serves as the basis for the workability properties of SCC, the workability properties of SCC could be assessed by investigating self compacting mortars (SCM).

In this study, 43 mixes of SCMs were prepared using binary and ternary mixes of mineral admixtures, SPs and VMAs. The fresh and hardened properties of SCMs were determined. The fresh properties that were determined included initial and final setting times, slump flow diameters, and V-funnel flow times. The hardened properties that were determined included the compressive strength and UPV at 7, 28, and 56 days.

5.2 Conclusions

As a result of this experimental study, the following conclusions could be made:

- The workability of SCM depends mainly on the type of SPs used. In this study Polycarboxylate based SPs, especially SP2, showed better results in improving the workability of SCMs, as determined by both of the workability tests.

- VMAs played an important role in both the fresh and hardened properties of concrete mixes. In the fresh properties, the use of VMAs together with SP, significantly improved the cohesiveness of the mixes, without any change in the

deformability of the mixes. In this study, VMA2 which was based on high molecular weight hydroxylated polymer showed better result in improving workability of SCMs. Moreover, the SP-VMA combinations increased the strength of SCMs.

- Use of mineral admixtures also improved the workability properties of SCMs. Among the mineral admixtures used, FA and LP proved to be good alternatives to the VMAs to increase the workability properties of mortars. BP and K, however, can not be used alone as they adversely affect the workability.

- A disadvantage of mineral admixtures against the chemical admixtures is the reduction in strength when part of the cement is replaced by the mineral admixtures. However, if the mineral admixtures are used as a replacement to the fine aggregate this reduction may not be observed.

- Both the chemical and mineral admixtures adversely affect the setting time of mortars. Among the mineral admixtures, however, FA increased the setting time of the mortars the worst.

- In order to hinder the disadvantages of a mineral admixture, another mineral admixture can also be added forming ternary mixes. Among the ternary mixes considered in this study FA-LP mixes increased the workability of the mortars without significantly affecting the setting time

- UPV could be used to nondestructively assess the internal structure of mortars. Even though, the measured parameters were different, there was a good correlation between the compressive strength and UPV of mortars. To use ultrasound for the standard mortar specimens, higher frequency transducers such as 150 kHz could be used.

5.3 Suggestions for Future Studies

As a result of this experimental study, the following suggestions for other researchers could be made:

- In this study mini slump flow test and v-funnel tests were used to measure the workability of SCMs. In addition to these empirical tests, in determining the workability properties of a SCM, rheological parameters could be more useful when determined using a rheometer.

- To observe the hardened properties with mineral admixtures, especially for a coarse FA, strength tests should be made beyond 56 days.

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